

**BIOLOGICAL NITRIFICATION AND DENITRIFICATION OF
HIGH AMMONIA LANDFILL LEACHATE USING
PRE DENITRIFICATION AND PRE/POST DENITRIFICATION PROCESSES**

by

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ABSTRACT

The purpose of this research was to investigate the nitrogen removal capabilities of two different biological process configurations treating high strength leachate containing up to 1200 mg N/l of ammonia. The first configuration was a predenitrification system known as the Modified Ludzack-Ettinger (MLE) process. The MLE Startup Phase consisted of starting up two MLE systems treating "base" leachate containing about 230 mg N/l of ammonia, followed by incrementally increasing leachate ammonia concentrations to a "target" level of 1200 mg N/l. Aerobic SRT's were maintained at 13 days during the MLE Startup Phase. Increases in clarifier sludge recycle flows to yield recycle ratios of 7:1 (System 1) and 8:1 (System 2), from 6:1, were investigated as a means to reduce effluent NO_x concentrations during the MLE Recycle Phase. An aerobic SRT of 10 days was initially used in both systems during the MLE Recycle Phase. A pre and postdenitrification system, known as the Bardenpho process, was the second configuration evaluated. The Bardenpho Phase examined the overall nitrogen removal capabilities of this process when treating leachate containing about 1100 mg N/l of ammonia.

Both MLE systems experienced nitrification failure during the initial attempt to reach the "target" leachate ammonia concentration of 1200 mg N/l (MLE Startup Phase). Anoxic methanol loadings were maintained at levels required for denitrifying the "base" leachate (i.e. 230 mg N/l). Rapid accumulation of ammonia in the systems, due to small amounts of anoxic ammonia assimilation caused by limited denitrification, apparently resulted in "free" ammonia toxicity of *Nitrosomonas* bacteria. Attempts to assimilate excess ammonia by increasing anoxic methanol loadings resulted in raising reactor pH levels, due to increased denitrification, and a further rise in "free" ammonia concentrations. Anoxic methanol loadings were increased simultaneously with leachate ammonia concentrations during the second attempt to reach the "target" ammonia concentration. Nitrification, and denitrification, was successfully established in both systems using this procedure.

Increases in clarifier sludge recycle ratios (MLE Recycle Phase), with corresponding decreases in reactor actual hydraulic retention times, resulted in the rapid rise of reactor and effluent ammonia concentrations.

in both systems. Increases in aerobic SRT from 10 days to 20 days resulted in larger reactor solids levels and a reduction in effluent ammonia concentrations to around 50 mg N/l. Decreases in leachate ammonia concentration of about 80 mg N/l resulted in effluent ammonia values of around 15 mg N/l. A total reduction in leachate ammonia concentration of about 200 mg N/l did not further reduce effluent ammonia levels. Complete and consistent anoxic denitrification was achieved in both systems regardless of recycle ratio. Anoxic methanol loadings of about 2.8 mg COD/mg NO_x-N resulted in 100% anoxic NO_x removal. Aerobic NO₂/NO_x ratios were about 0.60 in both systems. System 2 (r = 8:1) had significantly larger reactor solids levels than System 1 (r = 7:1) with slightly lower effluent total inorganic nitrogen (ammonia + NO_x) concentrations (170 mg N/l versus 190 mg N/l). However, both systems had effluent total inorganic nitrogen concentrations of less than 160 mg N/l, when operating with recycle ratios of 6:1. Hence, increased total inorganic nitrogen removal was not realized when using larger recycle ratios.

The Bardenpho System was capable of producing effluent containing less than 1 mg N/l of ammonia and 15 mg N/l of NO_x, when treating 1100 mg N/l ammonia leachate. An Aerobic #1 SRT of 20 days was used with Aerobic #1 and clarifier sludge recycle ratios of 4:1 and 3:1, respectively. Residual effluent NO_x was caused by incomplete ammonia removal in the first aerobic reactor and the production of NO_x in the second aerobic reactor. However, approximately 5 mg N/l of ammonia was assimilated in the second anoxic reactor, thus indicating the need for a small amount of ammonia to remain in the mixed liquor so as to not limit denitrification. Anoxic methanol loadings of about 3.7 to 3.8 mg COD/mg NO_x-N resulted in 100% anoxic NO_x removal. Aerobic #1 NO₂/NO_x ratios were about 0.60, with Aerobic #2 ratios < 0.09. The clarifier sludge recycle ratio had to be increased from 2:1 to 3:1, to prevent the accumulation of solids in the clarifier.

TABLE OF CONTENTS

ABSTRACT	ii
TABLE OF CONTENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	ix
ACKNOWLEDGEMENTS	xiii
INTRODUCTION	1
1.1 Leachate Generation and Quality	1
1.2 Environmental Impacts of Nitrogenous Wastes	4
1.3 Nitrogen Removal Methods	5
1.3.1 Physical-Chemical Methods	5
1.3.2 Biological Assimilation of Ammonia	5
1.3.3 Biological Nitrification and Denitrification	6
1.3.3.1 Nitrification	6
1.3.3.2 Denitrification	6
1.4 Treatment Method and Process Configurations	7
1.5 Study Rationale and Objectives	10
LITERATURE REVIEW	13
2.1 UBC Leachate Treatment	13
2.1.1 Heavy Metal Inhibition	13
2.1.2 External Carbon Sources for Denitrification	14

2.1.3	Cold Temperature Performance	15
2.1.4	Hydraulic Retention Time/Sludge Recycle Effects	15
2.1.5	Increased Leachate Ammonia Levels	16
2.2	Hydraulic Studies	16
2.3	Reactor Configuration	18
2.4	Nitrification Inhibition	18
EXPERIMENTAL SETUP AND OPERATION		21
3.1	MLE System Design	21
3.2	Bardenpho System Design	22
3.3	Leachate Feed	22
3.4	Chemical Addition	23
3.5	MLE System Startup and Operation	24
3.6	Bardenpho System Startup and Operation	26
ANALYTICAL METHODS		27
4.1	Ammonia ($\text{NH}_3 + \text{NH}_4^+$)	27
4.2	Nitrate plus Nitrite (NO_x)	28
4.3	Nitrite (NO_2^-)	28
4.4	Orthophosphate (Ortho-P)	28
4.5	Solids (TSS and VSS)	29
4.6	Biochemical Oxygen Demand (BOD_5)	29
4.7	Chemical Oxygen Demand (COD)	29
4.8	Alkalinity (as CaCO_3/L)	30
4.9	pH	30
4.10	Oxidation-Reduction Potential (ORP)	30
4.11	Dissolved Oxygen (DO)	31
4.12	Temperature	31

RESULTS AND DISCUSSION	32
5.1 MLE Startup Phase	33
5.1.1 Incremental Ammonia Loading and Nitrification Failure	34
5.1.2 Nitrification Recovery	45
5.1.3 Second Attempt at Incremental Ammonia Loading	46
5.1.4 Possible Explanations for Nitrification Failure	47
5.2 MLE Recycle Phase	62
5.2.1 Ammonia Levels - SRT Effects	63
5.2.2 Reactor Solids Levels - SRT Effects	70
5.2.3 Ammonia Levels - Ammonia Mass Loading Effects	74
5.2.4 Reactor Solids Levels - Ammonia Mass Loading Effects	75
5.2.5 Effluent Solids Levels	75
5.2.6 Ammonia Removal	78
5.2.7 Nitrification	83
5.2.8 NOx Levels	88
5.2.9 Denitrification	94
5.2.10 System NOx Removal	99
5.3 Bardenpho Phase	101
5.3.1 System Operation	102
5.3.2 Solids Levels	103
5.3.3 Ammonia Levels and Removal	105
5.3.4 Nitrification	111
5.3.5 NOx Levels and Removal	113
5.3.6 Denitrification	116
5.3.7 pH Levels	120
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	125
6.1 Summary	125

6.1.1	MLE Startup Phase	125
6.1.2	MLE Recycle Phase	126
6.1.3	Bardenpho Phase	128
6.2	Conclusions	129
6.2	Recommendations	130
REFERENCES		132
APPENDIX A Calculation Definitions		136
APPENDIX B Raw and Calculated Data		145
APPENDIX C Statistical Analyses		228

LIST OF TABLES

Table 3.1	Burns Bog Leachate Composition	23
Table 5.1	Reactor Alkalinity Data	45
Table 5.2	"Free" Ammonia Fraction at Various pH Values	56
Table 5.3	MLE Reactor Actual Hydraulic Retention Times	63
Table 5.4	Aerobic "Free" Ammonia Concentrations	69
Table 5.5	Anoxic "Free" Ammonia Concentrations	69
Table 5.6	Bardenpho Reactor Actual Hydraulic Retention Times	102

LIST OF FIGURES

Figure 1.1	MLE Process Configuration	9
Figure 1.2	Bardenpho Process Configuration	11
Figure 5.1	MLE Startup Phase - System #1	
	Simulated Leachate Ammonia Values	35
Figure 5.2	MLE Startup Phase - System #2	
	Simulated Leachate Ammonia Values	36
Figure 5.3	MLE Startup Phase - System #1	
	Anoxic and Aerobic Ammonia Values	38
Figure 5.4	MLE Startup Phase - System #2	
	Anoxic and Aerobic Ammonia Values	39
Figure 5.5	MLE Startup Phase - System #1	
	Anoxic Methanol Loading	40
Figure 5.6	MLE Startup Phase - System #2	
	Anoxic Methanol Loading	41
Figure 5.7	MLE Startup Phase - System #1	
	Anoxic and Aerobic pH Values	43
Figure 5.8	MLE Startup Phase - System #2	
	Anoxic and Aerobic pH Values	44
Figure 5.9	MLE Startup Phase - System #1	
	Anoxic and Aerobic VSS Values	49
Figure 5.10	MLE Startup Phase - System #2	
	Anoxic and Aerobic VSS Values	50
Figure 5.11	MLE Startup Phase - System #1	
	Anoxic % Ammonia Removal and Methanol Loading	52

Figure 5.12	MLE Startup Phase - System #2	
	Anoxic % Ammonia Removal and Methanol Loading	53
Figure 5.13	MLE Startup Phase - System #1	
	Anoxic Ammonia Removal Rate and Methanol Loading	54
Figure 5.14	MLE Startup Phase - System #2	
	Anoxic Ammonia Removal Rate and Methanol Loading	55
Figure 5.15	MLE Startup Phase - System #1	
	Anoxic and Aerobic Free Ammonia Values	57
Figure 5.16	MLE Startup Phase - System #2	
	Anoxic and Aerobic Free Ammonia Values	58
Figure 5.17	MLE Startup Phase - System #1	
	Anoxic and Aerobic NO _x Values	60
Figure 5.18	MLE Startup Phase - System #2	
	Anoxic and Aerobic NO _x Values	61
Figure 5.19	MLE Recycle Phase - System #1 (r = 7:1)	
	Anoxic and Aerobic Ammonia Values	65
Figure 5.20	MLE Recycle Phase - System #2 (r = 8:1)	
	Anoxic and Aerobic Ammonia Values	66
Figure 5.21	MLE Recycle Phase - System #1 (r = 7:1)	
	Anoxic and Aerobic pH Values	67
Figure 5.22	MLE Recycle Phase - System #2 (r = 8:1)	
	Anoxic and Aerobic pH Values	68
Figure 5.23	MLE Recycle Phase - System #1 (r = 7:1)	
	Anoxic and Aerobic VSS Values	71
Figure 5.24	MLE Recycle Phase - System #2 (r = 8:1)	
	Anoxic and Aerobic VSS Values	72
Figure 5.25	MLE Recycle Phase - System #1 (r = 7:1)	
	Effluent SS Values	76

Figure 5.26	MLE Recycle Phase - System #2 (r = 8:1)	
	Effluent SS Values	77
Figure 5.27	MLE Recycle Phase - System #1 (r = 7:1)	
	Anoxic, Aerobic and System % Ammonia Removal	79
Figure 5.28	MLE Recycle Phase - System #2 (r = 8:1)	
	Anoxic, Aerobic and System % Ammonia Removal	80
Figure 5.29	MLE Recycle Phase - System #1 (r = 7:1)	
	% Nitrification and Specific Nitrification Rate	85
Figure 5.30	MLE Recycle Phase - System #2 (r = 8:1)	
	% Nitrification and Specific Nitrification Rate	86
Figure 5.31	MLE Recycle Phase - System #1 (r = 7:1)	
	Anoxic and Aerobic NO _x Values	89
Figure 5.32	MLE Recycle Phase - System #2 (r = 8:1)	
	Anoxic and Aerobic NO _x Values	90
Figure 5.33	MLE Recycle Phase - System #1 (r = 7:1)	
	Anoxic and Aerobic NO ₂ Values	92
Figure 5.34	MLE Recycle Phase - System #2 (r = 8:1)	
	Anoxic and Aerobic NO ₂ Values	93
Figure 5.35	MLE Recycle Phase - System #1 (r = 7:1)	
	% Denitrification and Specific Denitrification Rate	95
Figure 5.36	MLE Recycle Phase - System #2 (r = 8:1)	
	% Denitrification and Specific Denitrification Rate	96
Figure 5.37	Bardenpho System	
	Anoxic and Aerobic VSS Values	104
Figure 5.38	Bardenpho System	
	Effluent TSS and VSS Values	106
Figure 5.39	Bardenpho System	
	Anoxic and Aerobic Ammonia Values	107

Figure 5.40	Bardenpho System	
	Anoxic and Aerobic % Ammonia Removal	108
Figure 5.41	Bardenpho System	
	Anoxic Ammonia Removal	110
Figure 5.42	Bardenpho System	
	% Nitrification and Alkalinity Consumption	112
Figure 5.43	Bardenpho System	
	Specific Nitrification Rates	114
Figure 5.44	Bardenpho System	
	Anoxic and Aerobic NO _x Values	115
Figure 5.45	Bardenpho System	
	Anoxic and Aerobic NO ₂ Values	117
Figure 5.46	Bardenpho System	
	% Denitrification	118
Figure 5.47	Bardenpho System	
	Specific Denitrification Rates	121
Figure 5.48	Bardenpho System	
	Anoxic NO _x Loads	122
Figure 5.49	Bardenpho System	
	Anoxic and Aerobic pH Values	123

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Chapter 1

INTRODUCTION

Landfilling of municipal solid waste (MSW) is the most economical and commonly used method of waste disposal (Henry and Heinke 1989). North America and the United Kingdom landfill 90% of their MSW that is sent for disposal. In Europe, although significant investments have been made in incineration and composting plants, over 60% of MSW is still landfilled.

Modern landfill design and operation have significantly reduced the environmental contamination potential of this method of waste disposal. Landfill gas is often collected and used for energy production. Highly contaminated liquid waste, called leachate, is also collected to prevent escape into the surrounding environment. However, due to the nature of leachate, it cannot be safely discharged into the environment without first receiving some form of treatment.

The following sections discuss leachate generation within landfills and mechanisms controlling leachate quality, and the need for leachate treatment. The purpose of this research was leachate treatment; thus, various leachate treatment methods, as well as the method and process configurations used in this study, and study objectives are also presented.

1.1 Leachate Generation and Quality

The downward movement of water through a landfill "leaches" contaminants derived from the waste and ultimately results in the production of leachate. Rainfall provides the major transport phase for the actual leaching of contaminants out of the landfill and also provides the required moisture for biological activity within the landfill (Pohland et al 1985). The dissolution of contaminants from the waste and into the infiltrating water is largely controlled by the biological reactions occurring inside the landfill. Pohland et al (1985) has described five distinct phases that occur during the "life" of a landfill. These phases are discussed below.

The first phase, Initial Adjustment, occurs when waste is initially placed into the landfill, settlement occurs, and each area, or "cell", of the landfill is closed.

Infiltration of precipitation eventually causes the field capacity of the waste to be exceeded, therefore, leachate is produced. The second, or Transition, phase is characterized by a change from aerobic to facultative and anaerobic conditions, as oxygen is replaced by nitrates and sulfates as the electron acceptor. Breakdown of organic waste material by acetogenic bacteria results in the production of intermediate organic volatile fatty acids (VFA's), therefore, the biochemical oxygen demand (BOD) of the leachate begins to rise.

Continued formation and domination of VFA's occurs during the third phase, Acid Formation. The presence of VFA's results in a drop in pH and causes the dissolution and complexation of metal species. Phosphorus is released and utilized by bacteria. Organically bound nitrogen, contained within amino groups (NH_2) of proteins (Tortora et al 1989), is converted into ammonia nitrogen (NH_3) by saprophytic bacteria (Sawyer and McCarty 1978). Some of the ammonia is utilized by bacteria as a nutrient with the remainder appearing in the leachate.

The intermediate VFA's produced in the previous phases are converted to methane and carbon dioxide by methanogenic bacteria during the fourth phase, Methane Fermentation. pH levels rise, with the concurrent precipitation of metals, as the buffer system within the landfill returns to that of the bicarbonate system rather than the previous system controlled by VFA's. Low oxidation-reduction potentials (ORP) result in the reduction of oxidized species. Leachate BOD levels decrease significantly as VFA's are converted to methane; however, high ammonia concentrations remain.

Final Maturation, phase five, is characterized by "relative dormancy" due to the absence of readily degradable organic matter. Gas production ceases, and oxygen and oxidized species may reappear with a corresponding increase in ORP. Slow degradation of more biologically resistant organic materials may produce humic-like substances capable of complexing and redissolving metals.

The terms "young" and "old" are often used to describe landfill age. A "young" landfill is one that is still in the Acid Formation phase. Leachate from such a landfill is characterized by very high BOD concentrations, due to the production of VFA's, and high ammonia concentrations (Robinson et al 1992). An "old" landfill, described as being in the Methanogenic phase, still produces leachate containing high ammonia levels; however, BOD concentrations are much lower due to the conversion of VFA's to methane and carbon dioxide.

United Kingdom landfills in the "young" Acid Formation phase were found to have mean BOD₅ and ammonia values of about 19,000 mg/L and 900 mg N/L, respectively (Robinson and Gronow 1993). Similarly, "old" Methanogenic landfills had mean BOD₅ and ammonia concentrations of about 375 mg/L and 900 mg N/L, respectively. The same study found that over 50% of landfills surveyed in the United Kingdom reached the Methanogenic phase within 3 years of waste placement; over 90% were in the Methanogenic phase after 10 years. The Tseung Kwan O Landfill in Japan, also in the Methanogenic phase, has ammonia and BOD₅ concentrations of about 2000 mg N/L and 200 mg/L, respectively (SENT 1992). The Burns Bog Landfill in Delta, British Columbia produces leachate containing about 200 mg N/L of ammonia and less than about 50 mg/L of BOD₅ (Carley and Mavinic 1991, Manoharan et al 1992, Azevedo 1993).

Biodegradable organic compounds and ammonia are the leachate constituents that pose the most significant environmental threats (Azevedo 1993). As discussed above, leachate from "older" landfills contains little BOD; therefore, ammonia levels in such leachate is the most important in terms of environmental impacts and treatment objectives (Robinson et al 1992). The research conducted for this study utilized an "old" leachate containing high ammonia and low carbon concentrations. Therefore, carbon (i.e. BOD) removal will not be further discussed, except as it pertains to biological nitrogen removal.

1.2 Environmental Impacts of Nitrogenous Wastes

The United States Environmental Protection Agency (EPA 1993) provides an excellent overview regarding the effects of nitrogen discharges into the environment and includes: eutrophication of surface waters, depletion of surface water dissolved oxygen (DO) levels by nitrification, ammonia toxicity of aquatic organisms, and public health concerns. The following is a brief summary of information contained in the aforementioned report.

Eutrophication is defined as excessive plant and/or algae "bloom" growth in rivers, lakes and estuaries. Nitrogen, along with phosphorus, carbon dioxide and light, is required for growth by plants and algae. Nitrogen is often unavailable in sufficient quantities, particularly in marine waters, to promote growth (i.e. growth limiting); therefore, the addition of nitrogen to surface waters via waste discharges can trigger the excessive growth of plants and/or algae. Effects of eutrophication include poor aesthetic appearance of water, odour problems, and lowering of DO levels due to decomposition of plant material. Respiration of aquatic organisms (e.g. fish, benthic animals) can be affected by reduced DO concentrations.

Water DO levels can be further lowered during nitrification of wastes containing ammonia by biological oxidation of ammonia to nitrite and nitrate.

Ammonia toxicity of aquatic organisms is caused by unionized "free" ammonia (NH_3). "Free" ammonia exists in equilibrium with the ammonium ion (NH_4^+). pH and temperature are the main factors controlling the equilibrium. The fraction of "free" ammonia, relative to "total" ammonia, increases with increases in both pH and temperature. "Free" ammonia concentrations of between 0.1 and 10 mg/L have been found to be acutely toxic to fresh and saltwater fish species.

Public health effects associated with nitrogen are specifically related to nitrates (NO_3^-) and nitrites (NO_2^-). Infant methemoglobinemia (i.e. "blue babies") is caused by the reduction of nitrate to nitrite in the stomach followed by nitrite oxidation of iron within hemoglobin molecules. The altered hemoglobin (methemoglobin) cannot exchange oxygen; therefore, suffocation of the victim can occur if not treated. In

addition, nitrites can also react with amines and amides to form N-nitroso compounds. These compounds have been found to be carcinogenic.

1.3 Nitrogen Removal Methods

1.3.1 Physical-Chemical Methods

Forgie (1988b) identifies air stripping as a potential method for ammonia removal from leachate. Lee and Naimie (1985) found that up to 70% of the ammonia could be stripped from a waste in an aerated reactor with a hydraulic retention time of 4 days and an initial pH of 10.0. The waste initially contained 300 mg/L of ammonia. However, air stripping of ammonia is costly because of the need for high pH levels (i.e. addition of basic solutions) and large aeration volumes. In addition, the process is temperature sensitive and fogging/icing can occur in cold weather (Metcalf & Eddy 1991).

Ion exchange, using clinoptilolite, can also be used for ammonia removal (Forgie 1988b). High costs for the media, and subsequent regenerations, prohibit using this method except in the case where removal of low concentrations of residual ammonia (e.g. 15 mg/L) is desired.

1.3.2 Bacterial Assimilation of Ammonia

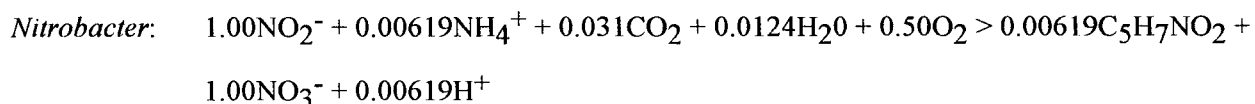
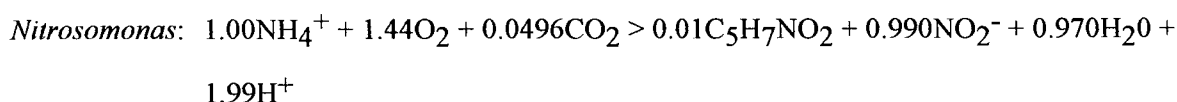
Robinson (1987) treated leachate from a landfill in the U.K., utilizing the concept that aerobic oxidation of carbonaceous matter requires ammonia nitrogen for the synthesis of cellular material. Leachate ammonia concentrations of about 800 mg N/L were reduced to less than 2 mg/L after treatment. The leachate contained insufficient biodegradable organic carbon to result in the assimilation of all the available ammonia (i.e. BOD:N < 100:5); therefore, jam waste from a local factory was used to supply the additional carbon. High sludge production is a potential disadvantage of this method of ammonia removal.

1.3.3 Biological Nitrification and Denitrification

1.3.3.1 Nitrification

Nitrification is the aerobic two-step conversion of ammonia (NH_4^+) first to nitrite (NO_2^-) and then to nitrate (NO_3^-). Two specific genera of bacteria are responsible for nitrification: *Nitrosomonas* converts ammonia to nitrite, and *Nitrobacter* converts nitrite to nitrate. These bacteria are autotrophic organisms; therefore, they derive energy from oxidation of the inorganic compounds ammonia and nitrite. In addition, inorganic carbon (i.e. carbon dioxide) is used for cell synthesis rather than organic carbon.

Stoichiometric equations describing combined energy production and cell synthesis for *Nitrosomonas* and *Nitrobacter* are as follows (EPA 1993):



The above equations assume *Nitrosomonas* and *Nitrobacter* cell synthesis rates of 0.08 g VSS/g $\text{NH}_4^+\text{-N}$ and 0.05 g VSS/g $\text{NH}_4^+\text{-N}$, respectively. Cellular composition is assumed to be $\text{C}_5\text{H}_7\text{NO}_2$.

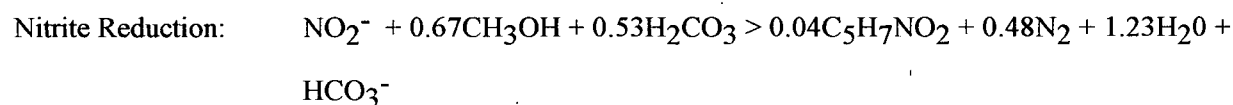
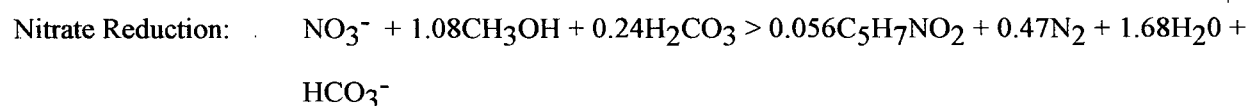
The production of hydrogen ions during nitrification results in the destruction of alkalinity to a ratio of 7.1 g CaCO_3 per g $\text{NH}_4^+\text{-N}$ nitrified. The above equations illustrate that most of the hydrogen ion production, hence alkalinity destruction, occurs during the ammonia oxidation step. Total oxygen consumption for nitrification, also based on stoichiometric requirements, is 4.6 g O_2 per g $\text{NH}_4^+\text{-N}$ nitrified.

1.3.3.2 Denitrification

Denitrification is the anoxic conversion of nitrate to nitrite, and then to gaseous nitrogen compounds (e.g. N_2) that are released into the atmosphere. Unlike nitrification, denitrification can be accomplished by

several genera of bacteria including *Achromobacter*, *Aerobacter*, *Alcaligenes*, *Bacillus*, *Brevbacterium*, *Flavobacterium*, *Lactobacillus*, *Micrococcus*, *Proteus*, *Pseudomonas*, and *Spirillum* (Metcalf and Eddy 1991). Denitrifying bacteria are heterotrophic organisms; therefore, they require organic carbon for both cell synthesis as well as an electron donor for energy production. These bacteria are also facultative, thus they have the ability to use oxygen, as well as nitrate and nitrite, as electron acceptors during energy production by modifying enzymes in their metabolic systems (EPA 1993). Energy production is most efficient when oxygen is the electron acceptor; hence, the bacteria will preferentially utilize oxygen over nitrate or nitrite. Therefore, the absence of oxygen is important for the reduction of nitrate and nitrite.

Stoichiometric equations, using methanol (CH₃OH) as the organic substrate, describing combined energy production and cell synthesis for the complete reduction of nitrate and nitrite are as follows (EPA 1993):



Complete nitrate reduction requires 2.47 g CH₃OH per g NO₃⁻-N (i.e. 3.7 g COD/g NO₃⁻-N); complete nitrite reduction requires 1.53 g CH₃OH per g NO₂⁻-N (i.e. 2.3 g COD/g NO₂⁻-N) (Azevedo 1993).

Hydroxide ions produced during reduction of nitrite react with carbon dioxide in the water to produce bicarbonate ions, therefore, bicarbonate alkalinity (EPA 1993). Alkalinity is generated at the ratio of 3.57 g CaCO₃ per g NO₂⁻-N denitrified (EPA 1975).

1.4 Treatment Method and Process Configurations

Biological nitrification and denitrification was the method selected for treatment of the high ammonia, low carbon landfill leachate used in this study. Several different process configurations have been successfully

used to remove ammonia from leachate and other high strength wastes. Extended aeration lagoons, operated in sequencing mode, have been used to nitrify leachate containing in excess of 1000 mg N/L of ammonia (Robinson et al 1992). Knox (1985) used a suspended growth, activated sludge system and an attached growth biological filter to nitrify leachate containing up to 500 mg N/L of ammonia. Peddie and Atwater (1985) used a rotating biological contactor to treat leachate containing ammonia levels of up to 50 mg N/L. A sequencing batch reactor, activated sludge system was used by Hosomi et al (1989) to nitrify and denitrify leachate containing about 200 mg N/L of ammonia. Similarly, Bortone et al (1992) used sequencing batch reactors to nitrify/denitrify piggery waste containing over 800 mg N/L of ammonia.

Two different complete mix, suspended growth, single sludge, activated sludge process configurations were selected for this study. The first was a predenitrification system known as the Modified Ludzack-Ettinger (MLE) process (Figure 1.1). As discussed later in Chapter 2, research has shown this process to be suitable for treating high ammonia leachates and other wastes. Leachate enters the anoxic reactor and is diluted by sludge returned from the clarifier. The mixed liquor then flows into the aerobic reactor where nitrifying bacteria oxidize ammonia to nitrite and nitrate (i.e. NO_x) (Ludzack and Ettinger 1962). Nitrified, settled sludge from the clarifier is returned to the anoxic reactor where denitrifying bacteria reduce NO_x to gaseous nitrogen compounds (e.g. N₂) that are "released" into the atmosphere.

The "predenitrification" and single sludge component of the MLE process offers several advantages over other activated sludge systems (Argaman 1982): dilution of incoming leachate, ability to use organic carbon present in leachate to denitrify return nitrified mixed liquor/sludge, removal of organic carbon in anoxic reactor minimizes oxidation in aerobic reactor, (thus reducing oxygen requirements), reduced alkalinity consumption minimizes chemicals needed for pH control, and the need for only one clarifier versus multiple clarifiers required for separate stage (i.e. multiple sludge) nitrification and denitrification.

The most significant shortcoming of "predenitrification only" systems, such as the MLE process, is effluent concentrations of oxidized nitrogen compounds (NO_x) can remain high because not all of the nitrified sludge can be returned to the anoxic reactor for denitrification. Effluent NO_x levels can be

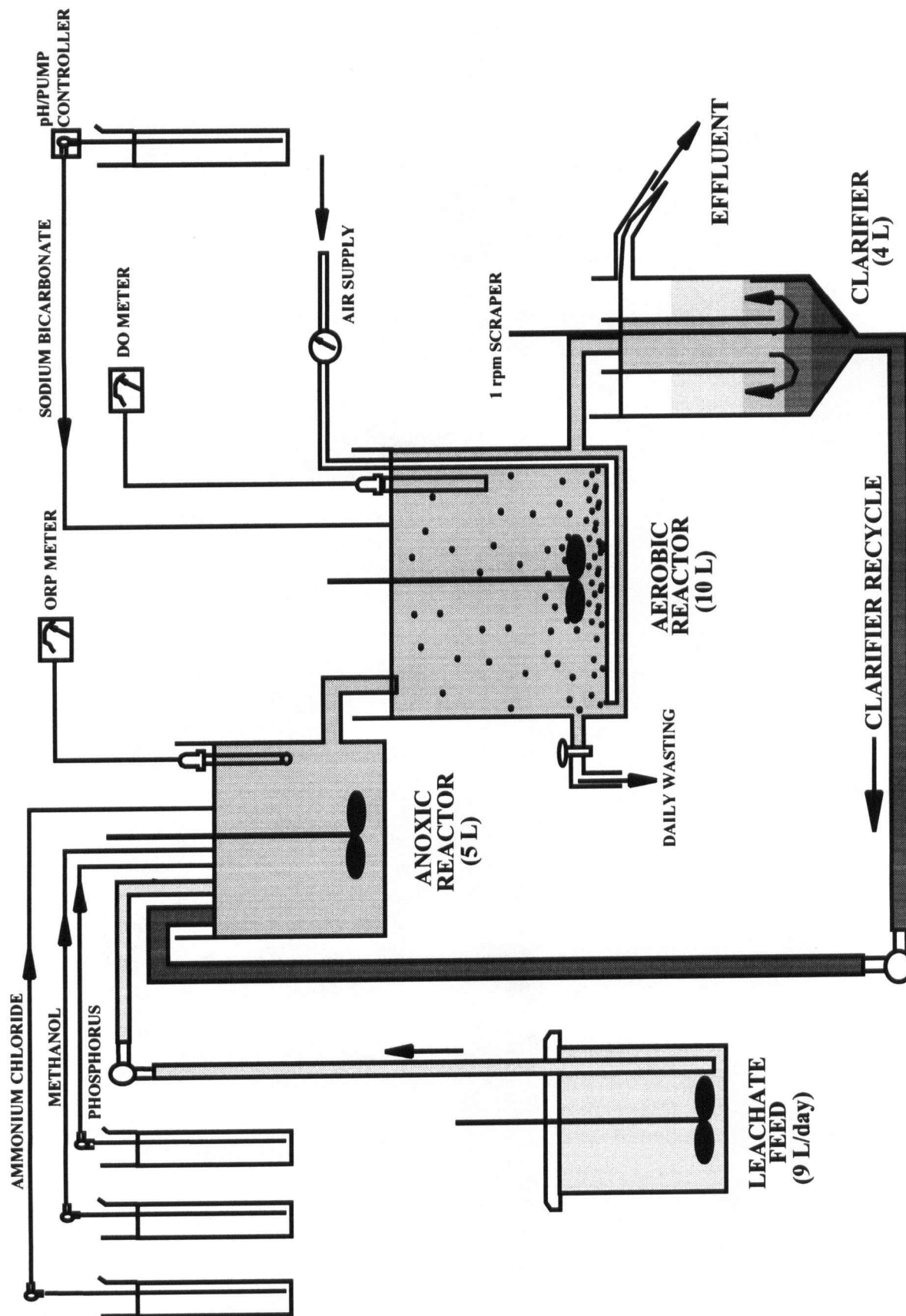


Figure 1.1 MLE Process Configuration

roughly estimated by dividing leachate ammonia concentrations by the sum of the leachate flow plus clarifier sludge recycle flow. Increases in clarifier sludge recycle flow, in theory, result in decreased effluent NOx concentrations. Other disadvantages include very high mass solids loading on the clarifier and high power costs associated with large recycle flows.

A pre and postdenitrification system, known as the Bardenpho process (EPA 1993), was the second process configuration examined (Figure 1.2) in this study. The "predenitrification" section of the Bardenpho system is similar to that of the MLE process. However, the source of NOx for denitrification in Anoxic #1 is the "aerated" mixed liquor returned from Aerobic #1 rather than "anoxic" clarifier sludge. The "postdenitrification" section allows for denitrification of NOx that is not returned to Anoxic #1; therefore, effluent from the Bardenpho system can be essentially free of NOx. The disadvantage of such a system, obviously, is the extra reactors and associated related costs.

1.5 Study Rationale and Objectives

The rationale for the present study was based on previous research conducted by Azevedo (1993) and Elefsiniotis et al (1989). Rising ammonia concentrations in leachate from landfills around the world prompted Azevedo (1993) to determine maximum leachate ammonia concentrations that could be successfully nitrified and denitrified using MLE systems. Results indicated that leachate ammonia concentrations of up to 1500 mg N/L could be treated to produce effluent containing < 1 mg N/L of ammonia. However, an excessive amount of NOx (i.e. 170 mg N/L) remained in the effluents due to the magnitude of the clarifier sludge recycle flow. Elefsiniotis et al (1989) attempted to reduce NOx concentrations in effluent from MLE systems treating leachate, containing about 240 mg N/L of ammonia, by increasing clarifier sludge recycle flows. Effluent NOx and suspended solids concentrations were found to increase when clarifier sludge recycle flows were greater than six times the leachate flow.

The purpose of this study was to investigate ways of reducing effluent NOx concentrations when treating high strength leachate containing up to 1200 mg N/L of ammonia. More specifically, the objectives of the study were:

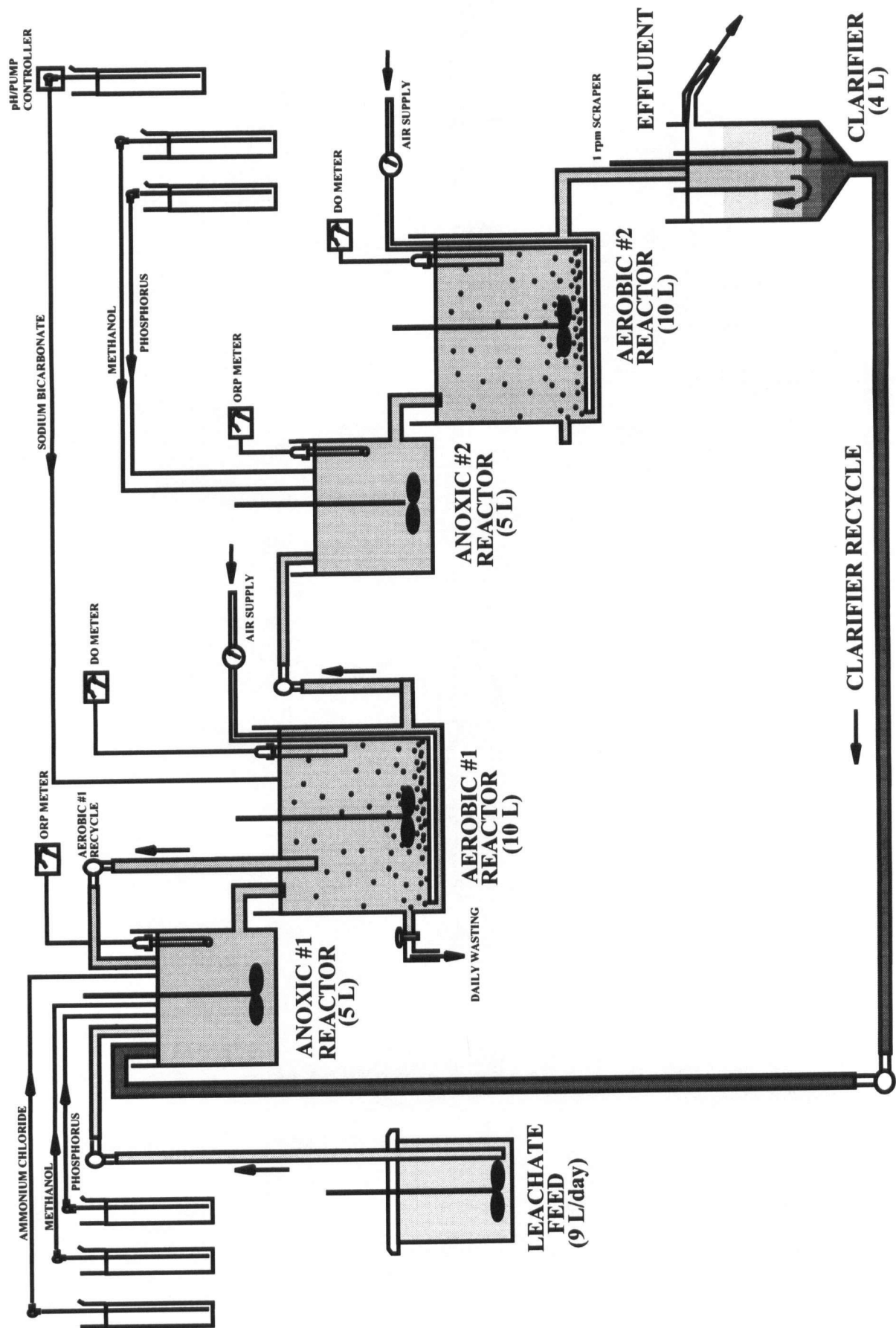


Figure 1.2 Bardenpho Process Configuration

1. Determine the effects of increasing clarifier sludge recycle flows in predenitrification MLE systems with respect to maximizing ammonia and NOx removal;
2. Investigate methods to mitigate against process instability when clarifier sludge recycle flows were increased in 1.; and
3. Based on limitations of the MLE systems as determined in 1. and 2., evaluate the nitrogen removal capabilities of a pre and postdenitrification Bardenpho system.

Chapter 2

LITERATURE REVIEW

This chapter presents a brief summary of literature related to nitrogen removal by biological nitrification and denitrification. Emphasis is placed on research utilizing continuous flow, suspended growth activated sludge systems treating high ammonia landfill leachates and industrial wastes.

2.1 UBC Leachate Treatment

This section summarizes extensive research regarding treatment of leachate using the Modified Ludzack-Ettinger (MLE) process that has been conducted at the University of British Columbia (UBC). Ammonia concentrations of approximately 200 mg N/L and biodegradable organic levels of under 50 mg O₂/L, as BOD₅, were typical of leachates used in the following studies.

2.1.1 Heavy Metal Inhibition

The effects of heavy metals on nitrification and denitrification of leachate were first investigated following inconsistent results obtained by Jasper et al (1985) and Dedhar and Mavinic (1985). Jasper et al (1985) found unstable ammonia removal when treating leachate containing a mean ammonia concentration of 160 mg N/L, using MLE systems with aerobic SRT's of up to 20 days. Mean % nitrification values varied from 7% to 45%. However, % denitrification values of over 90% were consistently attained once operational conditions were optimized. A study conducted by Dedhar and Mavinic (1985), using similar systems and leachate from the same landfill, found reliable ammonia removal (i.e. 100%) from leachate containing up to 288 mg N/L of ammonia. The only discernible difference between the two studies was the leachate used in the first study contained higher concentrations of zinc and manganese than leachate used in the second study.

Manoharan et al (1992) then investigated the effects of zinc, chromium, nickel, and manganese on nitrification and denitrification of leachate. The addition of zinc to leachate resulted in nitrification inhibition. However, increases in phosphorus addition to the systems resulted in nitrification recovery.

The lack of biologically available phosphorus, due to coprecipitation of zinc phosphate, was concluded to have caused nitrification failure. Leachate zinc concentrations of up to 130 mg/L did not affect treatability providing sufficient phosphorus was present. Addition of chromium (50 mg/L) and nickel (2.0 mg/L), separately, to leachate also resulted in nitrification inhibition. However, phosphorus deficiency was not noted at the point of inhibition for either chromium or nickel. Addition of manganese (50 mg/L) to leachate did not inhibit nitrification in a similar aerobic/anoxic system.

2.1.2 External Carbon Sources for Denitrification

The high ammonia leachates used in the various studies at UBC contain low concentrations of biodegradable organic carbon. Therefore, external carbon sources are required for denitrification. Manoharan et al (1989) investigated the use of methanol and glucose as carbon sources when treating leachate containing mean concentrations of ammonia and BOD₅ of 188 mg N/L and 25 mg O₂/L, respectively. Glucose was found to cause unreliable nitrification and denitrification. Fermentative conditions in the anoxic reactor were hypothesized to have provided a competitive environment for facultative anaerobes at the expense of denitrifying organisms. Unused glucose exiting the anoxic reactors caused inhibition of nitrification in the aerobic reactors. Methanol addition was found to result in stable and reliable nitrification and denitrification. In addition to process stability, methanol also has the benefits of low cost, availability, lack of nitrogen and phosphorus, favorable solids production, and low volatile organic compound potential (Yoder et al 1995).

Methanol, acetate, glucose, and brewery yeast were used as external carbon sources in a similar study by Carley and Mavinic (1991). Methanol and acetate were found to be the "most effective and trouble free" carbon sources. COD:NO_x requirements for complete denitrification were 6.2:1 for methanol and 5.9:1 for acetate. The brewery yeast also resulted in satisfactory system performance; however, a larger COD:NO_x ratio (8.5:1) was required for complete denitrification. Similar to the earlier study by Manoharan et al (1989), glucose was found to result in erratic system performance, due to suspected fermentative conditions in the anoxic reactor.

2.1.3 Cold Temperature Performance

Guo (1992) investigated the effects of low temperatures on nitrification and denitrification. Average effluent ammonia concentrations of less than 2 mg N/L were achieved when treating leachate containing about 200 mg N/L of ammonia at a temperature of 4°C and an aerobic SRT of 60 days. A 20 day aerobic SRT resulted in erratic nitrification with an average effluent ammonia concentration of about 9 mg N/L. Reductions in methanol loadings, following decreases in temperature, were necessary to prevent excess methanol from bleeding into the aerobic reactors and further inhibiting nitrification. Once the nitrifying organisms acclimatized to the reduced temperature, methanol loadings could be increased to match the increased denitrification requirements due to increased nitrification activity.

A study by Azevedo (1993) found that systems with 10 and 20 day aerobic SRT's experienced significant nitrification inhibition (i.e. % nitrification = 20%) at 10°C when treating leachate with a "simulated" ammonia concentration of 1500 mg N/L. Denitrification decreased from 99% to 30% in the 10 day SRT system and from 99% to 82% in the 20 day SRT system. Nitrification was reestablished when aerobic wasting and anoxic methanol addition were ceased.

2.1.4 Hydraulic Retention Time/Sludge Recycle Effects

Elefsiniotis et al (1989) investigated increasing sludge recycle flow rates, hence recycle ratios, as a means of reducing NO_x concentrations in effluents from MLE systems treating leachate containing about 240 mg N/L of ammonia. Sludge recycle ratios greater than 6:1 (anoxic AHRT < 1.71 hrs, aerobic AHRT < 3.42 hrs) resulted in unstable nitrification/denitrification and increased effluent NO_x and suspended solids concentrations. However, system ammonia removal remained at nearly 100%, regardless of the recycle ratio. Reductions in reactor actual hydraulic retention times at larger recycle ratios was thought to have caused insufficient contact time for complete nitrification and denitrification. Bacterial assimilation of ammonia and ammonia stripping ensured complete system ammonia removal, even though nitrification became unstable at higher recycle ratios.

2.1.5 Increased Leachate Ammonia Levels

Azevedo (1993) artificially increased ammonia concentrations in leachate being treated by 10 and 20 day aerobic SRT systems until the systems failed. Both systems were able to produce effluents with less than 1 mg N/L of ammonia and about 170 mg N/L of NO_x from leachate containing 1500 mg N/L of ammonia. Increases in leachate ammonia concentration from 1500 to 2000 mg N/L resulted in % nitrification values decreasing from greater than 90% to about 20% in both systems. "Free" ammonia toxicity of ammonia oxidizing organisms (*Nitrosomonas*), insufficient dissolved oxygen concentrations, and overflow problems were postulated to have caused nitrification failure.

2.2 Hydraulic Studies

Studies investigating the effects of hydraulic retention times and recycle ratios on MLE systems treating nitrogenous wastes are summarized below.

Argaman and Brenner (1986) found that decreasing aerobic AHRT's from 8.9 hrs to 4.6 hrs, by increasing sludge recycle flows, resulted in a decrease in aerobic ammonia removal from 95% to 40%, when treating domestic sewage that was spiked with ammonium chloride to provide an ammonia concentration of about 250 mg N/L. A further reduction in aerobic AHRT to 3.2 hrs yielded an aerobic ammonia removal efficiency of only 17%. Aerobic VSS levels were similar in all runs. Nitrification was found to follow zero-order kinetics, providing aerobic ammonia concentrations were greater than 2.0 mg N/L. Increased sludge recycle ratios, up to 14:1, did not result in reduced effluent NO_x concentrations because of carbon shortages in the wastewater. In addition, actual effluent NO_x concentrations were found to increase at higher recycle ratios due to poor denitrification kinetics associated with low carbon concentrations in the anoxic reactors. Mathematical modelling of predenitrification systems by Brenner and Argaman (1990) yielded similar findings.

Szpykiewicz et al (1991a,b) treated tannery wastewater containing about 200 mg N/L of ammonia and 1000 mg O₂/L BOD₅, using an MLE system having clarifier sludge (1:1) and aerobic mixed liquor recycles. Average effluent ammonia concentrations of less than 4 mg N/L were achieved with aerobic

AHRT's as low as 2.9 hrs. Increases in aerobic mixed liquor recycle from 10:1 to 14:1 did not result in reduced effluent NO_x levels due to carbon shortages. Anoxic dissolved oxygen concentrations were less than 0.1 mg/L, but the entrainment of oxygen into the anoxic mixed liquor, from the aerobic recycle, was estimated to have caused the elimination of 6% of the incoming COD by using oxygen as the electron acceptor rather than NO_x. Large COD:NO_x ratios (i.e. up to 12.5) were required for complete denitrification, thus suggesting the presence of significant quantities of oxygen entering the anoxic reactor.

Argaman (1982) also found very large anoxic BOD removals when using an aerobic mixed liquor recycle ratio of 30:1. The amount of BOD and NO_x removed across the anoxic reactor can be used to calculate a BOD:NO_x ratio of 29.2:1. Aerobic oxidation of organic carbon, within the anoxic reactor, was suggested as a reason for the large amount of anoxic BOD removal, even though dissolved oxygen concentrations were less than 0.5 mg/L.

A predenitrification modelling study conducted by Jain et al (1992) found that anoxic denitrification performance was negatively affected by the introduction of oxygen contained within the aerobic mixed liquor recycle. Higher recycle rates and/or lower anoxic AHRT's compounded the negative effects of oxygen on denitrification.

Robinson (1992) used an MLE system to treat leachate containing 1100 mg N/L of ammonia. A recycle ratio of 10:1 resulted in effluent NO_x concentrations between 75 and 100 mg N/L, with ammonia levels less than 0.1 mg N/L. AHRT's of the anoxic and aerobic reactors were about 17 hrs and 55 hrs, respectively.

The effect of decreasing reactor HRT's, in an MLE system, on nitrification/denitrification of domestic sewage was investigated by Wanner et al (1990). Decreases in aerobic HRT from 5.8 to 3.8 hrs did not affect nitrification. Similarly, denitrification remained unaffected when anoxic HRT's were reduced from 3.3 to 2.2 hrs. Recycle ratios were maintained at about 1.5:1 for all trials; therefore, decreases in HRT were caused by increasing influent flow rates.

Gee et al (1990) treated a simulated waste containing 1000 mg N/L of ammonia in a completely mixed aerobic reactor without solids recycle. Complete nitrification was still attained at an aerobic HRT of 2.7 days; however, nitrification failed when the HRT was further reduced to 2.0 days. VSS levels increased as the HRT was decreased from 10 days (200 mg/L) to 2.7 days (300 mg/L). The reduction in VSS at higher HRT's was assumed to be the result of cell decay.

2.3 Reactor Configuration

The importance of anoxic organic carbon levels on denitrification performance was investigated by Panzer et al (1981), by using a four stage anoxic reactor to simulate plug flow conditions in an MLE system treating tannery waste. Specific denitrification rates in the first stage were up to four times greater than those of the third and fourth stages. Decreasing COD concentrations in the latter stages resulted in substrate limited denitrification. Hence "staged" or plug flow anoxic reactors were concluded to more efficiently utilize available carbon for denitrification.

Chudoba et al (1985) compared plug flow and complete mix aeration tank configurations with respect to nitrification kinetics. The plug flow system had specific ammonia oxidation rates that were almost twice those of the complete mix system. The half velocity constant for the plug flow system was about 40% smaller than the complete mix system. Larger bulk ammonia concentrations in the plug flow system were thought to have allowed for the diffusion of ammonia into the centre of the flocs, thus allowing active nitrifiers to be present throughout the entire floc and resulting in lower half velocity constants and higher specific ammonia oxidation rates.

2.4 Nitrification Inhibition

The effects of carbon loading and heterotrophic activity on nitrification was studied by Hanaki et al (1990a). Ammonia oxidation within the complete mix aerobic reactor, without solids recycle, decreased as influent COD (glucose) levels were increased. In addition, ammonia oxidation was inhibited to a greater extent at lower HRT's for a given COD loading. It was hypothesized that "crowding" of ammonia oxidizing organisms by heterotrophic bacteria, at higher COD loadings, hindered the transport of ammonia

and oxygen from bulk solution to ammonia oxidizers within the flocs. Further study (Hanaki et al 1990b) confirmed that the inhibitory effect of organic loading on ammonia oxidation was enhanced by low dissolved oxygen concentrations.

Azevedo (1993) also found inhibition of nitrification when excess methanol from anoxic reactors was bleeding into aerobic reactors of MLE systems treating leachate. High aerobic BOD₅ values correlated "reasonably well" with lower % nitrification values. Bulk solution dissolved oxygen levels were always sufficient for nitrification. However, actual oxygen concentrations within the flocs may not have been sufficient for *Nitrosomonas* organisms.

Anthonisen et al (1976) investigated the effects of ammonia and nitrous acid on inhibition of nitrification. "Free" ammonia concentrations of 10 to 150 mg N/L were found to initiate inhibition of *Nitrosomonas* organisms; *Nitrobacter* inhibition began at concentrations of 0.1 to 1.0 mg N/L. Nitrous acid concentrations between 0.22 and 2.8 mg/L were found to initiate inhibition of both organisms. The degree of inhibition due to "free" ammonia and nitrous acid was theorized to be a function of temperature, acclimation, and numbers of nitrifying organisms.

Turk (1986) attempted to induce and sustain nitrite accumulation, by inhibiting *Nitrobacter*, in order to reduce organic carbon requirements for denitrification when treating nitrogenous wastes. "Free" ammonia concentrations of 5 to 10 mg N/L inhibited unacclimatized nitrite oxidizing organisms. However, "free" ammonia concentrations of up to 40 mg N/L did not inhibit either ammonia or nitrite oxidation of acclimated systems. Internal recycle, such as that used in a predenitrification process, continually recycles nitrifiers through high anoxic "free" ammonia concentrations and was found to be the most effective way of delaying acclimation.

The effects of extreme substrate, product and salt concentrations on the ammonia oxidizing bacteria *Nitrosomonas europaea* were investigated by Hunik et al (1992). Results of pure culture chemostat studies revealed that, although severe inhibition occurred for all substances tested, no significant differences

between ammonia, nitrite and various salts were observed. Osmotic pressure due to high salt concentrations were concluded to have caused the inhibitions. Nitrite was found to be inhibitory at low pH's, due to the formation of nitrous acid.

Chapter 3

EXPERIMENTAL SETUP AND OPERATION

Two different process configurations were used during the course of this study. The first was a predenitrification system known as the Modified Ludzack-Ettinger (MLE) process. Two identical MLE systems were used during the MLE Startup Phase and MLE Recycle Phase. The second process configuration was a pre and postdenitrification system known as the Bardenpho process. A single Bardenpho system was used during the Bardenpho Phase of the study.

3.1 MLE System Design

The MLE systems, shown in Figure 1.1, consisted of an anoxic reactor, aerobic reactor, and a clarifier. The anoxic reactor was used for denitrification of nitrified sludge returned from the clarifier. It was constructed from a plastic container and had a volume of 5 litres. An electric motor and stirring rod was used to keep the anoxic mixed liquor completely mixed and in suspension. A mixing speed of about 50 rpm provided adequate mixing while minimizing the entrainment of oxygen into the reactor. An ORP probe continuously monitored the oxidation-reduction potential within the anoxic reactor. Mixed liquor from the anoxic reactor flowed into the aerobic reactor by gravity.

The aerobic reactor was used for nitrification of mixed liquor from the anoxic reactor. It was also constructed from a plastic container, and had a volume of 10 litres. Two small porous stones, located at the bottom of the reactor, were used to supply air required for nitrification. Dissolved oxygen levels were maintained above 2.0 mg/L. Air flow was manually controlled using flow meters connected to the laboratory compressed air supply line. The mixed liquor was kept in suspension by an electric motor and stirring rod. Mixed liquor from the aerobic reactor flowed into the clarifier by gravity.

A clarifier constructed of Plexiglas, with a volume of 4 litres, was used to settle solids from the final effluent and to produce a thickened sludge that was returned to the anoxic reactor for denitrification. Mixed liquor entered the clarifier through an inner, cylindrical baffle intended to prevent short circuiting.

Sludge was withdrawn from the conical bottom of the clarifier. The sludge was pumped back to the anoxic reactor using a peristaltic pump operating intermittently at 1 minute on and 3 minutes off. Intermittent pumping was used to prevent recycle line blockages (Azevedo 1993). A stainless steel rod, attached to a 1 rpm electric motor, was used to scrape solids from the sides and bottom of the clarifier.

3.2 Bardenpho System Design

The Bardenpho System (Figure 1.2) was created using reactors from both MLE systems. The "predenitrification" section consisted of the anoxic and aerobic reactors from MLE System 1. The clarifier from System 1 was not used. The "postdenitrification" section consisted of the anoxic and aerobic reactors and clarifier from MLE System 2. Mixed liquor from Aerobic #1 was pumped to Anoxic #2 by a peristaltic pump operating at 1 minute on and 9 minutes off. Sludge from the clarifier was pumped to Anoxic #1 by a peristaltic pump operating at 1 minute on and 9 minutes off. Mixed liquor from Aerobic #1 was recycled to Anoxic #1 by a peristaltic pump operating at 1 minute on and 3 minutes off.

3.3 Leachate Feed

The leachate used in this study was from the Burns Bog Landfill located in Delta, British Columbia. Leachate was collected once a week and stored at 4°C to prevent any changes in quality. Actual leachate collection was from a sampling line connected to the pressurized pipeline exiting a wet well. The wet well was located at the southwest corner of the landfill.

The landfill began operations in 1966 (Azevedo 1993) and continues to be used today. Table 3.1 contains a summary of leachate composition for the study period. High ammonia and low carbon concentrations typical of an "older" landfill are illustrated in the data.

Table 3.1 Burns Bog Leachate Composition

Parameter	Mean Concentration (mg/L)	Range (mg/L)
NH ₄ -N	198	80 - 392
NO _x -N	0.4	0.2 - 1.6
NO ₂ -N	0.2	0.0 - 0.5
O-PO ₄	0.4	0.0 - 1.0
pH (pH units)	--	6.8 - 7.8
Alkalinity (as CaCO ₃)	1600	750 - 2300
TSS	45	16 - 89
VSS	23	8 - 48
BOD ₅	31	11 - 50
COD	374	188 - 596
Cr*	< 0.03	N.D. - 0.03
Ni*	< 0.03	N.D. - 0.04
Zn*	0.05	0.04 - 0.06

* City of Vancouver, Monthly Composite Data, July - November, 1995

Leachate was fed to the anoxic reactors of the MLE systems by peristaltic pumps that continuously pumped leachate from a covered, plastic pail that was slowly stirred using an electrical motor and stirring rod. Leachate was only fed to Anoxic #1 of the Bardenpho system. Stored leachate (4°C) was allowed to come to "room" temperature (20°C) before it was added to the feed pail. A siphon was used to transfer leachate from the storage containers to the feed pail, in order to prevent excess aeration of the leachate.

The leachate flow rate was set to approximately 9 L/d so as to be similar to previous UBC studies (Elefsiniotis et al 1989, Guo 1992, Azevedo 1993). The total flow into the systems was about 10 L/d, because of the various chemical additions.

3.4 Chemical Addition

The peristaltic pumps used to add various chemical solutions to the systems were set to pump at the lowest flow rates that could "reliably" be maintained (i.e. 5 to 10 mL/hr). This was done to minimize dilution and HRT effects from addition of chemical solutions. Chemical loadings, therefore, were adjusted by changing the concentration of the feed solutions.

Phosphorus solutions were added to the anoxic reactors of the systems to ensure biologically available phosphorus levels were sufficient for nitrification and denitrification. Both anoxic reactors of the Bardenpho system were fed phosphorus solutions. In keeping with earlier results by Manoharan et al (1992), reactor ortho-phosphate concentrations were generally maintained above 2.0 mg P/L. Dibasic sodium phosphate ($\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$) was used to make up the solutions. Mass loadings were calculated based on daily volumetric changes within the 1000 ml graduated cylinders, used for solution storage, and solution concentrations.

Methanol (CH_3OH), added to the anoxic reactors, was used as the organic carbon source required for denitrification. Solution concentrations were adjusted based on requirements for complete denitrification. Mass loadings were calculated based on daily volumetric changes within the 1000 ml graduated cylinders, used for solution storage, and solution concentrations.

Elevated leachate ammonia concentrations were "simulated" by adding ammonium chloride (NH_4Cl) solutions to the anoxic reactors of the MLE systems. Ammonium chloride was only fed to Anoxic #1 of the Bardenpho system. Ammonia concentrations of the "simulated" leachate were calculated based on daily volumetric changes within the 1000 ml graduated cylinders (used for solution storage), ammonium chloride solution concentrations, and "base" leachate feed rates and ammonia concentrations.

Sodium bicarbonate (NaHCO_3) solutions were added to the aerobic reactors as required to maintain aerobic pH levels at 7.5. This was done using Cole Parmer 7142 pH/pump controllers that continuously monitored aerobic pH levels and pumped sodium bicarbonate solutions from 1000 ml graduated cylinders into the aerobic reactors when the pH dropped below 7.5. The solutions were maintained at 80 g CaCO_3/L (i.e. near saturation) in order to minimize the volume of solution pumped into the reactors.

3.5 MLE System Startup and Operation

On July 7, 1994 the aerobic reactors and clarifiers of both MLE systems were filled with anoxic mixed liquor from the Biological Phosphorus Removal (Bio-P) Pilot Plant located at the University of British

Columbia.. Leachate and phosphorus solutions were directly fed into the aerobic reactors. Sludge from the clarifiers was recycled back to the aerobic reactors at a ratio of 6:1. Stable and complete nitrification of the "base" leachate was attained in both systems by day 35; therefore, the anoxic reactors were filled with Bio-P anoxic mixed liquor on August 11, 1994. Leachate, and methanol and phosphorus solutions were then fed to the anoxic reactors. Clarifier sludge was recycled to the anoxic reactors at a starting ratio of 6:1. Aerobic wasting began on August 19, 1994 at the rate of 0.5 L/d, and eventually increased to 0.67 L/d (September 14, 1994) and 1.0 L/d (November 29, 1994). Complete nitrification and denitrification of the "base" leachate was reached in both systems by day 70 (September 16, 1994).

Leachate ammonia concentrations were incrementally increased from levels contained within the "base" leachate to the "target" concentration of 1200 mg N/L. Anoxic methanol loadings were kept constant at levels required to denitrify the "base" leachate. The first attempt at reaching the "target" concentration occurred between September 17, 1994 and October 23, 1994. Nitrification failure in both systems, caused by "free" ammonia toxicity (discussed in Section 5.1), resulted in a second attempt to reach the "target" concentration. Starting again with the "base" leachate, ammonia levels were incrementally increased, at a rate similar to the first attempt, beginning on October 30, 1994. The same sludge was used; therefore, the reactors were not re-seeded. However, anoxic methanol loadings were also increased at the same time leachate ammonia concentrations were increased. By November 20, 1994 both systems were successfully treating leachate containing 1200 mg N/L of ammonia. Specific details regarding leachate ammonia increments and anoxic methanol loadings are presented in Sections 5.1 and 5.1.3.

The MLE Recycle Phase was conducted between December 14, 1994 and March 7, 1995. Clarifier sludge recycle flows were increased on December 14, 1994 to yield recycle ratios of 7:1 in System 1 and 8:1 in System 2. Aerobic SRT's of 10 days were initially used in both systems; however, these were eventually increased to 20 days, in order to improve nitrification performance. Reductions in leachate ammonia concentrations, begun on February 14, 1995, were initiated in an attempt to remove residual ammonia remaining in the effluents.

The MLE systems were setup in a temperature controlled room maintained at about 20°C.

3.6 Bardenpho System Startup and Operation

The two MLE systems were converted to the Bardenpho System on March 8, 1995. The conversion simply consisted of plugging the overflow from Aerobic #1 to Clarifier #1, positioning a peristaltic pump to transfer mixed liquor from Aerobic #1 to Anoxic #2, and relocating the sludge recycle line from Clarifier #2 to discharge into Anoxic #1. The mixed liquor recycle from Aerobic #1 to Anoxic #1 was set at a ratio of 4:1. The clarifier sludge recycle flow was set to give a recycle ratio of 3:1.

Sludge wasting was conducted at a rate of 0.5 L/d from Aerobic #1, thus resulting in an Aerobic #1 SRT of 20 days. A "simulated" leachate ammonia concentration of 1100 mg N/L was maintained throughout the Bardenpho Phase. The room temperature was kept at about 20°C. The Bardenpho Phase, upon the system reaching "steady state", was terminated on April 7, 1995.

Chapter 4

ANALYTICAL METHODS

This chapter outlines the analytical methods used in the determination of various chemical constituents within the leachate, reactor mixed liquors, and effluents. Samples were collected two or three times a week for analysis, except where otherwise indicated.

4.1 Ammonia ($\text{NH}_3 + \text{NH}_4^+$)

Leachate, mixed liquor and effluent samples were analyzed for ammonia using a Lachat Quikchem Automated Ion Analyzer. Samples were filtered through Whatman #4 filters, diluted as necessary, pH adjusted using sulphuric acid to a pH of 3.0, and stored at 4°C until analysis. Samples were pH adjusted to 3.0 because the ammonia standards were prepared with the same pH. Ammonia concentrations were determined using methods outlined in the Methods Manual for the Quikchem Automated Ion Analyzer (1987).

Aerobic mixed liquor ammonia concentrations were also estimated using an Orion Model 95-10 ammonia probe and a Cole Parmer Chemicadet Series 5984 pH/mV meter. This method allowed for daily "screening" of aerobic ammonia levels and gave an indication of system nitrification performance. Unfiltered 50 ml samples were pH adjusted to approximately pH 11 using 0.5 ml of 10 M NaOH as outlined in the Orion Ammonia Electrode Instruction Manual. An initial mV reading was taken, then 5 ml of an ammonium chloride standard solution was added to the sample and the final mV reading recorded. Standard solutions (1.4, 14, 140, 1400 mg N/L) containing approximately ten times the "suspected" sample ammonia concentration were added to the samples. The ammonia concentration of the sample was then calculated using the difference in the mV readings, the ammonia concentration of the standard solution, and a table contained in the Orion instruction manual.

4.2 Nitrate plus Nitrite (NO_x)

Leachate, mixed liquor and effluent samples were analyzed for NO_x using a Lachat Quikchem Automated Ion Analyzer. Samples were filtered through Whatman #4 filters, preserved with several drops of phenyl mercuric acetate, diluted as necessary, and stored at 4°C until analysis. NO_x concentrations were determined using methods outlined in the Methods Manual for the Quikchem Automated Ion Analyzer (1987).

4.3 Nitrite (NO₂⁻)

Leachate, mixed liquor and effluent samples were analyzed for NO₂ using a Lachat Quikchem Automated Ion Analyzer. Samples were filtered through Whatman #4 filters, preserved with several drops of phenyl mercuric acetate, diluted as necessary, and stored at 4°C until analysis. NO₂ concentrations were determined using methods outlined in the Methods Manual for the Quikchem Automated Ion Analyzer (1987).

4.4 Orthophosphate (Ortho-P)

Leachate, mixed liquor and effluent samples were analyzed for orthophosphate using a Lachat Quikchem Automated Ion Analyzer. Samples were filtered through Whatman #4 filters, preserved with several drops of phenyl mercuric acetate, and stored at 4°C until analysis. Orthophosphate concentrations were determined using methods outlined in the Methods Manual for the Quikchem Automated Ion Analyzer (1987).

A comparison of ortho-p concentrations when samples were filtered through Whatman #4 filters and 0.45 µm membrane filters was initially conducted in response to findings by Manoharan et al (1992). Ortho-P concentrations were virtually identical (i.e. within method reproducibility tolerances) in both sets of samples; therefore, Whatman #4 filtered samples were concluded to reliably estimate biologically available phosphorus levels and were used for the remainder of the study.

4.5 Solids (TSS and VSS)

Leachate, mixed liquor and effluent samples were analyzed for total suspended solids (TSS) and volatile suspended solids (VSS) using a modification (Azevedo 1993) of the Standard Methods (A.P.H.A. 1985) procedure. A stainless steel filtration apparatus and aluminum filter holders replaced the ceramic Gooch filtration units specified in Standard Methods. This modification reduced the possibility of errors associated with absorption of moisture onto the filter paper holders.

4.6 Biochemical Oxygen Demand (BOD₅)

Biochemical Oxygen Demand levels in the leachate, mixed liquors and effluents were determined using the methods outlined in Standard Methods (A.P.H.A. 1985). Samples were filtered through Whatman #4 filters prior to the addition of dilution water. The dilution water was seeded with 1 ml of aerobic mixed liquor per 10 l of dilution water. In addition, nitrification inhibitor (Hach Formula 2533) was added to the dilution water at a concentration of 10 mg/L, to eliminate the oxygen consumption effects of nitrifiers contained within the mixed liquor seed. A Yellow Springs Instrument Company Model 54 Dissolved Oxygen Meter and self mixing probe was used to determine initial and final dissolved oxygen concentrations of the samples.

Leachate, reactor and effluent samples were collected once a week for BOD₅ determination.

4.7 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand levels in the leachate, mixed liquors and effluents were determined using the closed reflux, colorimetric method outlined in Standard Methods (A.P.H.A. 1985). Samples were filtered through Whatman #4 filters, acidified to pH < 2 with sulphuric acid, and stored at 4°C until analysis. Mercuric sulphate was included in the digestion solution to eliminate effects of chloride contained within the samples. Samples were occasionally centrifuged after digestion to settle particulate matter (i.e. precipitates) suspended in the samples. COD values for samples containing nitrite were corrected by subtracting 1.1 mg O₂/L per mg NO₂-N/L to account for the oxygen demand of nitrite (A.P.H.A. 1985).

4.8 Alkalinity (as CaCO_3/L)

Leachate alkalinity analyses were conducted once a week on each batch of leachate collected from the landfill. Samples were filtered through Whatman #4 filters and analyzed using methods outlined in Standard Methods (A.P.H.A. 1985). Samples were titrated to a pH endpoint of 4.3 as determined using a pH meter and probe.

Reactor mixed liquor and effluent samples were occasionally analyzed for alkalinity during periods of nitrification inhibition. The analyses were conducted in the same manner as that for the leachate samples.

4.9 pH

Unfiltered leachate and mixed liquor pH levels were measured using a Cole Parmer Chemcadet Series 5986 pH meter with a Ag-AgCl combination pH electrode. Meter calibration was checked before each use with a pH = 7.01 buffer solution. Recalibration, if necessary, was performed using pH = 7.01 and pH = 10.01 buffer solutions.

Cole Parmer Model 7142 pH/pump controllers with Ag-AgCl combination pH electrodes monitored aerobic pH levels. The controllers were calibrated using pH = 7.01 and pH = 10.01 buffer solutions. However, electrical "noise" from the various motors resulted in pH levels displayed by the controllers to be slightly different from those obtained using the above "bench top" meter. Therefore, readings obtained using the "bench top" meter were used for data collection. In addition, the setpoints on the pH controllers were adjusted such that aerobic pH levels were 7.5 as indicated by the "bench top" meter. Aerobic pH probes were cleaned weekly with distilled water and, on occasion, using a mild soap solution.

4.10 Oxidation-Reduction Potential (ORP)

ORP values in the anoxic reactors were continuously monitored by submerged Broadly James Corporation ORP electrodes (one per reactor) connected to Cole Parmer Chemcadet Series 5984 pH/mV meters. Probe response was initially checked with pH-buffered quinhydrone solutions (Broadly James

Corporation Electrode Instructions ORP (REDOX) Combination Electrode). Both probes were "standardized" to read 000 mV in tap water. The ORP probes were cleaned weekly with distilled water.

4.11 Dissolved Oxygen (DO)

A Yellow Springs Instrument Company Model 54 Dissolved Oxygen Meter with a Yellow Springs Instrument Company Model 5739 submersible probe was used to determine in-situ aerobic mixed liquor DO concentrations about every second day. The meter was calibrated using the air calibration method as outlined in the Instruction Manual for YSI Models 54 ARC and 54 ABP Dissolved Oxygen Meters. The probe membrane was changed when the meter failed air calibration. The probe was cleaned with distilled water after each use.

4.12 Temperature

The experimental apparatus was set up in a temperature controlled room. Two identical, alcohol thermometers, in addition to the thermometer built into the temperature controller, were used monitor room temperature.

Chapter 5

RESULTS AND DISCUSSION

The results obtained from this study are presented and discussed in this chapter. The study was divided into three phases: (1) MLE Startup Phase; (2) MLE Recycle Phase; and (3) Bardenpho Phase. Two identical, predenitrification, single sludge, activated sludge systems, known as the Modified Ludzack-Ettinger (MLE) process, were used in the first two phases of the study. The third phase combined components of the two MLE systems into one four-stage, pre and postdenitrification system known as the Bardenpho process.

The MLE Startup Phase involved the initial startup of the two MLE systems using the "base" leachate followed by artificially increasing the leachate ammonia concentration to a "target" level of approximately 1200 mg N/L, to simulate a higher strength leachate. An initial clarifier recycle rate of 6:1 (sludge recycle flow: leachate flow) and aerobic solids retention time (SRT) of 13 days were used for both systems. Aerobic SRT's were reduced to 10 days once the "target" leachate ammonia concentration was reached.

The MLE Recycle Phase was begun once both systems were treating 1200 mg N/L ammonia leachate in a stable manner. According to MLE process theory, increases in sludge recycle rate should result in reduced effluent oxidized nitrogen (NO_x) concentrations. Therefore, the purpose of this phase was to investigate the effects of increased sludge recycle rates on nitrification, denitrification and effluent NO_x concentrations. Sludge recycle rates were increased to 7:1 in one system and 8:1 in the other system. The effects of increased SRT and reduced ammonia mass loadings on process performance were also investigated.

The final phase of the study, the Bardenpho Phase, was conducted to verify that a combined pre and postdenitrification system could successfully remove virtually all nitrogen from leachate containing 1200 mg N/L of ammonia.

Calculation definitions are shown in Appendix A with raw and calculated data contained in Appendix B.

5.1 MLE Startup Phase

This section presents and discusses data collected from the time the MLE systems were initially started (Day 1 - July 7, 1994) until the beginning of the MLE Recycle Phase (Day 157 - December 12, 1995). Three distinct periods existed during this startup phase: establishment of nitrification and denitrification using the "base" leachate, incrementally increasing leachate ammonia concentrations followed by nitrification failure in both systems, and systems recovery and second attempt at increasing leachate ammonia concentration. The failure of both systems, while attempting to reach the "target" leachate ammonia concentration of 1200 mg N/L, was unexpected, given the results obtained in a previous study by Azevedo (1993) where a simulated leachate with an ammonia concentration of 1500 mg N/L was successfully treated using identical systems. Hence this section will focus on documenting the systems nitrification failure, subsequent recovery and eventual success in reaching the "target" 1200 mg N/L ammonia concentration. In maintaining consistency with the earlier study conducted by Azevedo (1993), "ammonia" and "NH₄" refers to "total" ammonia. "Total" ammonia is the sum of "free" ammonia (NH₃) and the ammonium ion (NH₄⁺).

The objective of the MLE Startup Phase was to achieve stable nitrification and denitrification, in both systems, of leachate containing 1200 mg N/L of ammonia. Once the systems were successfully treating the "base" leachate (i.e. 230 mg NH₄-N/L), the ammonia concentration of the leachate was incrementally increased by the addition of ammonium chloride solutions to the systems. "Simulated" leachate containing ammonia concentrations of approximately 400, 600, 800 and 1000 mg N/L were incrementally fed to both systems. The procedure for increasing the leachate ammonia concentration consisted of feeding the appropriate amount of ammonium chloride to the anoxic reactors, to yield the desired simulated leachate ammonia concentration, while monitoring, daily, the aerobic reactor ammonia concentrations using the ammonia probe. The absence of ammonia accumulation in the aerobic reactors was interpreted as the systems responding favorably to the increased ammonia loading. The total volume of the anoxic and aerobic reactors and the clarifier was 19 litres; therefore, at a leachate feed rate of about

10 L/d, the system hydraulic retention time (SHRT) was approximately 2 days. At least 3 days were allowed between ammonia loading increments to ensure the systems were removing all of the ammonia.

Methanol loadings to the anoxic reactors remained constant during this period and were maintained at the actual amount required for complete denitrification of the "base" leachate. The rationale for this method was based on results from the previous study by Azevedo (1993). He found that large increases in methanol loading may result in excess bleeding of unused methanol from the anoxic reactors into the aerobic reactors, causing inhibition of nitrification, (presumably by heterotrophic competition for oxygen in the aerobic reactors and/or methanol toxicity to *Nitrosomonas*). Reaching the "target" leachate ammonia concentration of about 1200 mg N/L as quickly as possible was desired; therefore, in order to avoid the possible inhibitory effects of simultaneously increasing the methanol loadings, it was decided to first incrementally increase the ammonia loadings to the systems until the "target" leachate ammonia concentration was reached. Methanol loadings were then to be incrementally increased until complete anoxic denitrification of the "target" leachate was attained.

The following sections discuss the first attempt at reaching the "target" leachate ammonia concentration of 1200 mg N/L and the resulting nitrification failure in both systems, nitrification recovery, second attempt at reaching the "target" leachate ammonia concentration, and possible explanations for the initial nitrification failure.

5.1.1 Incremental Ammonia Loading and Nitrification Failure

By day 70, both systems were treating the "base" leachate with essentially 100 % removal of ammonia in the aerobic reactors and NO_x in the anoxic reactors. As shown in Figures 5.1 and 5.2, the "base" leachate being fed to both systems consistently contained about 230 mg N/L of ammonia during this period. The addition of ammonium chloride solutions to the anoxic reactors of both systems began on day 71, with a simulated leachate ammonia concentration of about 400 mg N/L. Further increments to 600 and 800 mg N/L ammonia were made on days 74 and 78, respectively.

Figure 5.1: MLE Startup Phase - System #1
Simulated Leachate Ammonia Values

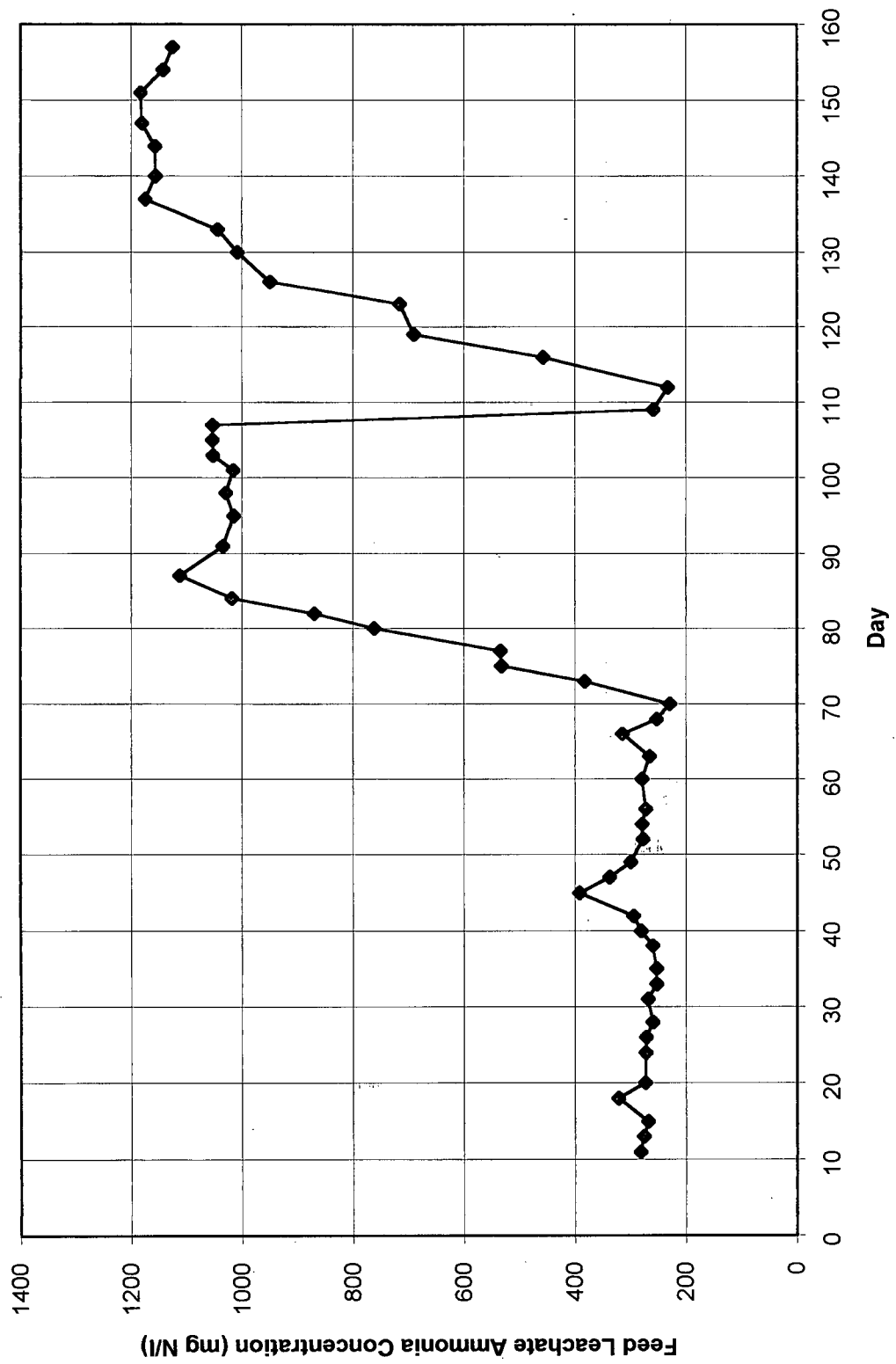
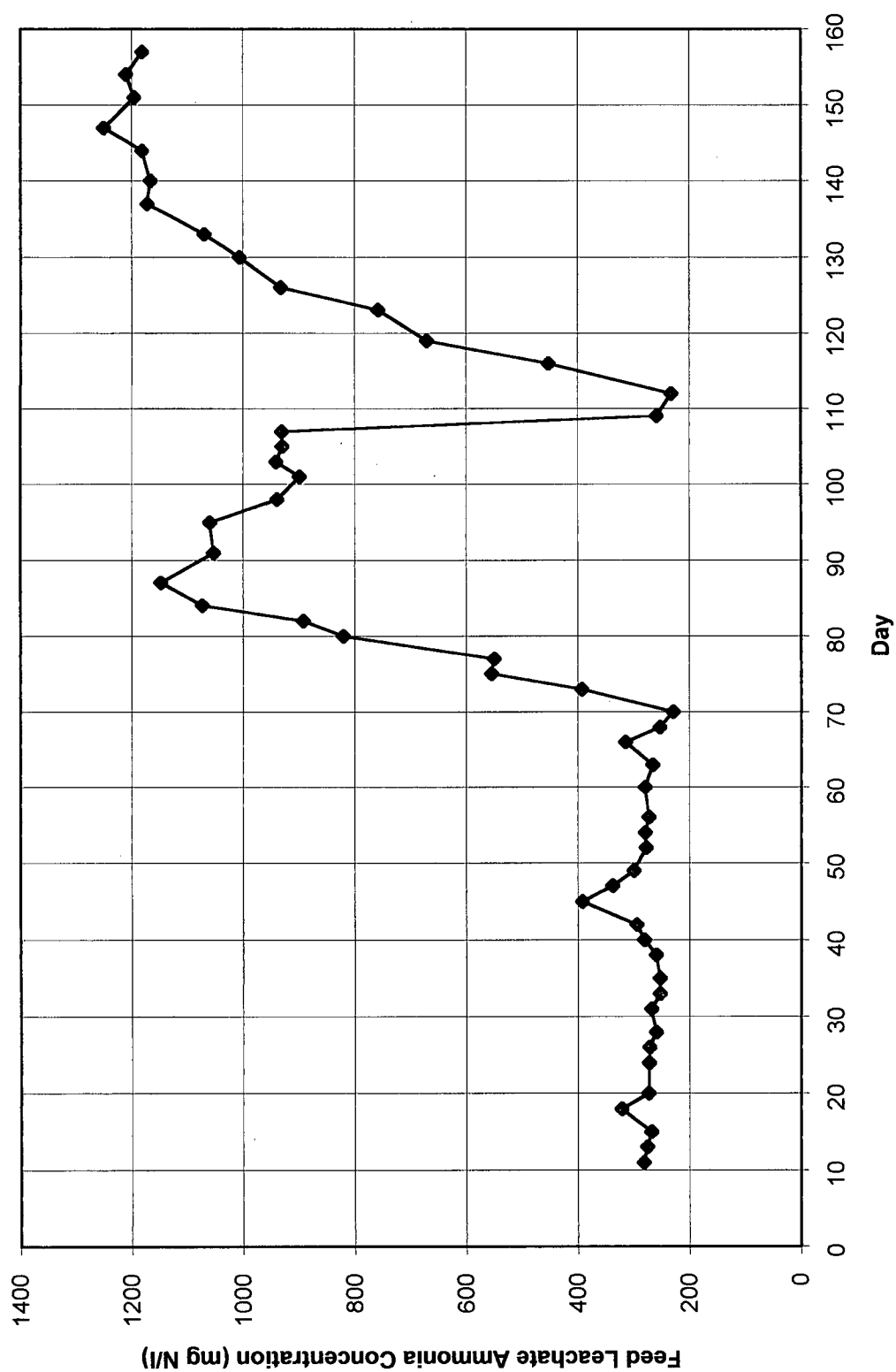


Figure 5.2: MLE Startup Phase - System #2
Simulated Leachate Ammonia Values



Figures 5.3 and 5.4 show the ammonia concentrations in the anoxic and aerobic reactors of Systems 1 and 2. Aerobic ammonia concentrations were still essentially zero at day 81; therefore, the simulated leachate ammonia concentration was increased to about 1000 mg N/L. Elevated aerobic ammonia concentrations appeared in both systems by day 84; hence no further increases in ammonia loading were made. By day 95, the aerobic ammonia concentration in System 1 was about 100 mg N/L and 270 mg N/L in System 2. Between days 91 and 95, the aerobic ammonia concentrations in System 2 were at least twice as high as the values for System 1, based on data obtained using the ammonia probe.

Azevedo (1993) found that after making similar increments in ammonia loading, an ammonia "spike" would appear in the anoxic and aerobic reactors immediately following the increment. However, aerobic ammonia levels would return to basically zero within several days, thus indicating complete ammonia oxidation. It should be noted that "nitrification" refers to the two step conversion of ammonia to nitrite and then to nitrate. "Ammonia oxidation" is the conversion of ammonia to nitrite. These terms are used interchangeably, in this discussion, to describe the conversion of ammonia to NO_x. Since reactor ammonia concentrations had been continually rising for almost two weeks (days 82 - 95) in both systems, it was suspected that nitrification was actually failing and not just undergoing a transient response to the increment of feeding 1000 mg N/L ammonia leachate. Two remedial measures were attempted to remove excess ammonia and restore complete nitrification in the systems: (1) increased methanol loadings to both systems; and (2) a decrease in ammonia loading to System 2, in response to the much larger reactor ammonia concentrations compared to System 1. Methanol loadings, shown in Figures 5.5 and 5.6, to both systems were increased slightly on day 95, with the intent of stimulating more heterotrophic bacterial growth in the anoxic reactors and, therefore, assimilating some of the excess ammonia. Since the methanol loadings were based on denitrifying the NO_x produced when treating the "base" leachate (i.e. 230 mg NH₄-N/L), there was little danger of excess methanol bleeding into the aerobic reactors from the anoxic reactors. On day 95, the ammonia concentration of the simulated leachate being fed to System 2 was reduced to about 900 mg N/L. System 1 continued to be fed 1000 mg N/L ammonia leachate.

Figure 5.3: MLE Startup Phase - System #1
Anoxic and Aerobic Ammonia Values

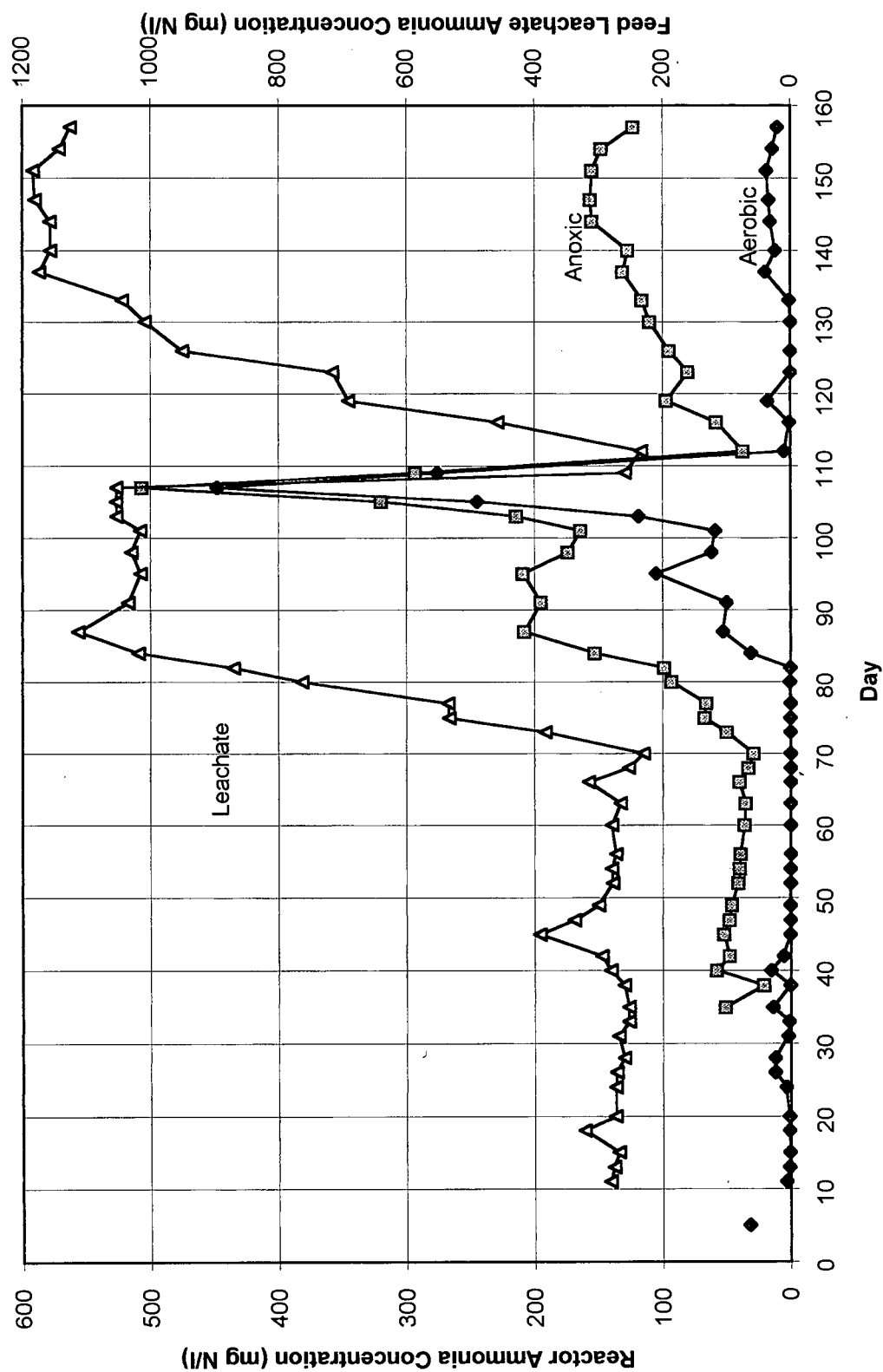


Figure 5.4: MLE Startup Phase - System #2
Anoxic and Aerobic Ammonia Values

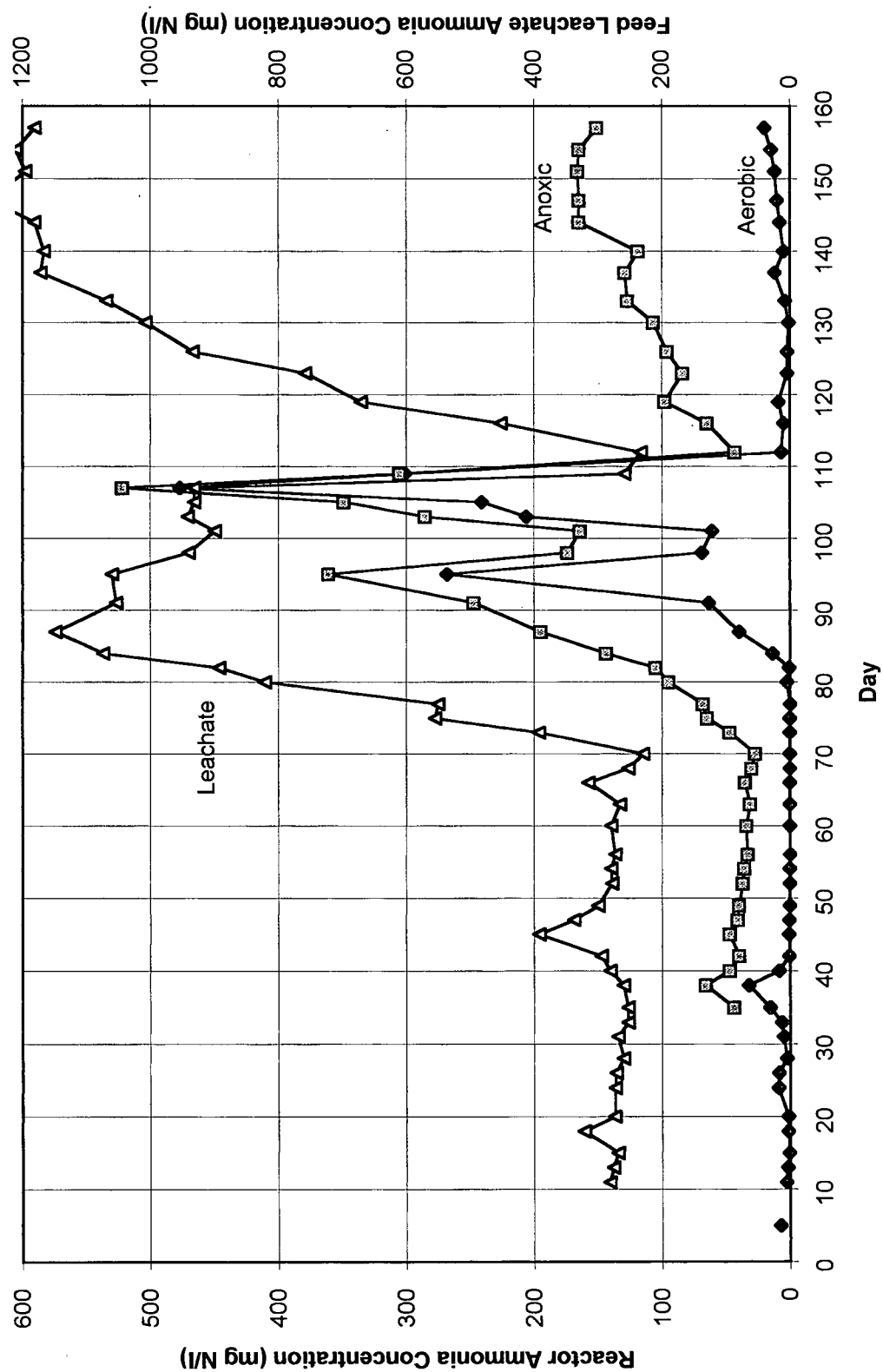


Figure 5.5: MLE Startup Phase - System #1
Anoxic Methanol Loading

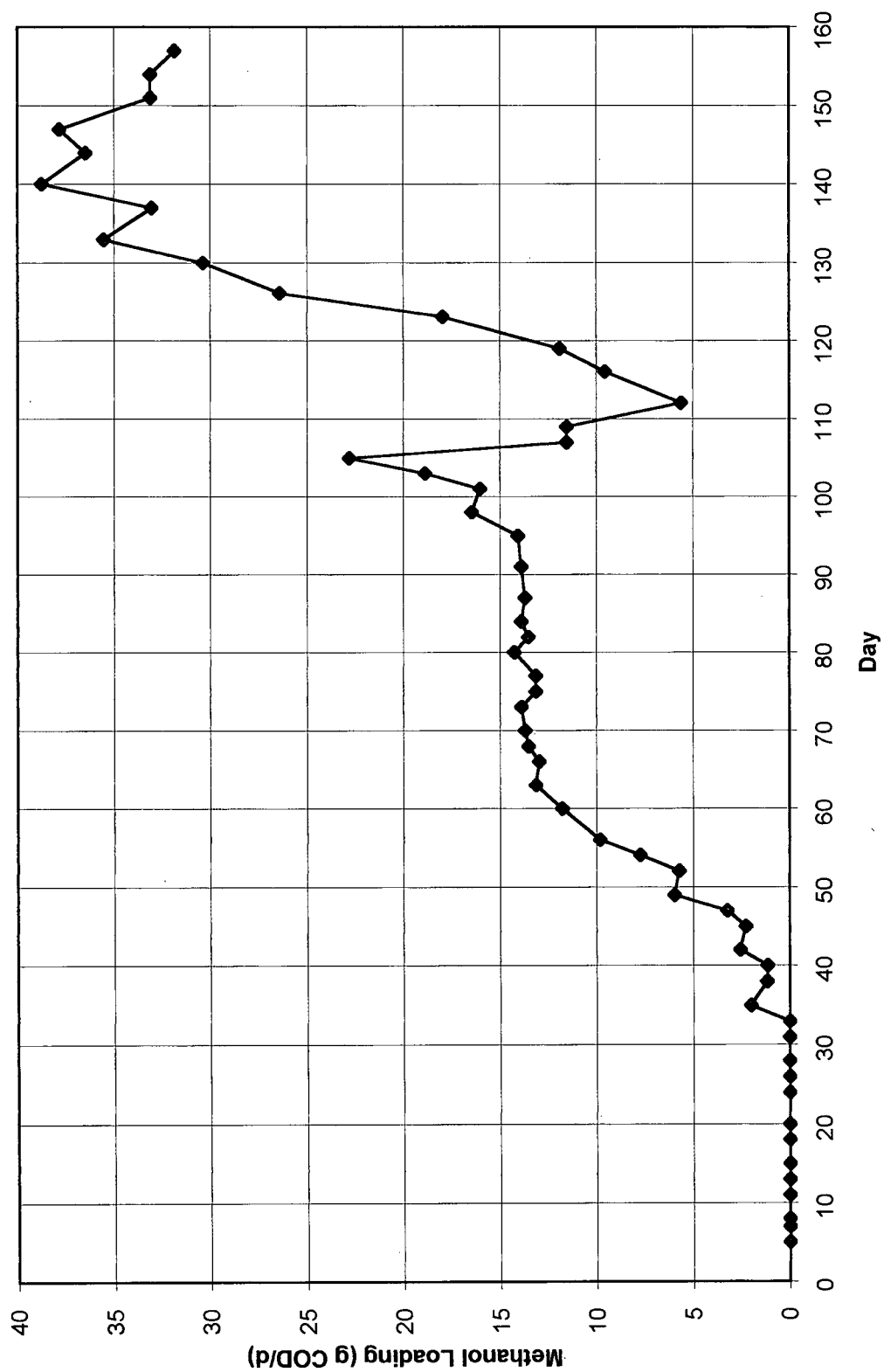
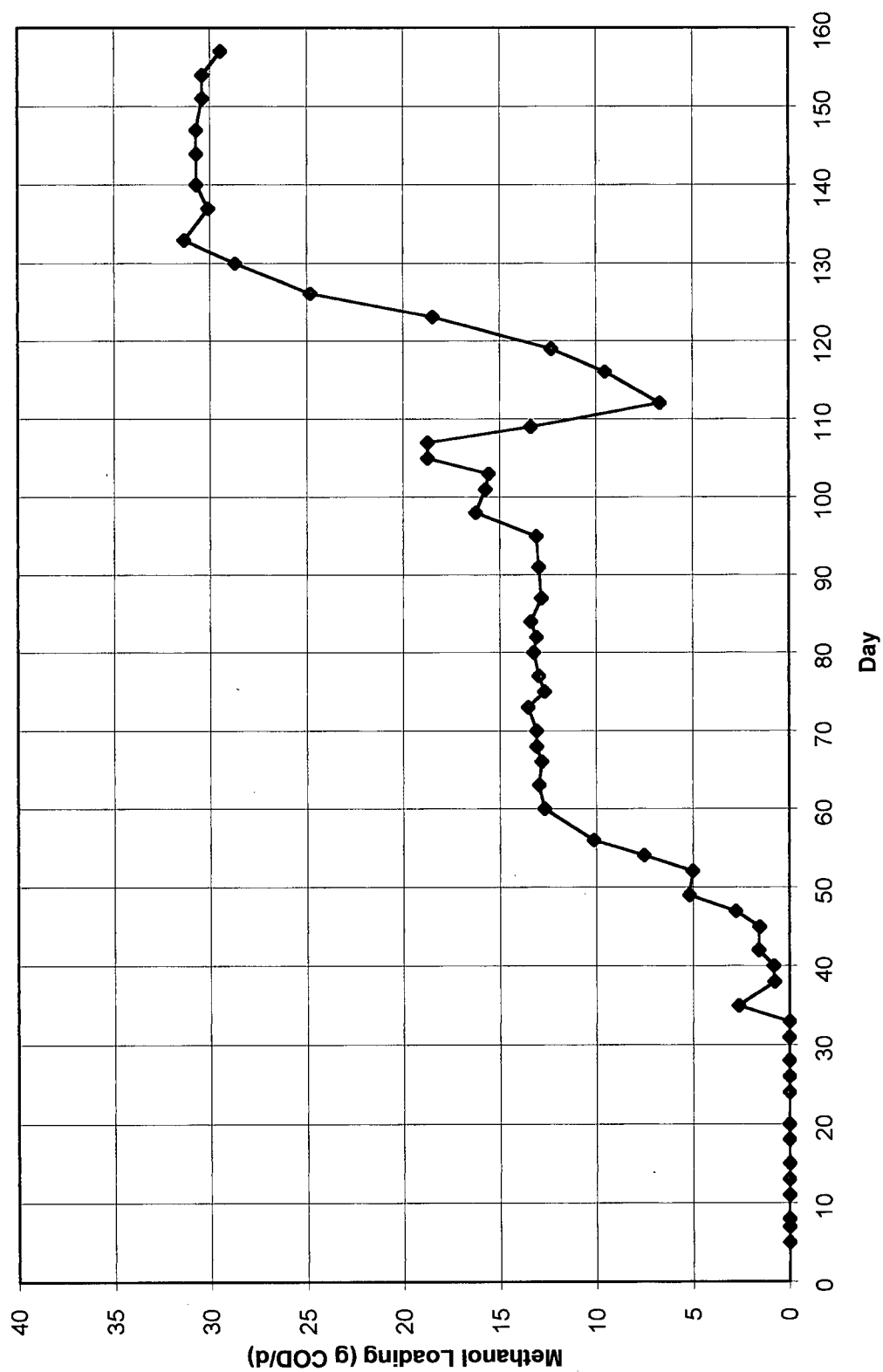


Figure 5.6: MLE Startup Phase - System #2
Anoxic Methanol Loading



The result of these measures was an immediate drop in reactor ammonia concentrations and, by day 98, both systems had almost identical ammonia concentrations in their respective reactors (anoxic = 170 mg N/L; aerobic = 60 mg N/L). However, by day 103, reactor ammonia levels were quickly rising again in both systems. Methanol loadings were again increased to both systems on day 103 but without any apparent effect. By day 107, anoxic ammonia concentrations in both systems exceeded 500 mg N/L, with aerobic concentrations of about 450 mg N/L.

Further evidence supporting nitrification failure in both systems can be found in pH and alkalinity data. Figures 5.7 and 5.8 show the anoxic and aerobic pH of systems 1 and 2 during the MLE startup phase. Sufficient alkalinity was present in the leachate to maintain aerobic pH values greater than 7.5 until the simulated leachate ammonia concentration reached approximately 600 mg N/L. pH/pump controllers were then used to maintain aerobic pH levels at a setpoint of 7.5, within approximately plus or minus 0.1 units, by the addition of sodium bicarbonate solution. Sodium bicarbonate addition stopped on day 104 for System 1 and on day 102 for System 2, because the aerobic pH levels had increased above the 7.5 setpoint. By day 105, anoxic and aerobic pH levels were almost equal and basically the same in each of the systems. Earlier, anoxic pH levels were always higher than aerobic values, indicating the consumption of alkalinity during aerobic nitrification with the subsequent return of alkalinity during anoxic denitrification. pH levels kept rising until the ammonium chloride feed was turned off; this increase was attributed to continued denitrification of the remaining NO_x (formed previously) in the reactors that returned even more alkalinity to the mixed liquor.

Based on these data, it appeared that nitrification in both systems was severely failing and it was feared that the systems would not recover while being fed such high ammonia leachate. Thus, it was decided to stop the addition of ammonium chloride solutions to the systems on day 107 and, therefore, continue to feed only the "base" leachate. Methanol loadings were also reduced in a corresponding manner to prevent excess methanol from bleeding into the aerobic reactors.

Figure 5.7: MLE Startup Phase - System #1
Anoxic and Aerobic pH Values

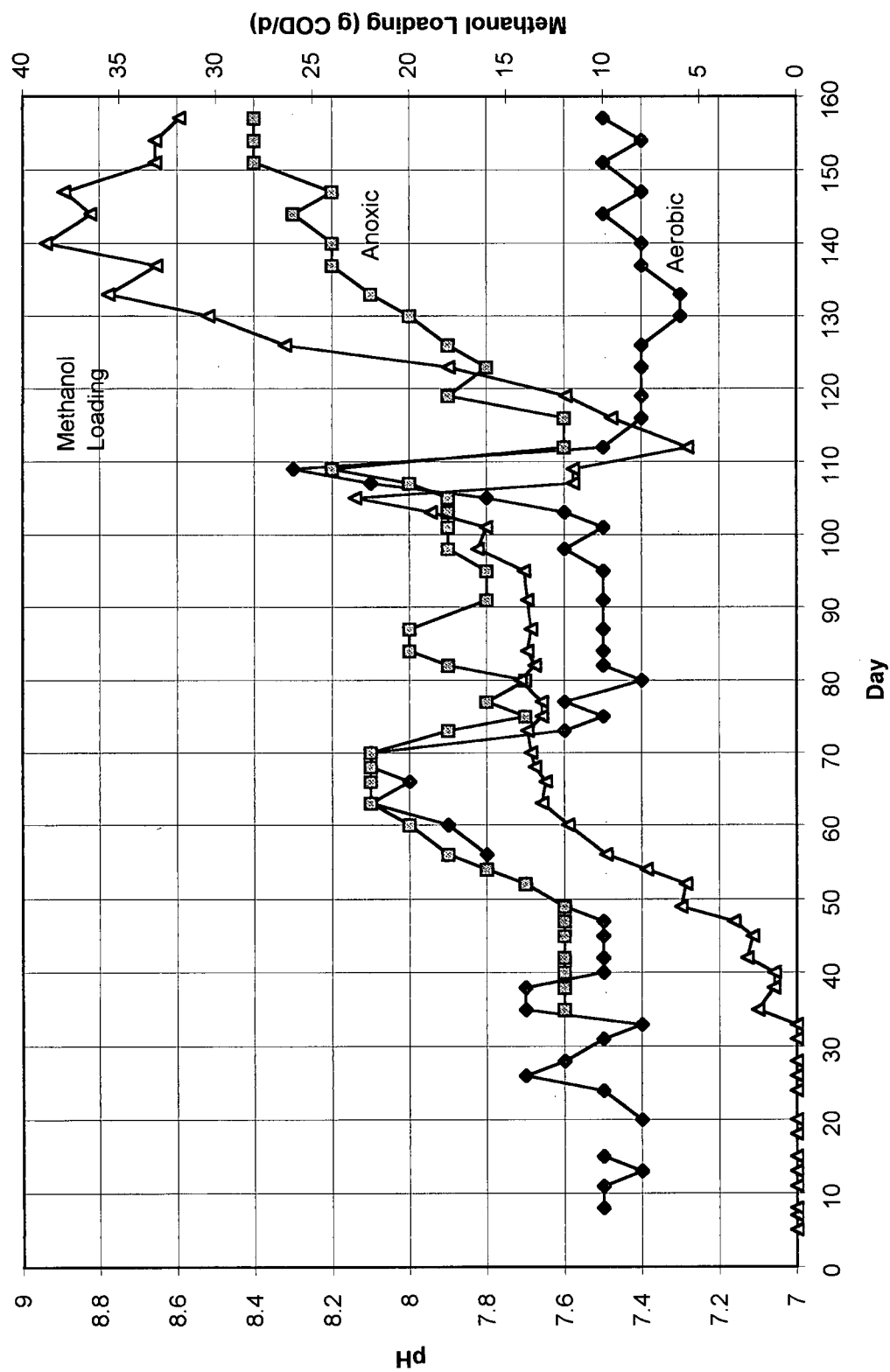
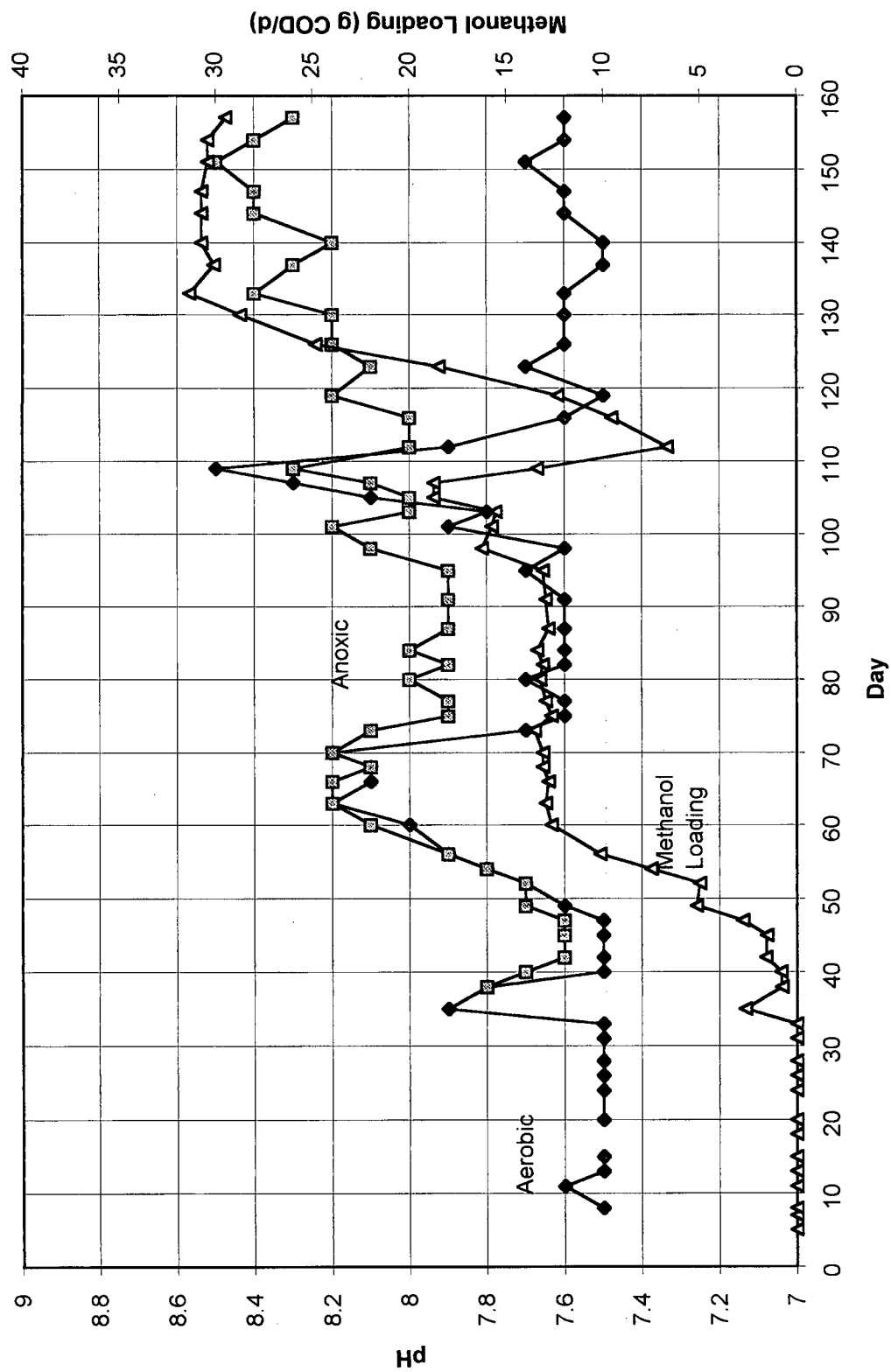


Figure 5.8: MLE Startup Phase - System #2
Anoxic and Aerobic pH Values



5.1.2 Nitrification Recovery

It took approximately 5 days (day 112) for the aerobic ammonia concentrations, in both systems, to decrease to values of less than 10 mg N/L, once the ammonium chloride feed was turned off (day 107). Removal of excess ammonia from the systems took longer than expected, given that the volume contained within the systems would have been exchanged within 2 days (i.e. nominal HRT = approximately 2 days). The additional 3 day lag period before essentially complete nitrification was restored provides additional evidence that nitrification was severely inhibited, and is further supported by an examination of nitrification alkalinity consumption data.

The amount of alkalinity consumed across the aerobic reactors (anoxic alkalinity minus effluent alkalinity) gives an indication of nitrification performance and, more specifically, the condition of the *Nitrosomonas* organisms responsible for the oxidation of ammonia. Alkalinity is consumed during nitrification at a theoretical ratio of 7.1 mg CaCO₃/L per mg NH₄-N/L nitrified (EPA 1993). Table 5.1 contains alkalinity data for both systems and shows the amount of alkalinity consumed across the aerobic reactors.

Table 5.1 Reactor Alkalinity Data

System 1: Day	Anoxic Alkalinity (mg CaCO ₃ /L)	Effluent Alkalinity (mg CaCO ₃ /L)	Aerobic Consumption (mg CaCO ₃ /L)
107	986	757	229
109	1189	1015	171
111	814	493	321
System 2: Day			
107	1186	1000	186
109	1357	1229	128
111	1043	729	314

Anoxic ammonia concentrations, because of dilution of leachate by the clarifier recycle flow, would "normally" be about 140 mg N/L when receiving leachate containing 1000 mg N/L of ammonia. Therefore, aerobic alkalinity consumption, based on the theoretical 7.1:1 ratio, would be expected to be around 1000 mg CaCO₃/L, for these systems, when completely nitrifying leachate containing 1000 mg N/L of ammonia. The data in Table 5.1 indicate that nitrification activity continued to decrease even after

the additional ammonia loadings to the systems were ceased on day 107. As indicated earlier, the liquid in the systems would have been exchanged by day 109 (SHRT = 2 days), yet the amount of alkalinity consumed by nitrification decreased by about 25% and 31% for systems 1 and 2, respectively, between days 107 and 109. By day 111, nitrification had been significantly restored in both systems as illustrated by the large increases in aerobic alkalinity consumption. The systems continued to be fed only "base" leachate until day 114.

5.1.3 Second Attempt At Incremental Ammonia Loading

The second attempt at reaching the "target" simulated leachate ammonia concentration of 1200 mg N/L was conducted in a similar manner as the first attempt described in Section 5.1.1, with the exception of the methanol loadings. Ammonia loading increments, shown in Figures 5.1 and 5.2, were similar to those of the first procedure. As in the first attempt, a period of 10 days (day 114 to day 124) was used to increase the leachate ammonia concentration from that of the "base" leachate to a simulated 1000 mg N/L concentration. Further ammonia increments were then made so that, by day 135, both systems were receiving leachate containing between 1150 and 1200 mg N/L of ammonia. Increases in methanol loading were made to both systems within a day or so following the ammonia increments. Methanol loadings, shown in Figures 5.5 and 5.6, were initially calculated based on a assumed denitrification methanol COD: NO_x requirement of about 4:1 (Azevedo 1993). Further adjustment of methanol loadings were made once the "target" leachate ammonia concentration was reached, to ensure complete anoxic denitrification of this leachate.

Both systems responded to increases in ammonia and methanol loading in a similar and positive manner. Anoxic and aerobic ammonia concentrations for systems 1 and 2 are shown in Figures 5.3 and 5.4, respectively. After day 114, anoxic ammonia values show a gradual rise in response to increases in leachate ammonia concentration. Aerobic ammonia concentrations showed a slight increase as the ammonia loading was increased and remained between 10 and 20 mg N/L. Complete anoxic denitrification (i.e. anoxic NO_x < 1 mg N/L) was reached by day 140 in System 1 and by day 130 in System 2.

5.1.4 Possible Explanations for Nitrification Failure

Operating conditions during the initial attempt at reaching the "target" leachate ammonia concentration and the second attempt were virtually identical, with the exception of the methanol loadings. Aerobic dissolved oxygen concentrations were always kept above 2 mg/L to prevent inhibition of nitrification. The addition of phosphate solutions to the systems ensured that reactor dissolved ortho-phosphate concentrations were maintained above 2 mg/L; therefore, biologically available phosphorous was not limited at any time. Similarly, pH/pump controllers maintained aerobic pH levels at approximately 7.5 by the addition of sodium bicarbonate solutions. Therefore, the failure of nitrification, or more specifically ammonia oxidation, during the initial attempt at reaching the "target" leachate ammonia concentration was thought to be the result of "free" ammonia (NH_3) toxicity to the *Nitrosomonas* organisms that oxidize ammonia to nitrite. Anthonisen et al (1976) found that "free" ammonia concentrations of 10 to 150 mg/L could inhibit ammonia oxidation in complete mix reactors.

This section attempts to answer the obvious question as to why reactor ammonia, and "free" ammonia, concentrations, during the first attempt at reaching the "target" leachate ammonia concentration, increased to a point that resulted in inhibition of nitrification. As indicated earlier, the only significant difference between the first attempt and the successful second attempt was the methanol loadings. The failure or success of nitrification under rapidly increasing ammonia mass loading conditions, for the given process configuration, appears to be somewhat dependent on the denitrification process. Therefore, this section will focus on the effect of methanol loadings on process performance and possible explanations for the initial nitrification failure of the systems.

The addition of methanol to the anoxic reactors provides an organic carbon source for heterotrophic bacteria that are able to use oxidized nitrogen compounds (NO_x) as electron acceptors in the absence of elemental oxygen. This results in the reduction of NO_x to gaseous nitrogen compounds (e.g. N_2), thus providing "denitrification" of the nitrified sludge returned from the clarifier. Several effects are caused by addition of organic carbon to the anoxic reactors: (1) cell synthesis by heterotrophic bacteria; (2)

production of alkalinity during the reduction of nitrate; and (3) removal of NO_x from the mixed liquor during heterotrophic energy production.

Heterotrophic Cell Synthesis

The synthesis of new cellular material by heterotrophic bacteria requires nitrogen in addition to organic carbon. Bacteria can use reduced nitrogen, in the form of ammonia nitrogen, to meet this requirement (Tortora et al 1989). In a predenitrification system such as the MLE process, raw leachate enters the anoxic reactors directly and is diluted by the return of nitrified sludge from the clarifier. However, ammonia concentrations in the anoxic reactor are still high, thus an excess amount of ammonia is available for heterotrophic cell synthesis during denitrification. Increasing the methanol loading to the anoxic reactor, providing excess NO_x is present in the reactor, causes synthesis of more new heterotrophic cells, while simultaneously assimilating more ammonia. Therefore, reactor solids concentrations and the amount of ammonia removal in the anoxic reactors would be expected to increase and possibly prevent rapid accumulation of ammonia in the anoxic reactors and eventually the aerobic reactors.

Figures 5.9 and 5.10 show the anoxic and aerobic volatile suspended solids concentrations (VSS) as well as the methanol loadings for systems 1 and 2, respectively. Reactor solids concentrations responded quickly to changes in methanol loading in both systems. On day 81, when the systems began receiving 1000 mg N/L ammonia leachate, the anoxic VSS in System 1 was about 3000 mg/L with an aerobic VSS concentration of 2000 mg/L. However, during the second attempt at feeding approximately 1000 mg N/L ammonia leachate at around day 126, the anoxic VSS concentration was about 4300 mg/L and around 3200 mg/L in the aerobic reactor. Similarly for System 2, anoxic VSS concentrations increased from 3300 mg/L to 3700 mg/L and aerobic VSS values went from about 2400 mg/L to 2900 mg/L. The differences in reactor VSS concentrations were probably the result of increased growth of heterotrophic denitrifying organisms, rather than increases in autotrophic nitrifying bacteria. It should be noted that when the systems were treating the "base" leachate during the recovery period between days 107 and 114, the reactor solids concentrations returned to levels (i.e. anoxic = 2800 mg/L, aerobic = 2000 mg/L) close to those that existed prior to initial increases in leachate ammonia concentration that began on day 71.

Figure 5.9: MLE Startup Phase - System #1
Anoxic and Aerobic VSS Values

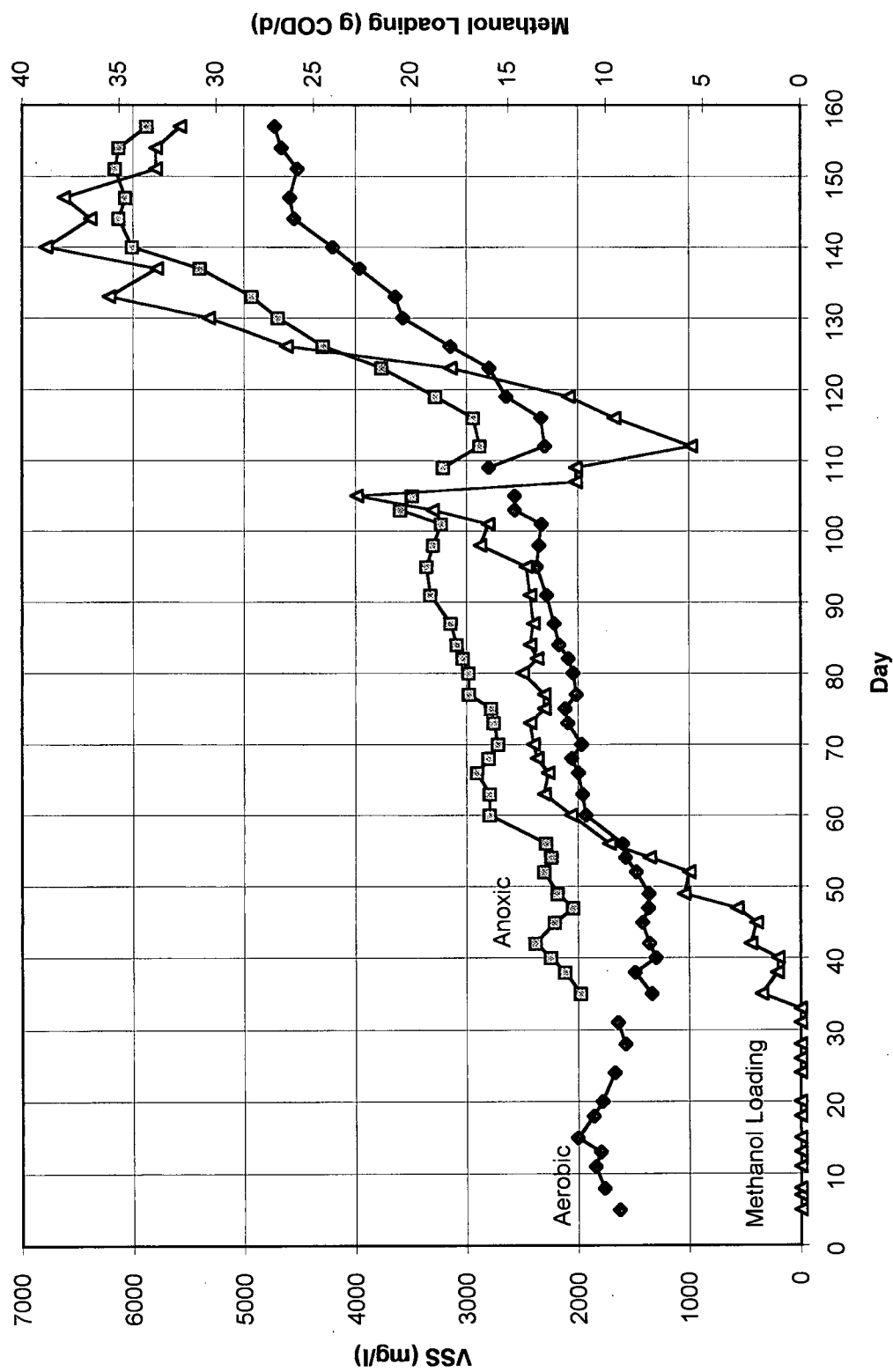
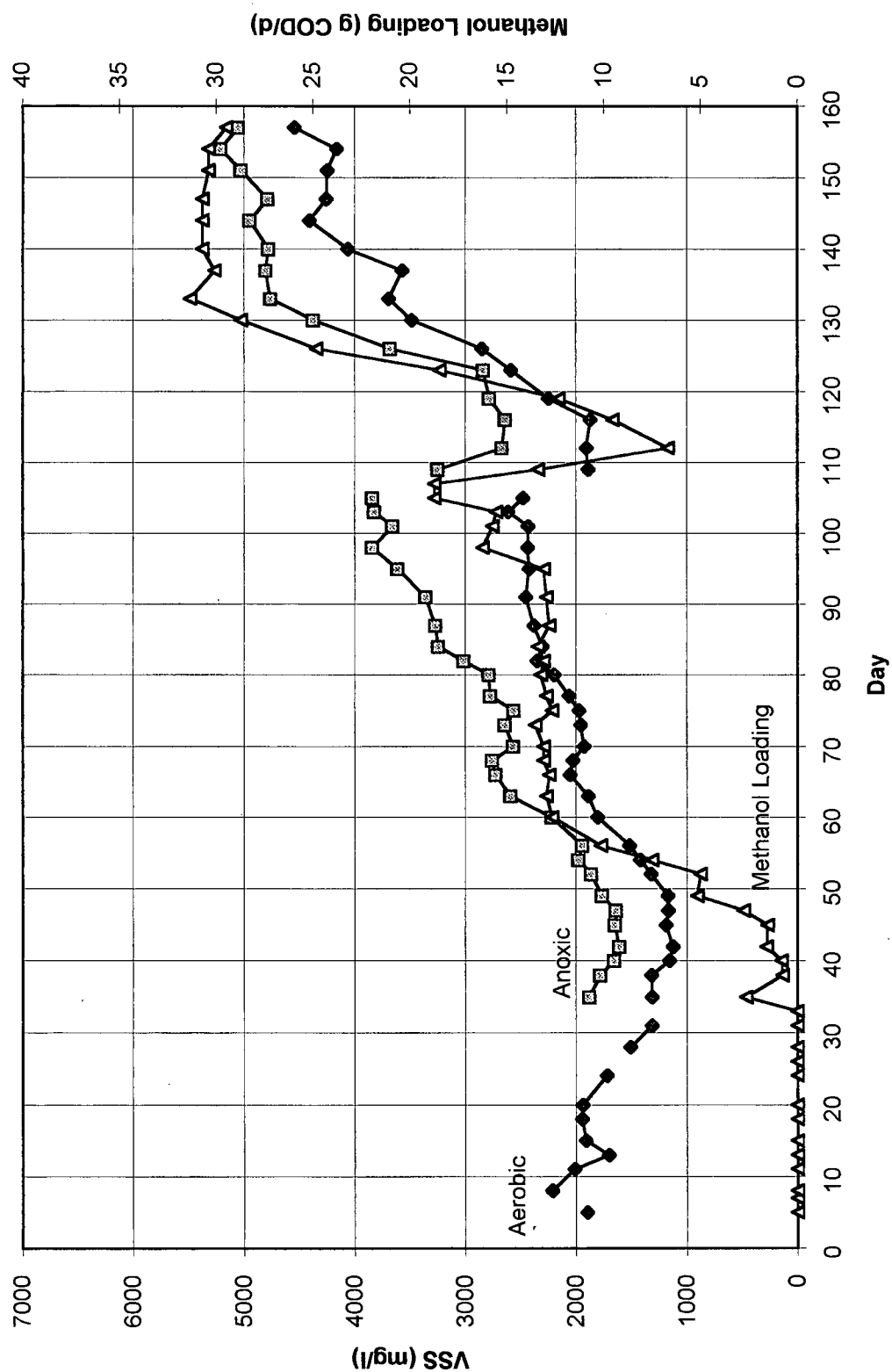


Figure 5.10: MLE Startup Phase - System #2
Anoxic and Aerobic VSS Values



The amount of ammonia removed in the anoxic reactor can be expressed in terms of the percent of ammonia removed relative to the amount of ammonia entering the anoxic reactor. These data are shown in Figures 5.11 and 5.12 for systems 1 and 2, respectively. Between days 81 and 107, both systems showed fluctuating ammonia removal values due to the transient state of the systems; however, usually less than 10% of ammonia entering the anoxic reactors was being removed (assimilated). This contrasts sharply with the anoxic ammonia removal after about day 112, when methanol loadings were quickly increased; up to about 30% of ammonia entering the anoxic reactors was assimilated. Once the methanol loadings were leveled off and heterotrophic growth reached steady state (as shown in almost constant reactor VSS values in Figures 5.9 and 5.10 after day 140) ammonia removal decreased rapidly from almost 30% to about 7%. Figures 5.13 and 5.14 show the actual daily mass of ammonia removed in the anoxic reactors for systems 1 and 2, and they indicate similar trends to those shown in Figures 5.11 and 5.12.

Figures 5.3 and 5.4 show that, both concentrations of ammonia in the anoxic reactors and the rate that they increased during the initial attempt (days 71 - 107) at reaching the "target" leachate ammonia concentration, were much larger than similar data during the second period of ammonia loading increments (days 114 - 138). This appears to confirm the effect of methanol loading on anoxic heterotrophic ammonia assimilation and the prevention of ammonia buildup that may ultimately result in "free" ammonia toxicity of ammonia oxidizing organisms.

Alkalinity Production

Bicarbonate alkalinity is produced during denitrification at the theoretical rate of 3.57 mg CaCO_3 per mg of nitrate reduced to nitrogen gas (EPA 1993). Increasing the methanol loading to the anoxic reactors results in an increased amount of nitrate reduction (providing excess NO_x is present) and, therefore, alkalinity production. The extra alkalinity results in an increase in reactor pH values. Figures 5.7 and 5.8 show the influence of methanol loading on reactor pH values for systems 1 and 2; pH values increased shortly after boosts in methanol loading; aerobic pH levels increased from 7.5 to 8.3 in System 1 and from 7.6 to 8.5 in System 2. Aerobic pH values remained constant, except during the failure period, when

Figure 5.11: MLE Startup Phase - System #1
Anoxic % Ammonia Removal and Methanol Loading

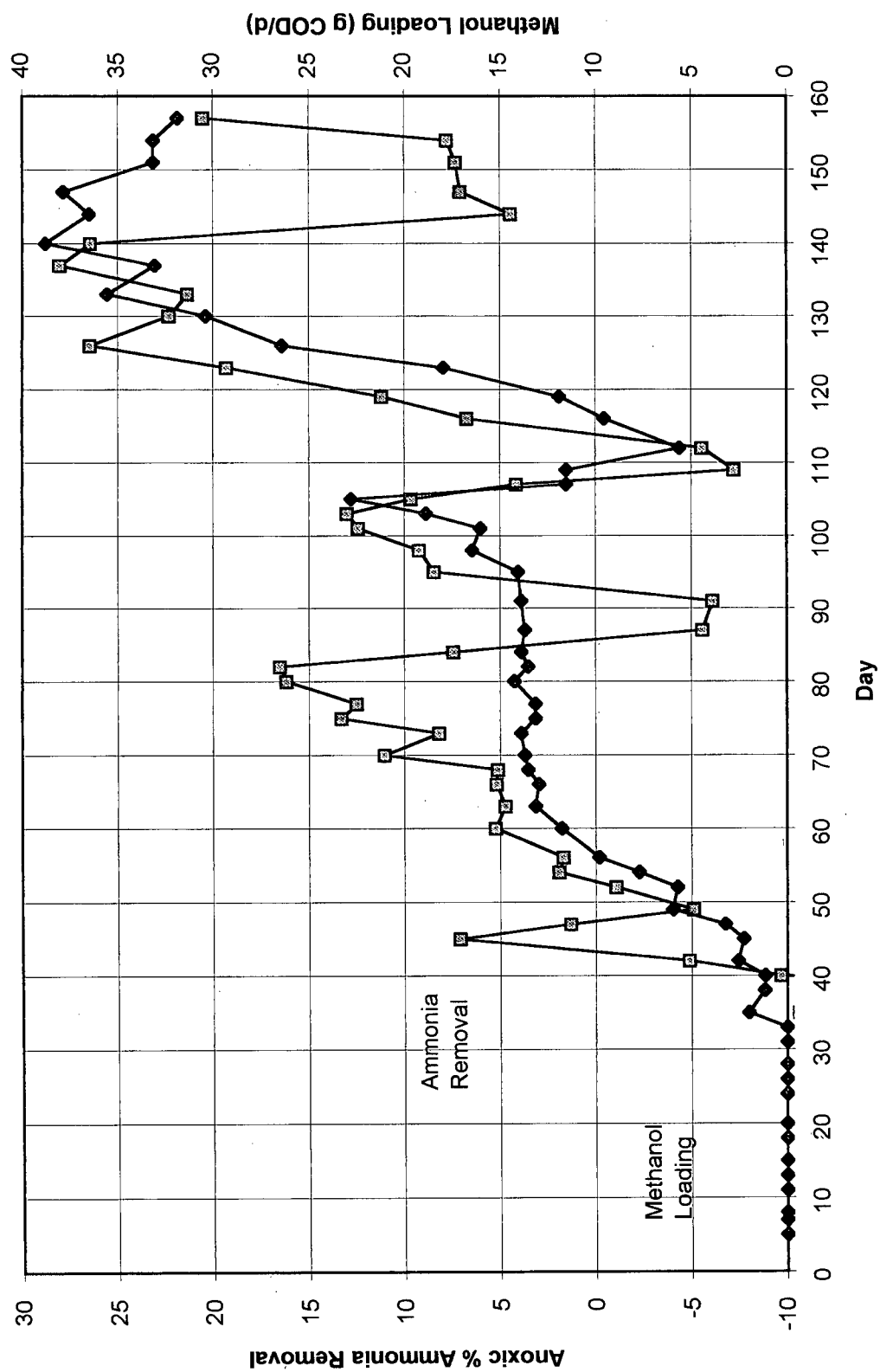


Figure 5.12: MLE Startup Phase - System #2
Anoxic % Ammonia Removal and Methanol Loading

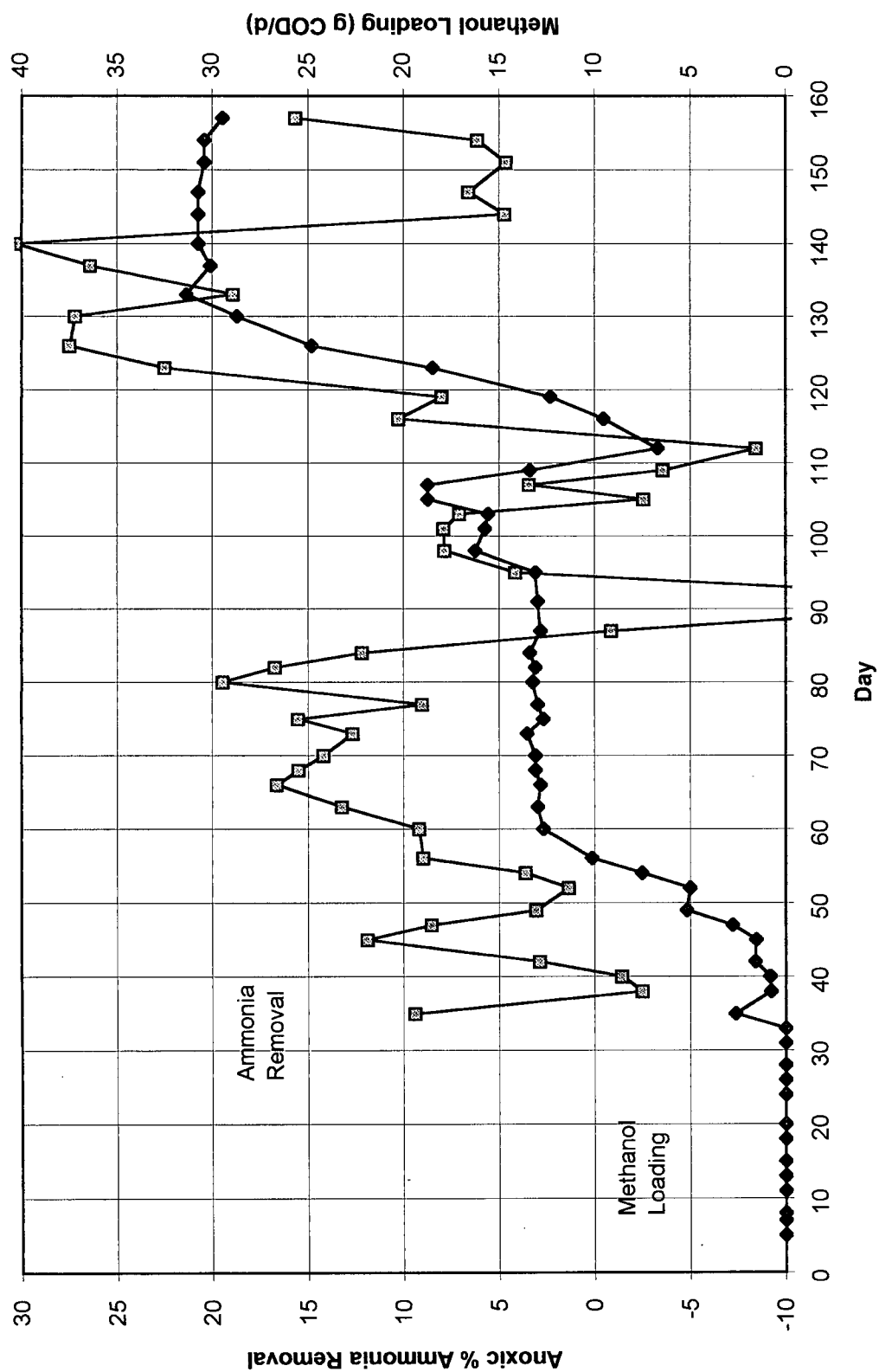


Figure 5.13: MLE Startup Phase - System #1
Anoxic Ammonia Removal and Methanol Loading

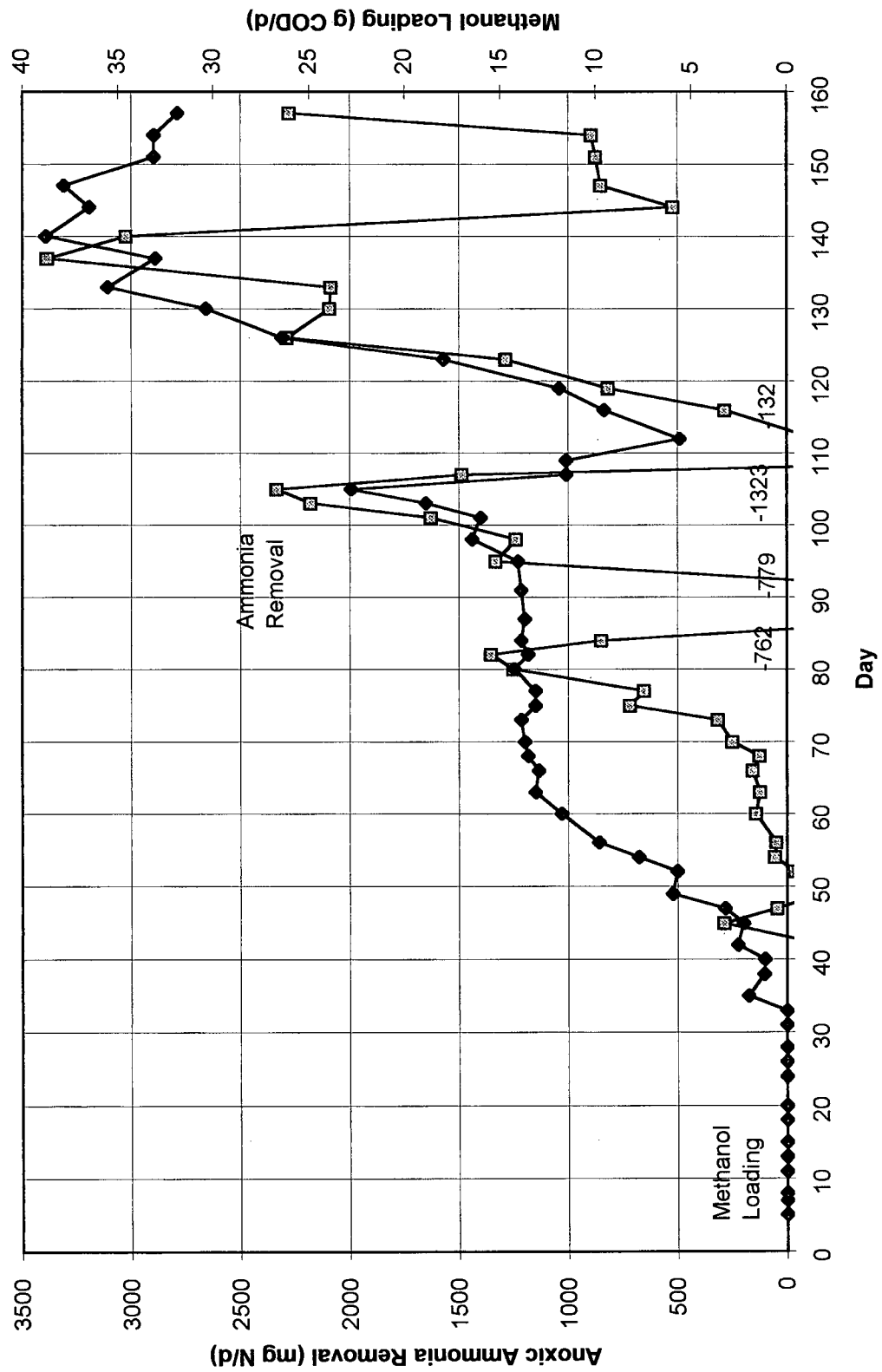
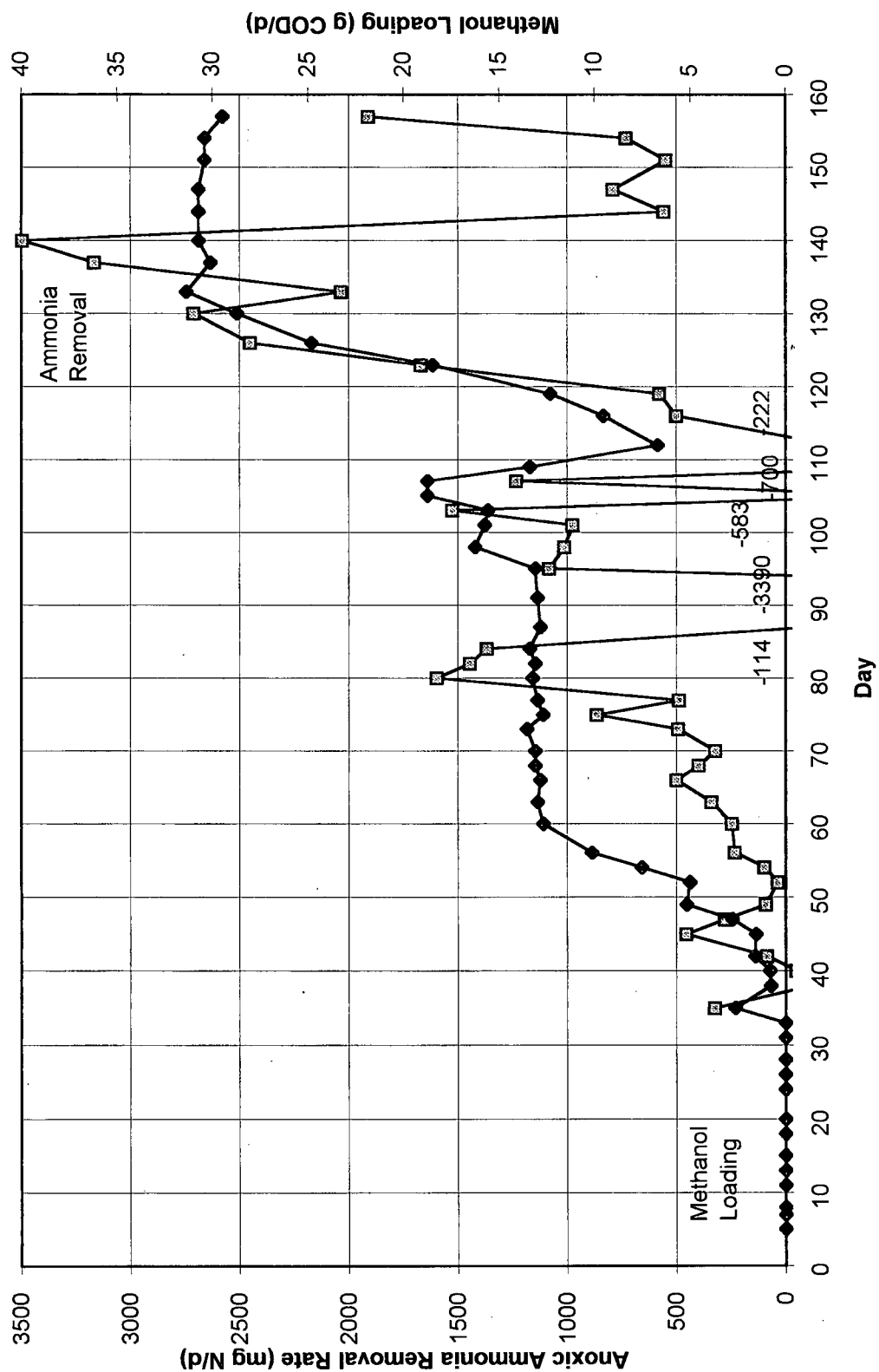


Figure 5.14: MLE Startup Phase - System #2
Anoxic Ammonia Removal Rate and Methanol Loading



the pH/pump controllers were adding extra alkalinity to account for increased nitrification requirements when the leachate ammonia concentrations were increased to about 600 mg N/L.

Section 5.1.1 discussed how methanol loadings were boosted in an attempt to assimilate excess ammonia when nitrification was failing. This may have been much more damaging than helpful, in terms of restoring nitrification, because increases in methanol loading raised reactor pH values. The fraction of "total" ammonia that exists as "free" ammonia is dependent upon pH (Benefield et al 1982). Table 5.2 shows the "free" ammonia fraction relative to "total" ammonia for various pH values (20 degrees Celsius) and illustrates the sensitivity of "free" ammonia to changes in pH.

Table 5.2 "Free" Ammonia Fraction at Various pH Values

pH	Percent of "Total" Ammonia Present as "Free" Ammonia
7.5	1.2
7.8	2.4
8.0	3.8
8.2	5.8
8.4	9.0

The increase in aerobic pH levels initiated by increased methanol loadings raised the aerobic "free" ammonia fraction in System 1 from 1.2% to 7.2% and from 1.5% to 11.0% in System 2. Figures 5.15 and 5.16 show the "estimated" reactor "free" ammonia concentrations and the anoxic methanol loadings. The increases in reactor pH levels resulting from increases in methanol loading may have been large enough to raise the "free" ammonia concentration in the aerobic reactors to the point of inhibiting ammonia oxidation by *Nitrosomonas* organisms. As shown in Table 5.2, a relatively small increase in pH from 7.5 to 7.8 doubles the concentration of "free" ammonia, for a given "total" ammonia concentration.

Anoxic "free" ammonia values, after about day 140, eventually reached levels higher than those present when nitrification basically "shut down" after day 103. Therefore, recycling of *Nitrosomonas* bacteria, contained within the clarifier return sludge, through the anoxic reactors does not appear to contribute to the inhibition of these organisms. The "free" ammonia concentrations in the aerobic reactors, although much

Figure 5.15: MLE Startup Phase - System #1
Estimated Anoxic and Aerobic Values

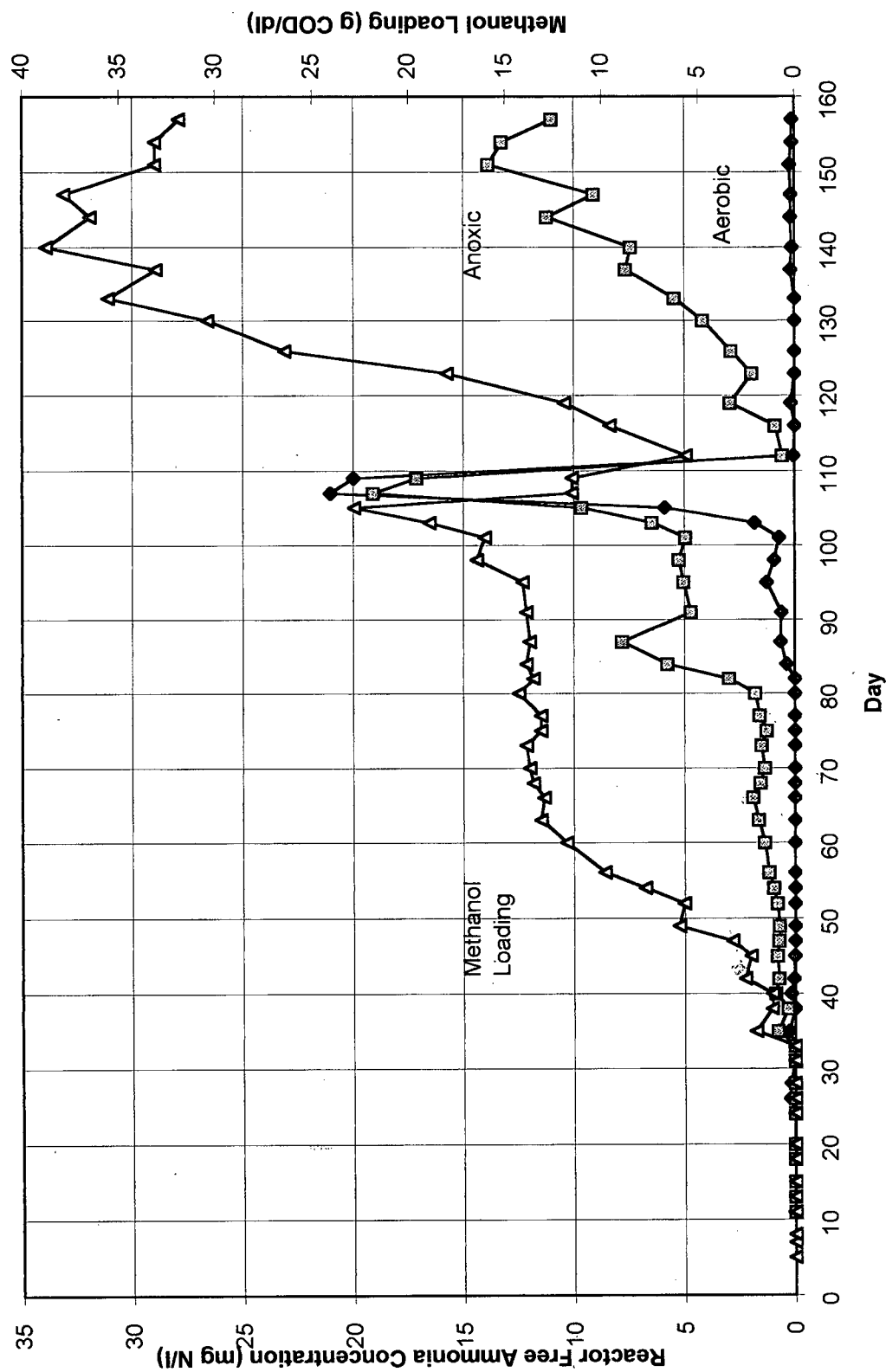
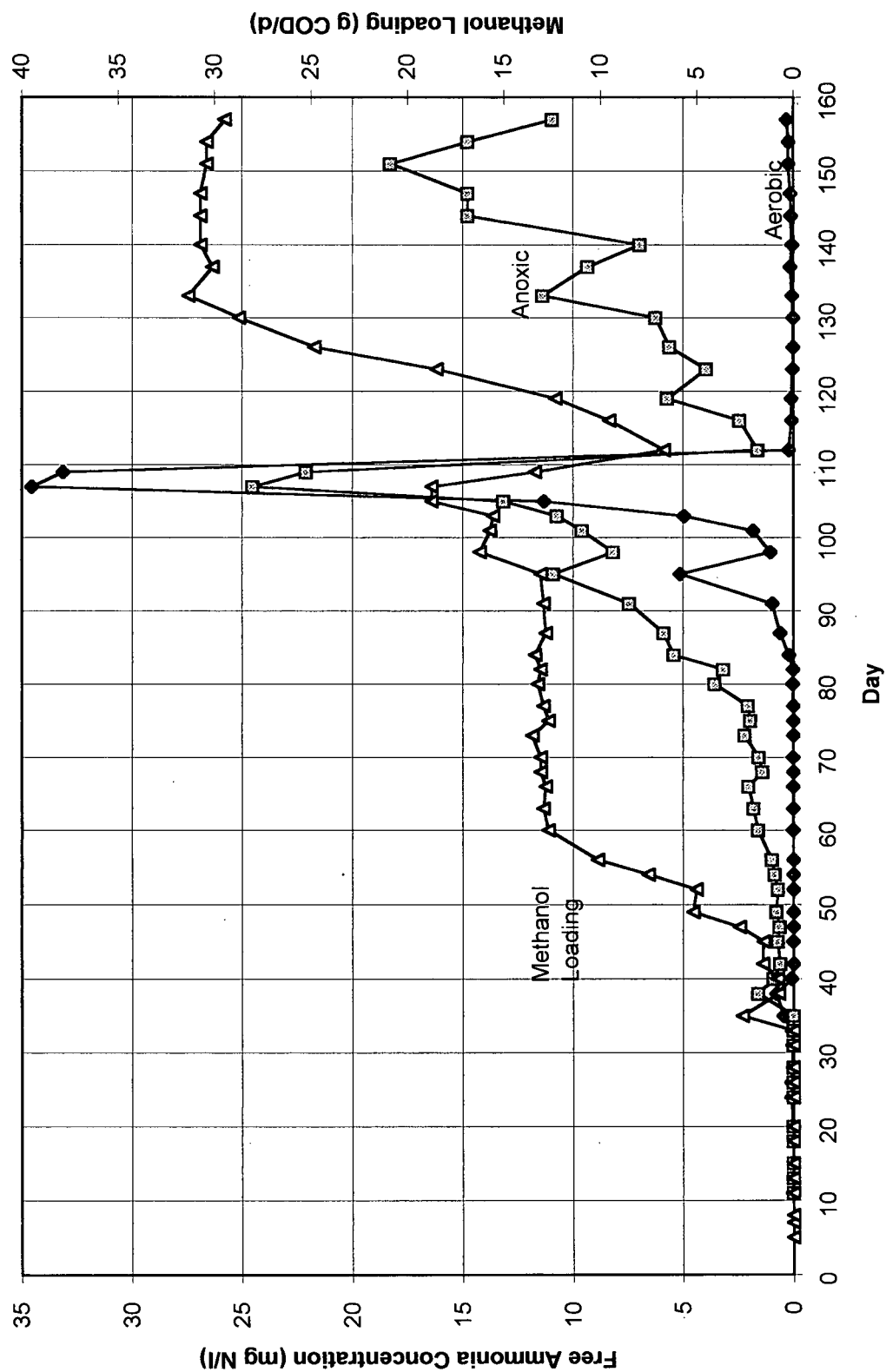


Figure 5.16: MLE Startup Phase - System #2
Estimated Anoxic and Aerobic Free Ammonia Values



lower than anoxic levels, may cause the actual inhibition to *Nitrosomonas* because these bacteria are "active" only in the aerobic reactors.

The combination of reaching inhibitory aerobic "free" ammonia concentrations and high ammonia mass loadings to the systems appears to have resulted in a "snowball" effect, from which recovery was not possible unless the ammonia loadings were reduced.

NO_x Removal

Oxidized nitrogen compounds (NO_x) that are returned to the anoxic reactors by the clarifier sludge recycle are used as electron acceptors by the heterotrophic denitrifying bacteria that oxidize methanol. This results in reduction of NO_x into gaseous nitrogen compounds that diffuse out of solution and into the atmosphere. Anoxic and aerobic NO_x values for systems 1 and 2 are shown in Figures 5.17 and 5.18, respectively. The low rate of methanol loading during the first attempt at reaching the "target" leachate ammonia concentration resulted in the accumulation of large amounts of NO_x in the reactors. This contrasts to the much lower values that appeared during the second attempt, when methanol loadings were increased following increases in leachate ammonia concentration (i.e. to keep pace with NO_x production).

It was initially thought that high concentrations of NO_x in the reactors may possibly contribute to inhibition of nitrification. However, a review of the literature found evidence to the contrary. A chemostat nitrification study conducted by Gee et al (1990a) observed successful nitrification of an artificial waste containing 1000 mg N/L of ammonia, even though reactor nitrate concentrations were around 1000 mg N/L. Hunik et al (1992) found that high ionic concentrations inhibited pure cultures of *Nitrosomonas europaea* but specific differences were not observed between nitrite/nitrate and potassium, sodium, sulphate or chloride.

Figure 5.17: MLE Startup Phase - System #1
Anoxic and Aerobic NOx Values

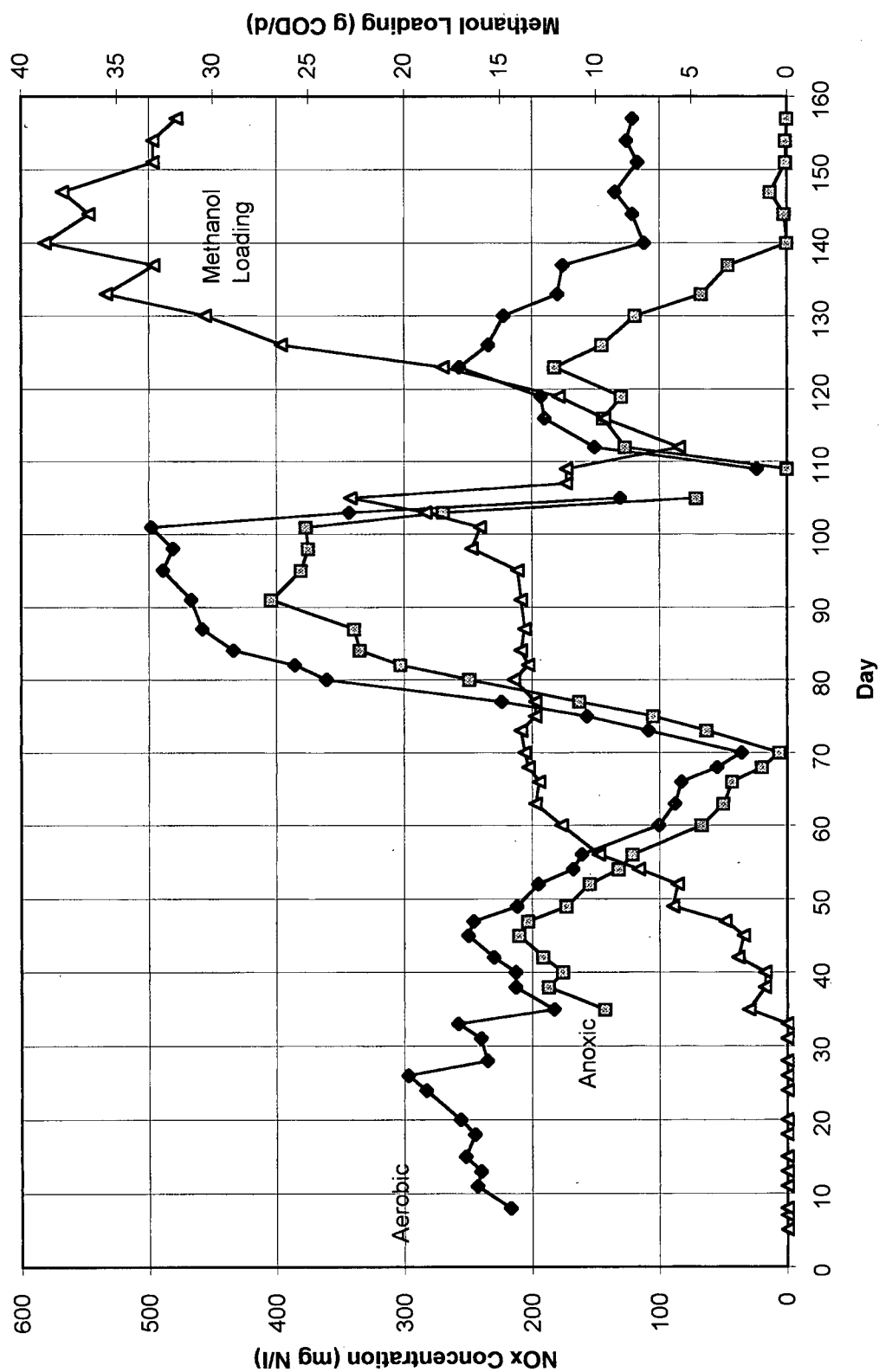
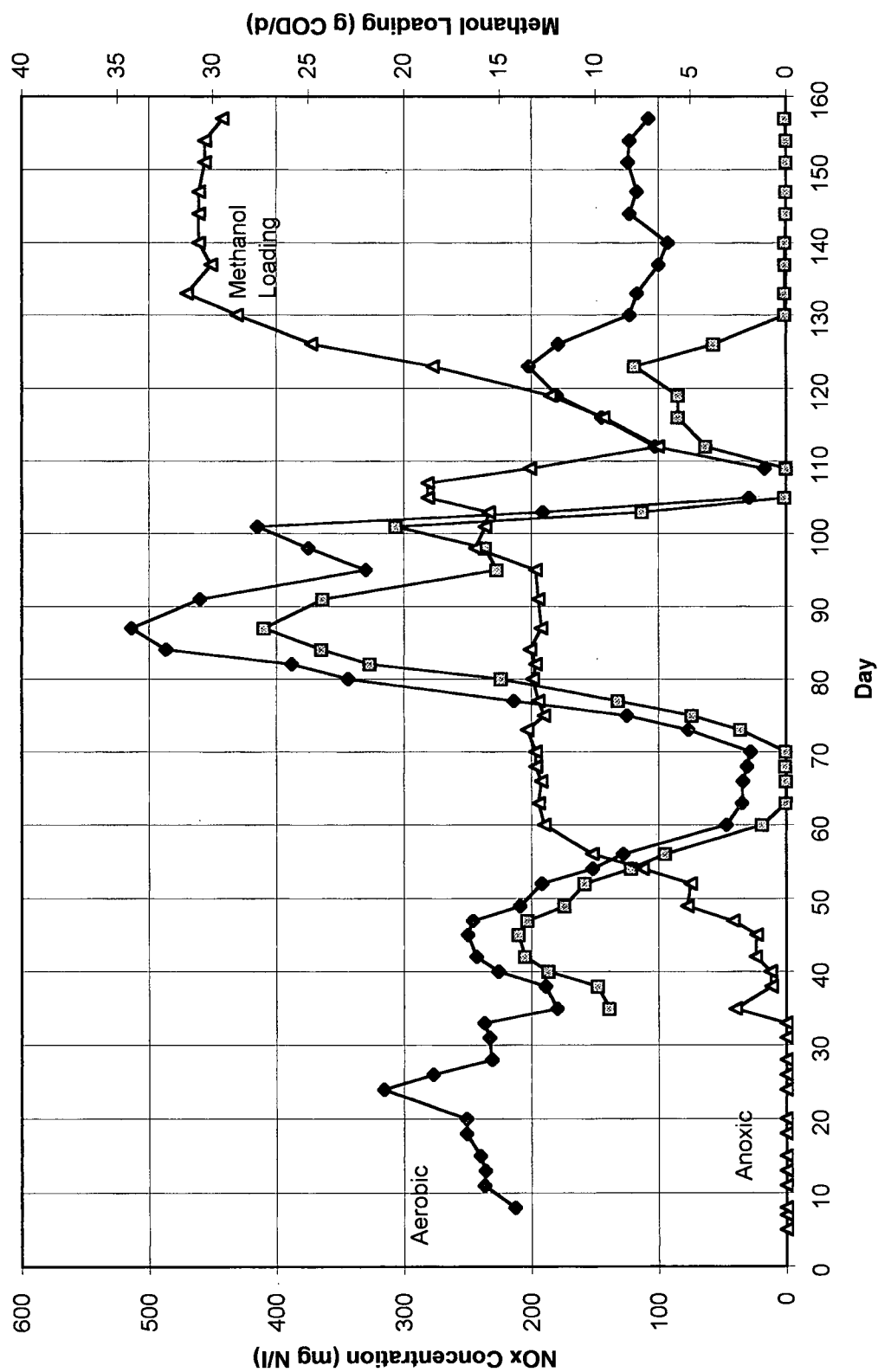


Figure 5.18: MLE Startup Phase - System #2
Anoxic and Aerobic NOx Values



5.2 MLE Recycle Phase

This section presents and discusses data collected during the MLE Recycle Phase (Day 159 - December 14, 1994 to Day 242 - March 7, 1995). The objective of this phase was to determine if effluent NO_x concentrations could be reduced when treating the "target" leachate containing 1200 mg N/L of ammonia, while maintaining consistent ammonia removal and stable nitrification and denitrification, by increasing the sludge recycle flow. During the MLE Startup Phase, the sludge recycle flows were set to approximately six times the leachate flow to maintain consistency with earlier UBC studies. Hence the recycle ratio (r) of sludge recycle flow to leachate flow was 6:1. More specifically, the recycle ratio was defined in this study as:

$$\text{Recycle Ratio (r)} = (\text{Sludge Recycle Flow}) / (\text{"Simulated" Leachate Flow})$$

where:

$$\text{"Simulated" Leachate Flow} = \text{"base" leachate flow} + \text{NH}_4\text{Cl solution flow.}$$

The earlier study by Elefsiniotis et al (1989) found an "r" of 6:1 to be optimal for identical systems treating leachate containing about 240 mg N/L of ammonia. This "r" value corresponded to actual hydraulic retention times (AHRT) of 1.71, 3.42 and 1.37 hours in the anoxic reactor, aerobic reactor and clarifier, respectively. Similarly, Azevedo (1993) used a 6:1 recycle ratio while attempting to treat leachate containing up to 2000 mg N/L of ammonia.

During the recycle phase, "r" was set to 7:1 in System 1 and 8:1 in System 2. Increasing the sludge recycle flow decreased the AHRT in the reactors and clarifier. Table 5.3 contains the mean AHRT values, along with standard deviations, for the various reactors during the MLE Recycle Phase. The AHRT was defined as:

$$\text{AHRT} = (\text{Reactor Volume}) / (\text{Total Flow through Reactor})$$

where:

$$\text{Total Flow through Reactor} = \text{leachate flow} + \text{clarifier sludge recycle flow} + \text{chemical flow.}$$

Table 5.3 MLE Reactor Actual Hydraulic Retention Times

Reactor	System #1 - r = 7:1 Mean AHRT (hr); Std. Dev.	System #2 - r = 8:1 Mean AHRT (hr); Std. Dev.
Anoxic	1.61; 0.0095	1.43; 0.0167
Aerobic	3.18; 0.0186	2.84; 0.0336
Clarifier	1.27; 0.0074	1.14; 0.0134

The very small standard deviations shown in Table 5.3 indicate the consistency of the AHRT's during the recycle phase. Mean reactor AHRT's of System 1 were found to be statistically different from those of System 2, as determined by t-tests conducted at a 5% level of significance. These calculations are contained in Appendix C.

The buildup of ammonia in the two systems during the MLE Recycle Phase resulted in two mitigation measures being attempted in order to ultimately reduce effluent ammonia concentrations: (1) increase in solids retention time (SRT); and (2) reduction in leachate ammonia concentration. The following sections separately discuss the effects that changes in SRT and leachate ammonia concentrations (i.e. ammonia mass loadings) had on reactor and effluent ammonia concentrations and reactor solids concentrations.

5.2.1 Ammonia Levels - SRT Effects

The clarifier sludge recycle flows were increased on Day 159 to provide recycle ratios of 7:1 in System 1 and 8:1 in System 2. Effluent ammonia concentrations prior to Day 159 varied between about 10 and 20 mg N/L for both systems. The residual ammonia remaining in the effluent was unexpected, given that Azevedo (1993) found that leachate containing 1500 mg N/L of ammonia could be completely nitrified (i.e. effluent ammonia < 1 mg N/L) using identical systems and a recycle ratio of 6:1. No explanation could be found for the presence of the residual ammonia; however, both systems appeared to be operating in a stable manner and it was decided to increase the recycle flows regardless of the small amount of ammonia remaining in the effluents.

Both systems appeared to be operating "normally" during the first two weeks after the recycle flows were increased. Aerobic SRT's were kept at 10 days. Reactor ammonia levels for System 1, shown in Figure 5.19, remained fairly constant until about day 175 when aerobic levels started to rise. Anoxic and aerobic ammonia concentrations then increased rapidly between days 186 and 189 and eventually reached about 250 mg N/L and 110 mg N/L, respectively. A similar occurrence happened, although slightly sooner, in System 2 as shown in Figure 5.20. Between days 175 and 179, anoxic and aerobic ammonia concentrations increased to about 200 mg N/L and 90 mg N/L, respectively. By day 189 the anoxic ammonia concentration was about 340 mg N/L, with an aerobic concentration of 215 mg N/L.

Elefsiniotis et al (1989) also found that nitrification became unstable after an approximate 2 week period, following increases in recycle ratio beyond 6:1. The higher reactor ammonia concentrations in System 2 compared to System 1, and also the faster accumulation of ammonia, may have been due to the shorter AHRT's of System 2. However, instability with the pH/pump controller used for System 2 resulted in pH values above the setpoint of 7.5. pH instability was due to problems with the pH probe and signal "noise" caused by the electrical motors on the mixers; therefore, the pH/pump controller was adding too much sodium bicarbonate to the reactor, thus raising the pH above the desired "actual" setpoint. Figures 5.21 and 5.22 show the reactor pH values for systems 1 and 2, respectively. Aerobic pH levels in System 1 stayed within plus or minus 0.1 units of the 7.5 setpoint. However, aerobic pH levels in System 2 were increasing between days 161 and 175. An increase in aerobic pH from 7.6 to 8.0 results in increasing the "free" ammonia fraction of "total" ammonia by 2.5 times. Therefore, "free" ammonia toxicity may have inhibited nitrification (i.e. *Nitrosomonas* organisms) in System 2 earlier than in System 1. Table 5.4 illustrates calculated aerobic "free" ammonia concentrations during the period of ammonia accumulation.

Anoxic "free" ammonia concentrations (Table 5.5) remained fairly constant during this period and were similar in both systems. In addition, these values are very similar to those both prior to and during the remainder of the recycle phase. Anoxic pH levels, shown in Figures 5.21 and 5.22, were similar in both systems and remained in the range of 8.3 to 8.5. Therefore, it appears that the inhibition of *Nitrosomonas*

Figure 5.19: MLE Recycle Phase - System #1($r = 7:1$)
Anoxic and Aerobic Ammonia Values

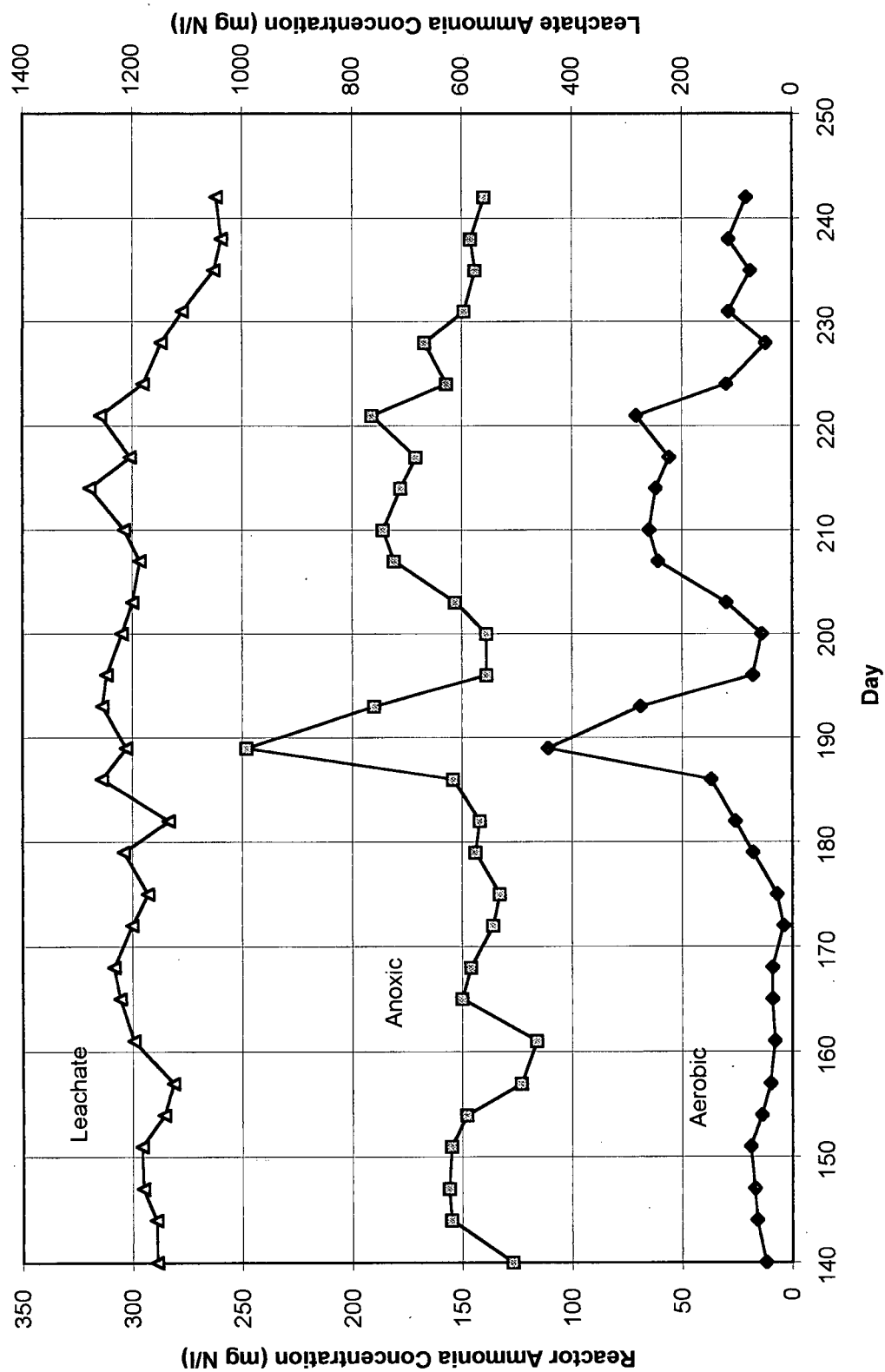


Figure 5.20: MLE Recycle Phase - System #2 ($r = 8:1$)
Anoxic and Aerobic Ammonia Values

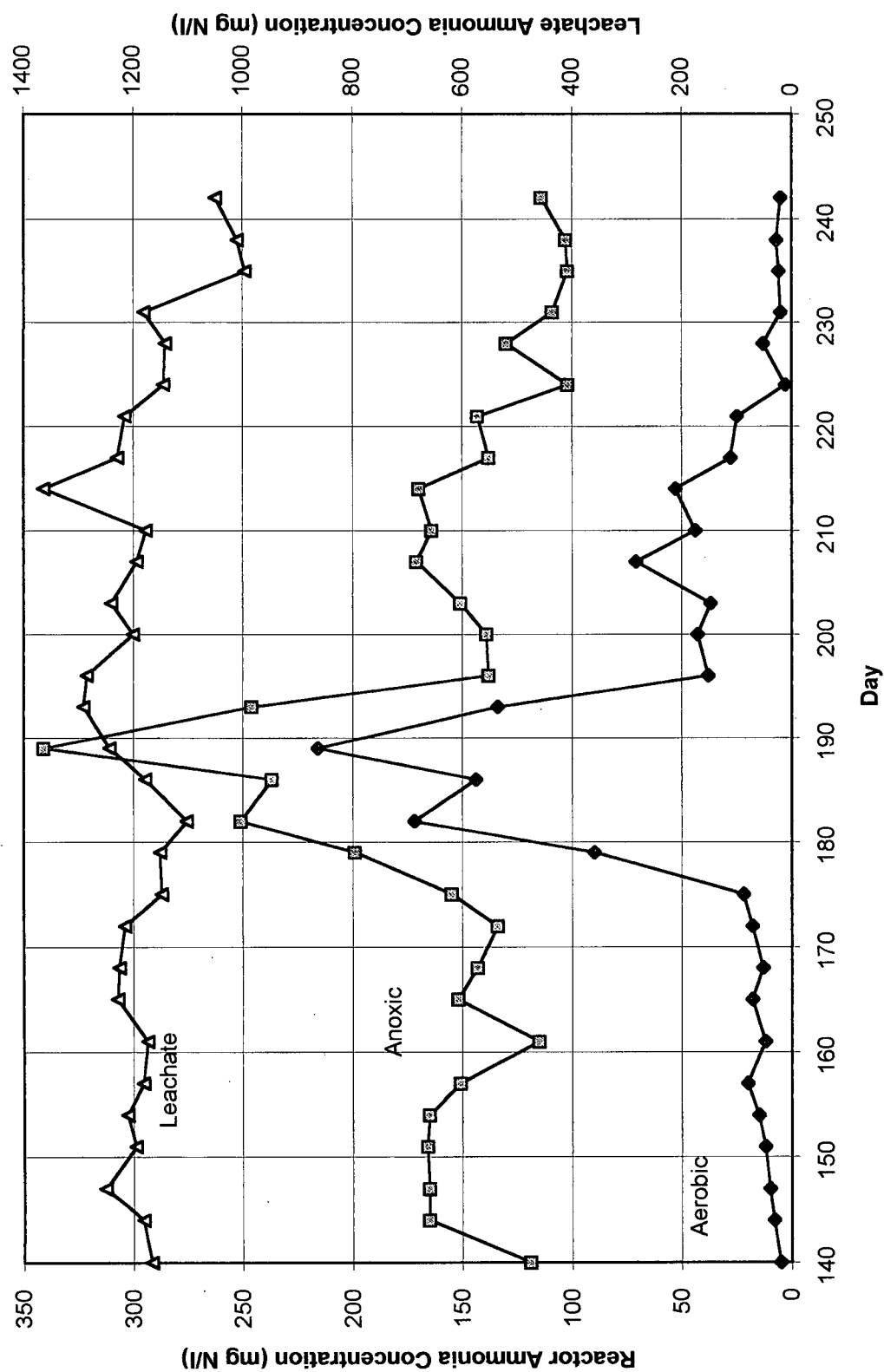


Figure 5.21: MLE Recycle Phase - System #1 ($r = 7:1$)
Anoxic and Aerobic pH Values

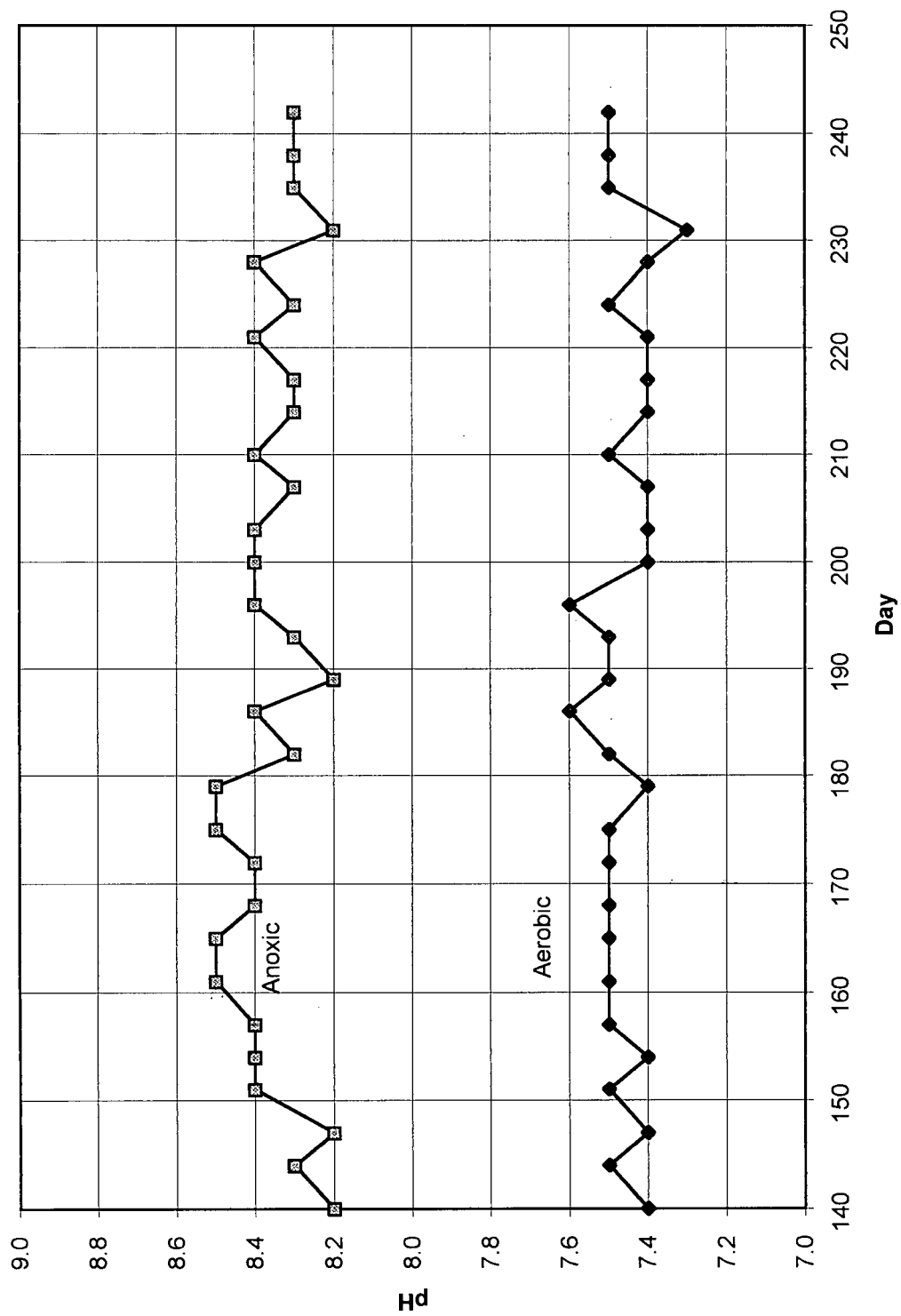
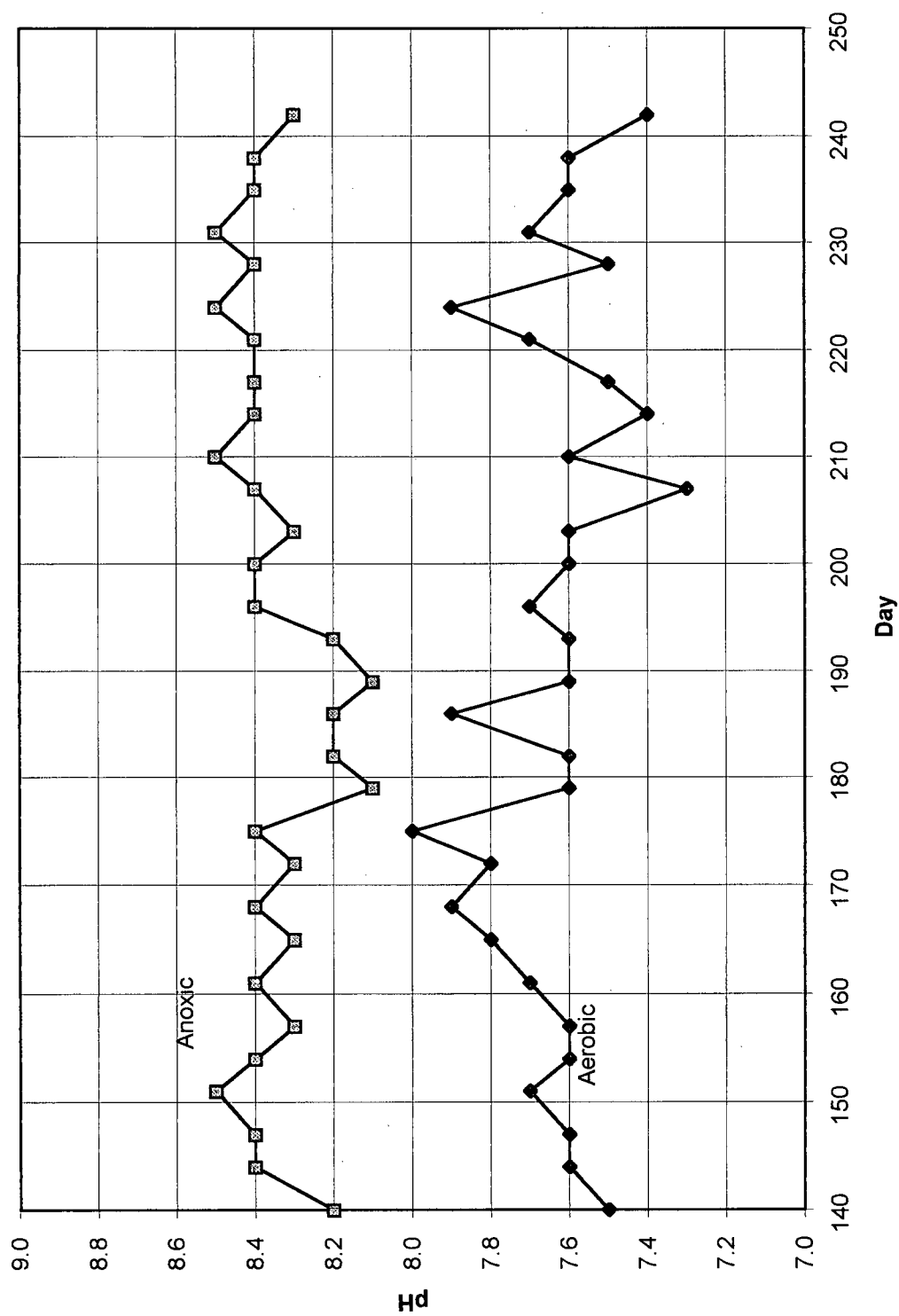


Figure 5.22: MLE Recycle Phase - System #2 ($r = 8:1$)
Anoxic and Aerobic pH Values



may be dependent on "free" ammonia levels in the aerobic reactors, where the autotrophic bacteria are "active" rather than conditions within the anoxic reactor.

Table 5.4 Aerobic "Free" Ammonia Concentrations

Day	System 1 - Aerobic Free Ammonia Concentration (mg N/L)	System 2 - Aerobic Free Ammonia Concentration (mg N/L)
175	0.1	0.8
179	0.2	1.4
182	0.3	2.6
186	0.6	4.3
189	1.4	3.3

Table 5.5 Anoxic "Free" Ammonia Concentrations

Day	System 1 - Anoxic Free Ammonia Concentration (mg N/L)	System 2 - Anoxic Free Ammonia Concentration (mg N/L)
175	14.7	13.9
179	15.9	9.3
182	10.3	14.7
186	13.8	13.8
189	14.5	16.0

In order to prevent the continued rise of reactor ammonia levels, and further inhibition of nitrification, the aerobic wasting rate was decreased from 1.0 L/d to 0.67 L/d on day 189. This resulted in an increase in aerobic SRT from 10 days to 15 days. The purpose of reducing the wasting rate was to increase the mass of nitrifying bacteria within the systems and, therefore, enable the oxidation of excess ammonia in the reactors. As shown in Figures 5.19 and 5.20, reactor ammonia concentrations quickly decreased once the wasting rate was reduced. The effect of reducing the wasting rate on reactor solids concentrations is discussed in detail in Section 5.2.2.

Aerobic ammonia concentrations of about 15 mg N/L in System 1 and 40 mg N/L in System 2 were still present on day 200. Therefore, a further reduction in aerobic wasting to 0.5 L/d (SRT = 20 days) was begun on day 200, to determine if the remaining ammonia could be removed from the aerobic mixed

liquor and hence effluent. However, reactor ammonia levels in both systems actually increased following the further reduction in wasting rate. The average anoxic ammonia concentration between days 203 and 221, for System 1, was 177 mg N/L, with an average aerobic concentration of 58 mg N/L. For System 2, the mean anoxic and aerobic values were 156 mg N/L and 43 mg N/L, respectively.

5.2.2 Reactor Solids Levels - SRT Effects

Reactor volatile suspended solids (VSS) concentrations are shown in Figure 5.23 for System 1 and Figure 5.24 for System 2. Anoxic VSS concentrations were always higher than aerobic concentrations in both of the systems. Large diameter overflows and tubing were used between the anoxic and aerobic reactors to prevent plugging of the tubing. Plugging did not occur at any time during the study; however, there was some retention of solids in the tubing despite frequent flushing (i.e. several times a week) of the tubing using mixed liquor. The retention of solids in the tubing likely contributed to some of the differences between anoxic and aerobic concentrations, but this would be a minor contributor.

Reactor VSS concentrations are dependent on several variables including leachate ammonia concentration, anoxic methanol loading and clarifier recycle flow. Leachate ammonia concentrations, and hence ammonia mass loadings, were virtually identical for both systems and would not have contributed to significant VSS differences between the two systems. A t-test conducted on the mean ammonia mass loadings during the recycle phase determined that differences in actual ammonia loadings to the two systems were statistically insignificant (Appendix C). System 1 methanol loadings were higher than those for System 2 at the beginning of the recycle phase. As a result, System 1 had anoxic VSS concentrations that were about 1000 mg/L higher than those for System 2 during the initial period.

As expected, reactor VSS concentrations began to steadily increase when the aerobic wasting rate was reduced from 1.0 L/d to 0.67 L/d on day 189 and then to 0.5 L/d on day 200. Both systems contained similar reactor solids concentrations on day 189. Anoxic and aerobic VSS values for System 1 were about 5600 mg/L and 4100 mg/L, respectively. System 2 had an anoxic VSS concentration of 5200 mg/L and an aerobic concentration of about 4300 mg/L. Between days 189 and 221, anoxic and aerobic VSS

Figure 5.23: MLE Recycle Phase - System #1 ($r = 7:1$)
Anoxic and Aerobic VSS Values

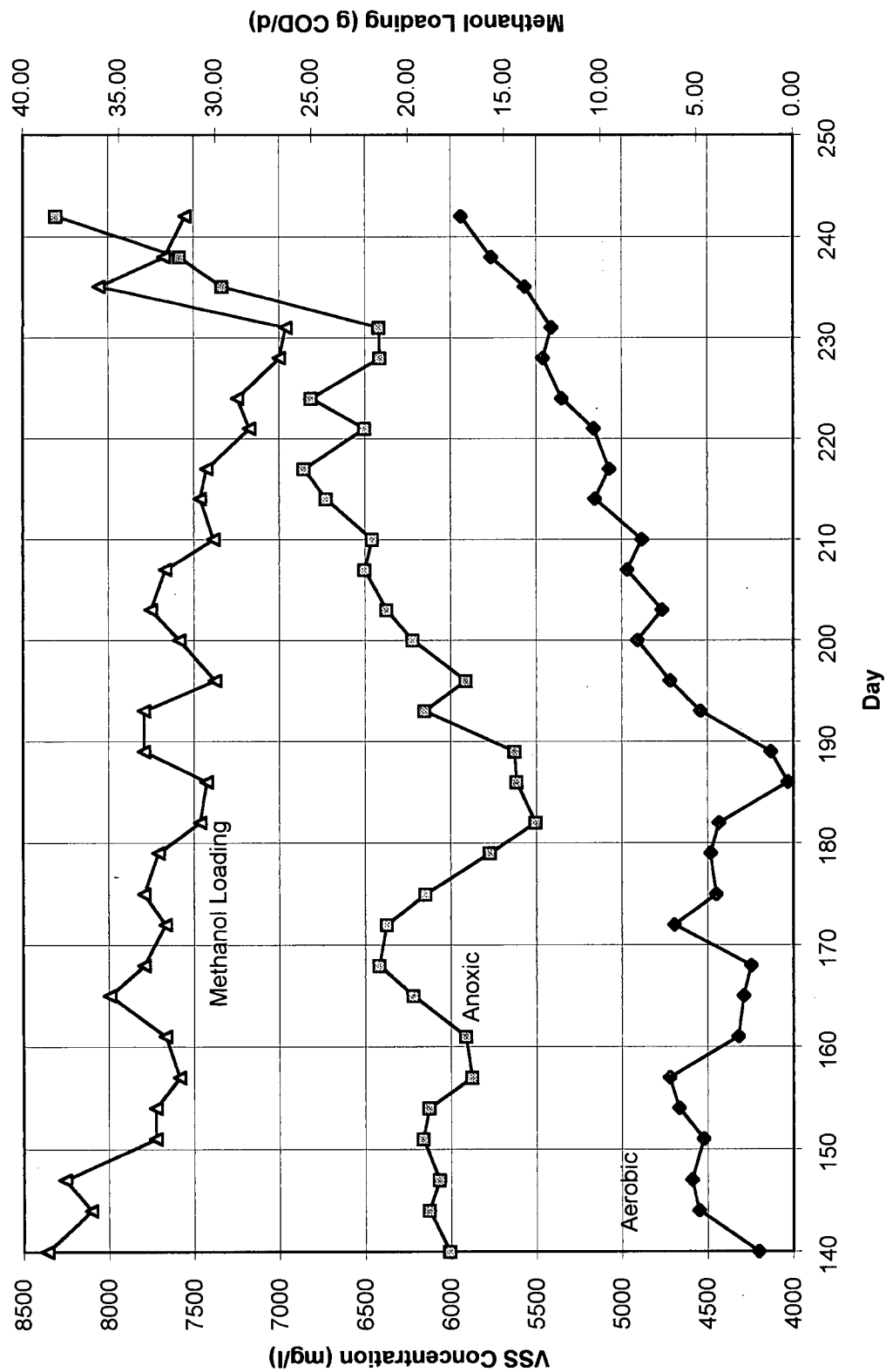
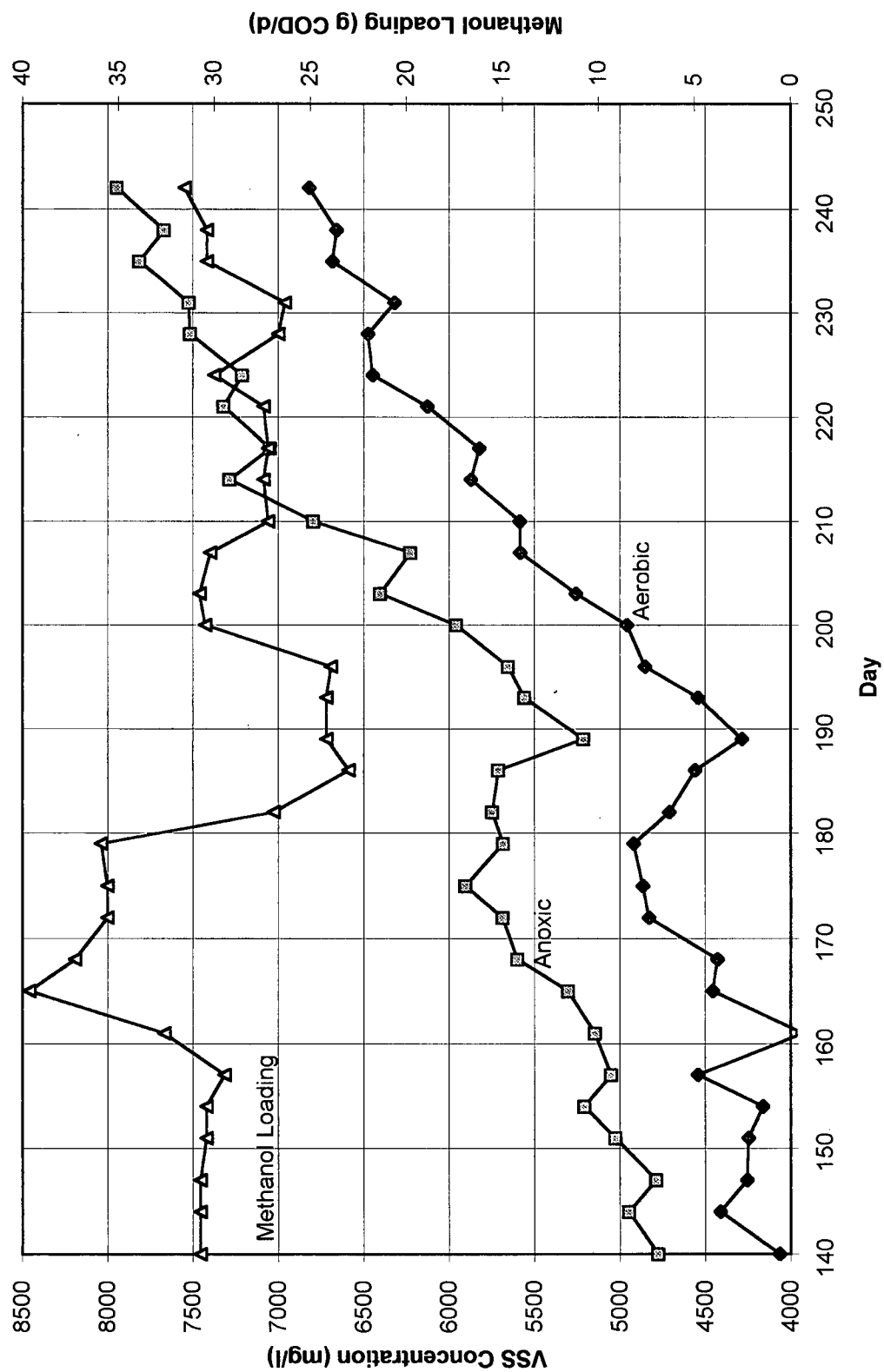


Figure 5.24: MLE Recycle Phase - System #2 ($r = 8:1$)
Anoxic and Aerobic VSS Values



concentrations for System 1 had increased by about 900 mg/L and 1100 mg/L, respectively. Increases of 2100 mg/L and 1900 mg/L in the anoxic and aerobic reactors, respectively, occurred during the same period in System 2.

Average methanol loadings during this period were similar for both systems and even slightly lower for System 2: 31.5 g COD/d for System 1 and 27.5 g COD/d for System 2. Hence, the greater increase in VSS levels in System 2 was probably the result of the higher rate of clarifier recycle flow. There are at least two possible explanations that support this theory. The first is based on kinetic theory that describes the performance of a completely mixed reactor with solids recycle. Reactor VSS levels can be estimated using the following equation (Mavinic 1993):

$$S = ((SRT * (Q + r*Q))/(V)) * ((a*(Lo - Le))/(1 + b*SRT))$$

where:

S = reactor VSS concentration (mg/L)
 SRT = solids retention time (d)
 Q = leachate flow (L/d)
 r = recycle ratio
 V = reactor volume (l)
 a = growth yield coefficient
 b = decay coefficient (d⁻¹)
 Lo - Le = change in substrate concentration across reactor (mg/L)

The above equation indicates that increases in sludge recycle flow, hence recycle ratio, result in increased reactor VSS levels. The term (Lo - Le), across the aerobic reactor, will decrease in an MLE system because of additional dilution of leachate in the anoxic reactor. However, the net effect of increasing the sludge recycle flow, based on the above equation, is an increase in reactor VSS levels. Increases in sludge recycle flow decrease reactor AHRT's, therefore, a larger mass of bacteria is required to consume the same amount of substrate during the reduced time period.

Secondly, excess solids from the mixed liquor can accumulate in the bottom of the clarifiers if solids separation is highly efficient (i.e. low effluent solids concentrations) and the clarifier recycle flow is too

low to remove all of the accumulated solids. Therefore, assuming there was some accumulation of solids in the clarifiers, the higher recycle flow in System 2 would take a greater mass of solids out of "storage" from the clarifier and into the anoxic and aerobic reactors.

The effect of the actual mass of solids on ammonia removal efficiencies is discussed in Section 5.2.6.

5.2.3 Ammonia Levels - Ammonia Mass Loading Effects

Aerobic ammonia levels and, therefore, effluent ammonia levels in both systems were still large (i.e. > 25 mg N/L) after a period of one aerobic sludge age at an SRT of 20 days. Hence, the concentration of ammonia in the "simulated" leachate was reduced on day 221, to see if effluent ammonia concentrations could be lowered. Anoxic and aerobic ammonia concentrations in System 1 (Figure 5.19) showed an immediate decrease in response to the reduction in leachate ammonia concentration. The ammonia concentration of leachate being fed to System 1 was initially reduced by about 80 mg N/L. This resulted in a 40 mg N/L reduction in the aerobic ammonia concentration (i.e. 70 mg N/L to 30 mg N/L). By day 232, the leachate ammonia concentration had been reduced to about 1050 mg N/L, for a total reduction of almost 200 mg N/L. However, aerobic ammonia levels remained fairly constant following the initial decrease in leachate ammonia concentration on day 221, and had a mean value of 23 mg N/L between days 224 and 242. System 2 demonstrated a similar response to the reduction in leachate ammonia concentration. The ammonia concentration of leachate being fed to System 2 was initially reduced on day 221 by about 70 mg N/L. The aerobic ammonia concentration decreased from 25 mg N/L to 3 mg N/L. By day 232 the leachate ammonia concentration was reduced to give a total reduction of about 200 mg N/L. As with System 1, aerobic ammonia concentrations remained essentially constant after day 224, with a mean concentration of 7 mg N/L between days 224 and 242.

Between days 224 and 242, the mean anoxic ammonia concentrations for systems 1 and 2 were 151 mg N/L and 110 mg N/L, respectively. Lower anoxic ammonia concentrations in System 2 were the result of the larger recycle flow, providing more dilution of the reactor contents combined with much lower ammonia concentrations in the returned sludge (i.e. = effluent concentration) compared to System 1.

5.2.4 Reactor Solids Levels - Ammonia Mass Loading Effects

As indicated in Section 5.2.2, ammonia loadings to the two systems were almost identical during the recycle phase, including the period after day 221 when leachate ammonia concentrations were reduced to lower effluent ammonia concentrations. Therefore, the differing magnitude of changes in reactor VSS levels between System 1 and System 2 during this period are unlikely due to differences in ammonia loadings.

Reactor VSS concentrations would have remained constant or decreased slightly after day 221, due to the reduced ammonia loadings. However, as seen in Figures 5.23 and 5.24, reactor VSS levels were sensitive to changes in methanol loading. The sharp rise in VSS levels after day 231, particularly in System 1, were the result of large boosts in methanol loading that stimulated more growth of heterotrophic bacteria. Methanol loadings were increased in response to accumulation of NO_x due to methanol shortages in the systems.

The ratio of volatile suspended solids to total suspended solids (VSS/TSS) remained fairly constant during the entire recycle phase and was in the range of 0.88 to 0.91, regardless of reactor or system.

5.2.5 Effluent Solids Levels

Figures 5.25 and 5.26 illustrate the effluent TSS and VSS levels for systems 1 and 2. System 1 consistently had lower effluent solids concentrations, and more stable settling performance, than System 2. This is most likely the result of the longer AHRT and lower solids loading rate, due to lower aerobic SS concentrations, of System 1. This agrees with Elefsiniotis et al (1989), when using identical systems, who found that effluent solids concentrations increased considerably at recycle ratios beyond 6:1 (and thus lower clarifier AHRT's) and also resulted in more unstable clarifier performance. Interestingly, Azevedo (1993) found that effluent SS concentrations were consistently well over 100 mg/L when treating leachate containing between 1000 and 1500 mg N/L of ammonia. As shown in Figures 5.25 and 5.26, both systems used in the present study usually had less than 30 mg/L of SS in the effluents.

Figure 5.25: MLE Recycle Phase - System #1 ($r = 7:1$)
Effluent SS Values

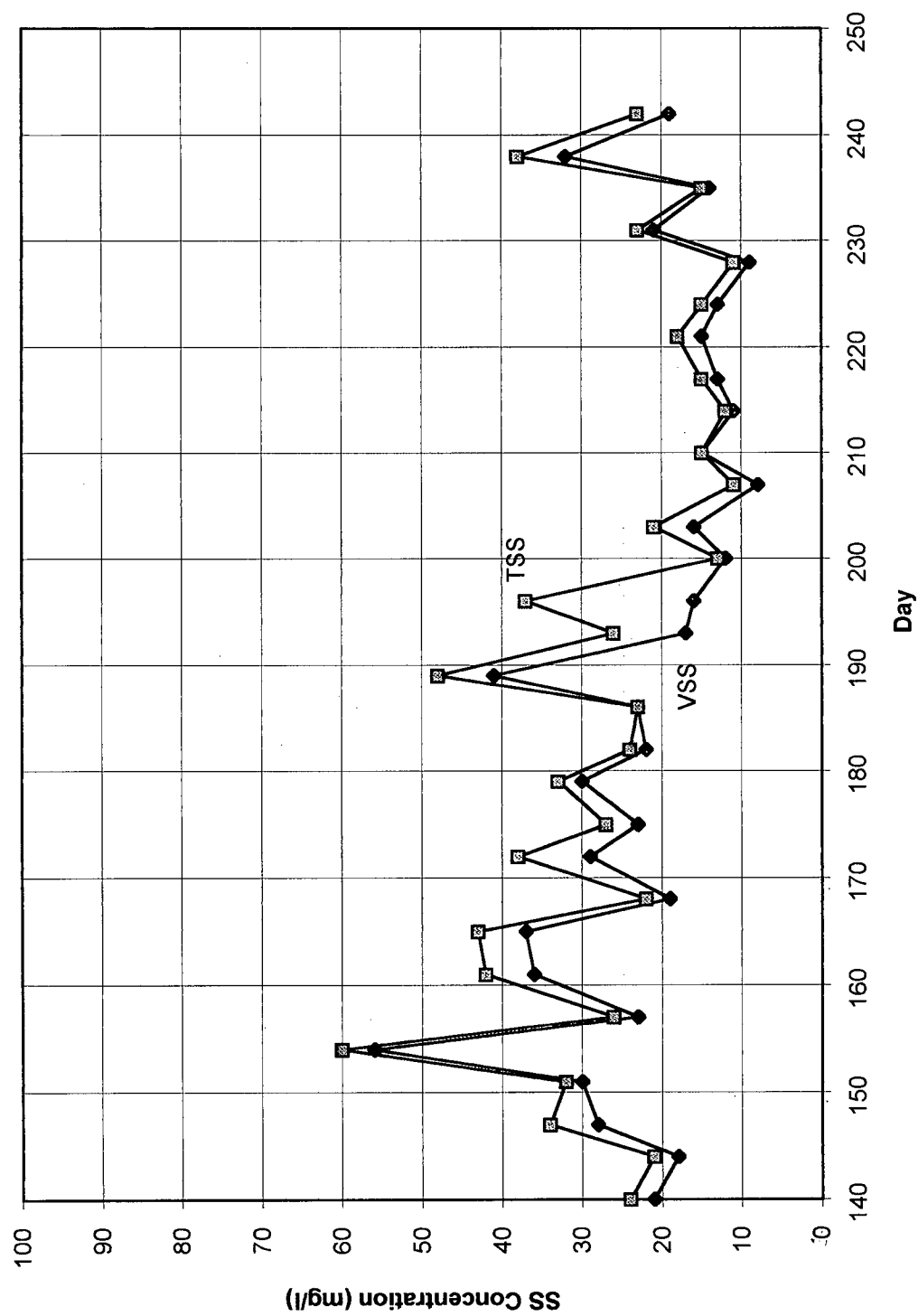
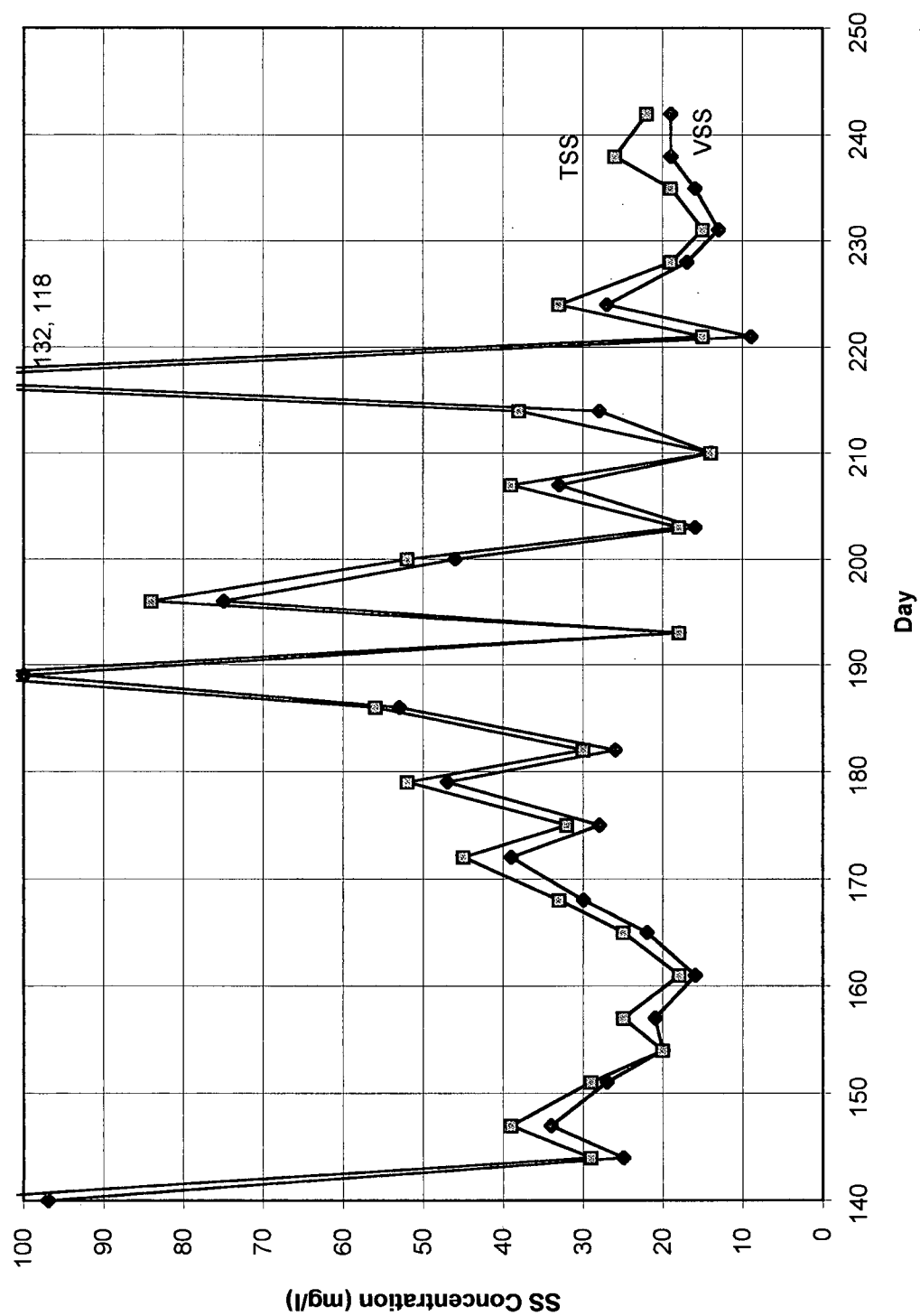


Figure 5.26: MLE Recycle Phase - System #2 ($r = 8:1$)
Effluent SS Values



5.2.6 Ammonia Removal

The removal of ammonia from leachate is the combined result of physical "stripping" in the aerobic reactors, bacterial assimilation, and nitrification. Ammonia "stripping" is the diffusion of unionized (i.e. gaseous) ammonia from the mixed liquor to the atmosphere. Vigorous mixing of mixed liquor in the aerobic reactors, caused by aeration, enhances the rate of diffusion. High pH values cause a shift in ammonia from the ionized form to the unionized form and, therefore, increases the amount of ammonia that could potentially be stripped. However, the short aerobic hydraulic retention times, combined with almost neutral aerobic pH levels used in this study, result in a relatively small potential for ammonia stripping. Lee and Naimie (1985) found that only 8% of ammonia could be stripped from an aeration unit with a pH of 7.5 and a hydraulic retention time of 4 days.

Assuming that ammonia removal due to stripping is negligible, bacterial assimilation and nitrification are the main mechanisms for ammonia reduction. Nitrification performance is specifically discussed in Section 5.2.7. Figures 5.27 and 5.28 show the percent ammonia removals for systems 1 and 2, respectively. Both figures show the inhibition of nitrification that occurred between days 175 and 189. During this period, System 2 reactor ammonia levels (Figure 5.20) were higher than those for System 1 (Figure 5.19) and are reflected in the lower amount of aerobic and overall system ammonia removal in System 2.

Figures 5.23 and 5.24 show that the rate of increase in aerobic VSS levels between days 189 and 200 (15 d SRT) was about the same for both systems. However, after day 200 (20 d SRT), aerobic VSS levels in System 2 were increasing much more rapidly than those in System 1. Correspondingly, after day 207, aerobic ammonia removal efficiencies in System 2 (Figure 5.28) were higher than those of System 1 (Figure 5.27). The greater mass of solids in System 2 would have contained more nitrifying bacteria that, in turn, may have been able to oxidize and/or assimilate more ammonia and result in larger aerobic and system ammonia removal efficiencies and lower effluent ammonia concentrations. The mean daily aerobic nitrification rates (i.e. daily aerobic NO_x production), between days 207 and 242, were 11090 mg N/d for System 1 and 11579 for System 2. The difference between these data sets was found to be

Figure 5.27: MLE Recycle Phase - System #1 ($r = 7:1$)
Anoxic, Aerobic and System % Ammonia Removal

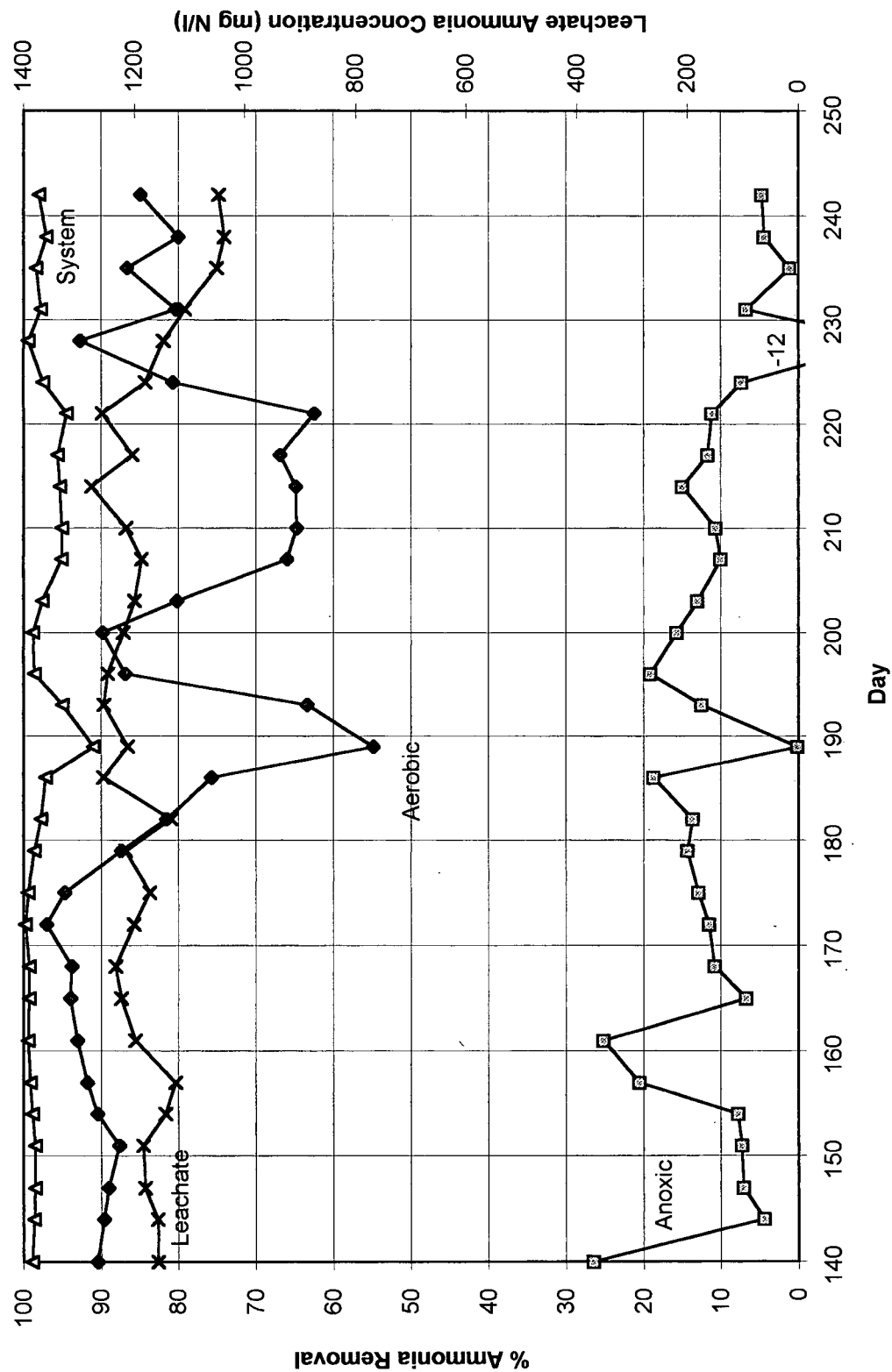
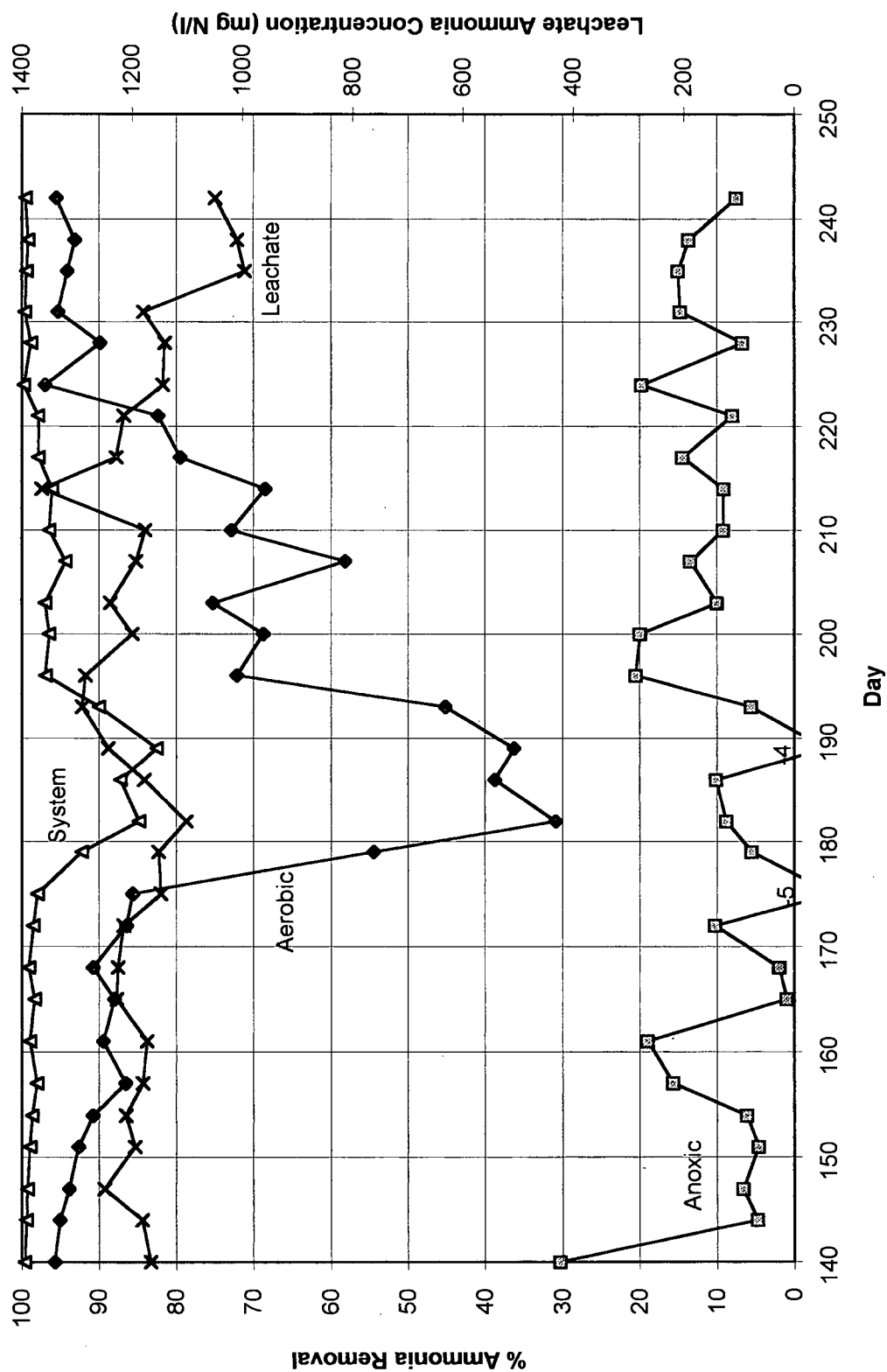


Figure 5.28: MLE Recycle Phase - System #2 ($r = 8:1$)
Anoxic, Aerobic and System % Ammonia Removal



statistically insignificant (Appendix C), however, the data do show that, on average, System 2 produced about 4.4% more NO_x than System 1. Therefore, the greater aerobic ammonia removal efficiencies of System 2 were probably the result of a combination of "extra" ammonia assimilation and oxidation.

Figures 5.27 and 5.28 show that both systems had similar anoxic ammonia removal efficiencies once nitrification had been reestablished on about day 196. Between days 196 and 221, System 1 had a mean anoxic ammonia removal efficiency of about 13%, with System 2 having a 16% efficiency. Similarly, the mean daily anoxic ammonia removal rates, during the same period, were 1895 mg N/d for System 1 and 1905 mg N/d for System 2. Even though the two systems had different recycle ratios, the total daily mass of NO_x returned to the anoxic reactors for denitrification was approximately the same in both systems. The mean daily anoxic NO_x loads for the period between days 196 and 221 were 12,400 mg N/d and 12,000 mg N/d for systems 1 and 2, respectively. Therefore, the rate of growth of heterotrophic bacteria, and thus assimilation of ammonia, should be similar in both systems. This hypothesis is confirmed by the virtually identical mean daily anoxic ammonia removal rates.

Section 5.2.3 discussed how reactor and effluent ammonia levels dropped to approximate steady state levels by day 224, after the first decrease in ammonia mass loading on day 221. System 1 had effluent ammonia concentrations of about 23 mg N/L, with System 2 concentrations around 7 mg N/L. Figures 5.27 and 5.28 show that between days 221 and 242, System 2 had anoxic ammonia removal efficiencies that were up to 2.5 times greater than those for System 1. Expectedly, a similar relationship exists with the actual daily mass of ammonia removed in the anoxic reactors. The reason for this difference is not clear, given the anoxic methanol loadings to the systems were almost equal during this period and would have resulted in similar rates of heterotrophic growth and ammonia assimilation. This higher rate of anoxic ammonia removal may have also contributed to the much lower effluent concentrations in System 2, compared to System 1.

Ammonia removal has been shown to decrease and become unstable when clarifier recycle ratios were increased to 7:1 and 8:1, from 6:1, thus reducing reactor AHRT's. However, lower rates of aerobic

wasting (i.e. increased SRT's) resulted in increases in reactor solids concentrations and greater and more stable ammonia removal in both systems. As noted earlier, System 2 had slightly lower effluent ammonia concentrations than System 1, during the period from day 203 to 221, even though System 2 had shorter AHRT's. However, as discussed in Section 5.2.2, System 2 had significantly higher reactor solids concentrations during this period and presumably a larger mass of nitrifying bacteria. Therefore, the effects of decreased AHRT beyond the "critical" point (i.e. AHRT's at $r = 6:1$) cannot be ascertained because of the differences in reactor solids concentrations. It does appear that increases in clarifier recycle flow can increase solids concentrations and thus improve ammonia removal, possibly negating any negative effects that reduced AHRT's, caused by the increased recycle flow, may have on ammonia removal. However, the "limiting condition" for this operational approach was not explored in this study. Reductions in leachate ammonia concentration (Section 5.2.3) were also found to improve ammonia removal and result in lower effluent ammonia concentrations. Several points are noteworthy regarding the reduction of leachate ammonia concentration and its effects on effluent ammonia levels. Leachate ammonia concentrations in both systems were reduced by about 200 mg N/L, but System 2 had much lower effluent ammonia concentrations than System 1. As indicated in Section 5.2.3, mean aerobic (i.e. effluent) ammonia concentrations between days 224 and 242 were 23 mg N/L for System 1 and 7 mg N/L for System 2. Again, the presumed greater mass of nitrifying organisms present in System 2 are likely responsible for the lower effluent ammonia concentrations and likely offset potential negative effects of lower AHRT's.

The large reductions in leachate ammonia concentration necessary to effect significantly smaller reductions in effluent ammonia concentrations is particularly interesting. The rate of ammonium oxidation by *Nitrosomonas* bacteria can be described by the kinetic equation proposed by Monod (EPA 1993):

$$q_n = (q'_n) * (N / (K_n + N))$$

where:

q_n	=	ammonium oxidation rate, g NH ₄ -N oxidized/g VSS/d
q'_n	=	maximum ammonium oxidation rate, g NH ₄ -N oxidized/g VSS/d
N	=	ammonia concentration, mg N/L
K_n	=	half-saturation coefficient for <i>Nitrosomonas</i> , mg N/L

K_n values (20 degrees Celsius) have been reported to vary from 0.6 to 3.6 mg N/L (EPA 1993). Therefore, if the actual K_n values were at the lower end of this range, the rate of ammonium oxidation could be assumed to be independent of the ammonia concentration (i.e. zero-order reaction) and always proceeding at its maximum rate. This assumes that the aerobic ammonia concentrations are much larger than the "low end" K_n values. However, if this were the case, it would be expected that reductions in effluent ammonia concentrations would be closer to reductions in leachate ammonia concentration. As discussed in Section 5.2.3, both systems produced effluent containing almost constant ammonia levels, after the initial decrease (i.e. 70 to 80 mg N/L) in leachate ammonia concentration on day 221, even though the leachate ammonia concentration was eventually reduced by about 200 mg N/L. It may be that the rate of ammonia oxidation was reaching substrate limiting conditions and thus slowing down. Further reductions in leachate ammonia concentration or increases in reactor solids levels would have likely resulted in lower effluent ammonia concentrations.

5.2.7 Nitrification

The previous section discussed how ammonia removal is the combined result of bacterial assimilation of ammonia and nitrification. The % nitrification can be calculated by dividing the amount of NOx produced across the aerobic reactor by the mass of ammonia entering the aerobic reactor. Some of the ammonia entering the aerobic reactor would be assimilated by both autotrophic nitrifiers and heterotrophic bacteria feeding on organic carbon and, therefore, not available for conversion into NOx. Hence % nitrification values can be lower than the ammonia removal values presented in the previous section, and less than 100%, even when there is 100% ammonia removal. Thus, % nitrification values could be considered "conservative" in this situation.

Percent nitrification values can also be greater than 100% for several reasons, including, NOx accumulation, standard errors in sampling and analytical techniques, and the conversion (hydrolysis) of organic nitrogen in the mixed liquor to ammonia and then oxidation to NOx (Carley and Mavinic 1991). The latter can be the result of organic nitrogen originally present in the leachate and also the release of organic nitrogen from cells undergoing lysing within the system (Elefsiniotis et al 1989). Ammonia has

been found to make up from 86% (Carley and Mavinic 1991) to 96% (Elefsiniotis et al 1989) of the total nitrogen in the "base" leachate used in this study. In addition, ammonium chloride was used to increase the "base" leachate ammonia concentration from about 230 mg N/L to 1200 mg N/L. Therefore, % nitrification values greater than 100%, that are due to the conversion of organic nitrogen, are more likely the result of organic nitrogen originating from bacterial cells rather than the "base" leachate itself.

Figures 5.29 and 5.30 show % nitrification data for systems 1 and 2. Expectedly, trends in % nitrification closely mimic those of aerobic ammonia removal shown in Figures 5.27 and 5.28. The inhibition of nitrification is evident in both systems between about days 175 and 189. System 2 had aerobic ammonia concentrations that were up to two times as large those in System 1 and much lower % nitrification values during this period, thus indicating that nitrification inhibition in System 2 was much more severe than in System 1. Nitrification was quickly restored in both systems once aerobic wasting was reduced on day 189.

Methanol shortages during the time around days 196 and 231 resulted in the accumulation of excess NO_x in both systems. The "unsteady" conditions within the systems during these periods likely contributed to % nitrification values exceeding 100%, due to the effect that excess NO_x has on the % nitrification calculation.

The effect that reducing leachate ammonia concentration, after day 221, had on % nitrification is difficult to determine, because of the NO_x accumulation that occurred during this period. Aerobic ammonia removal in System 1 (Figure 5.27) increased from about 65% on day 221 to between 80% and 85%. However, Figure 5.29 indicates that % nitrification decreased from about 90% (day 221) to around 70% after day 235. Aerobic ammonia removal in System 2 (Figure 5.28) increased from about 80% on day 221 to around 95%. Figure 5.30 shows that % nitrification in System 2 remained at around 95% after day 235. As discussed in the previous section, higher reactor solids concentrations in System 2 likely resulted in the greater % ammonia removal and, therefore, higher % nitrification values than System 1.

Figure 5.29: MLE Recycle Phase - System #1 ($r = 7:1$)
 % Nitrification and Specific Nitrification Rate

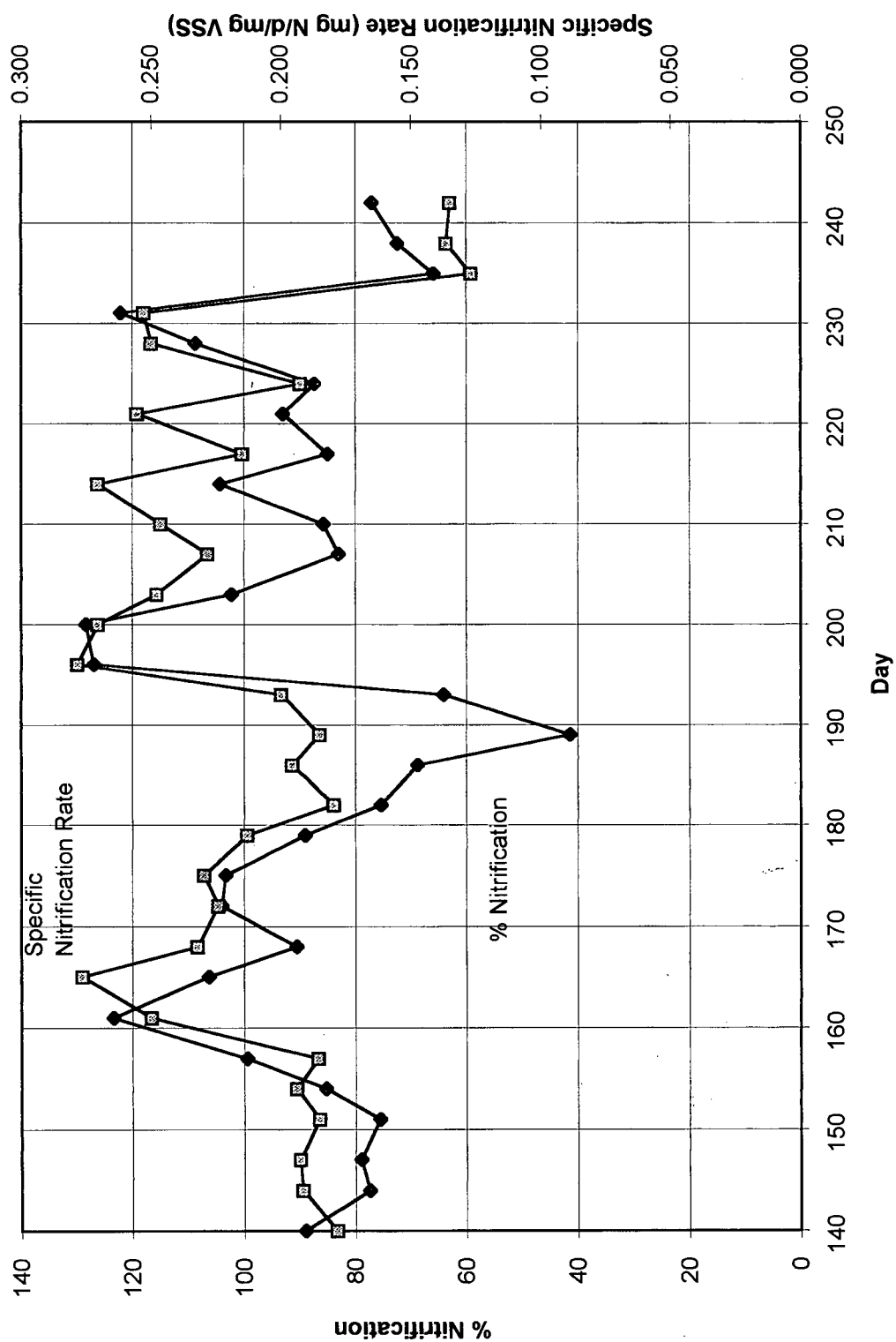
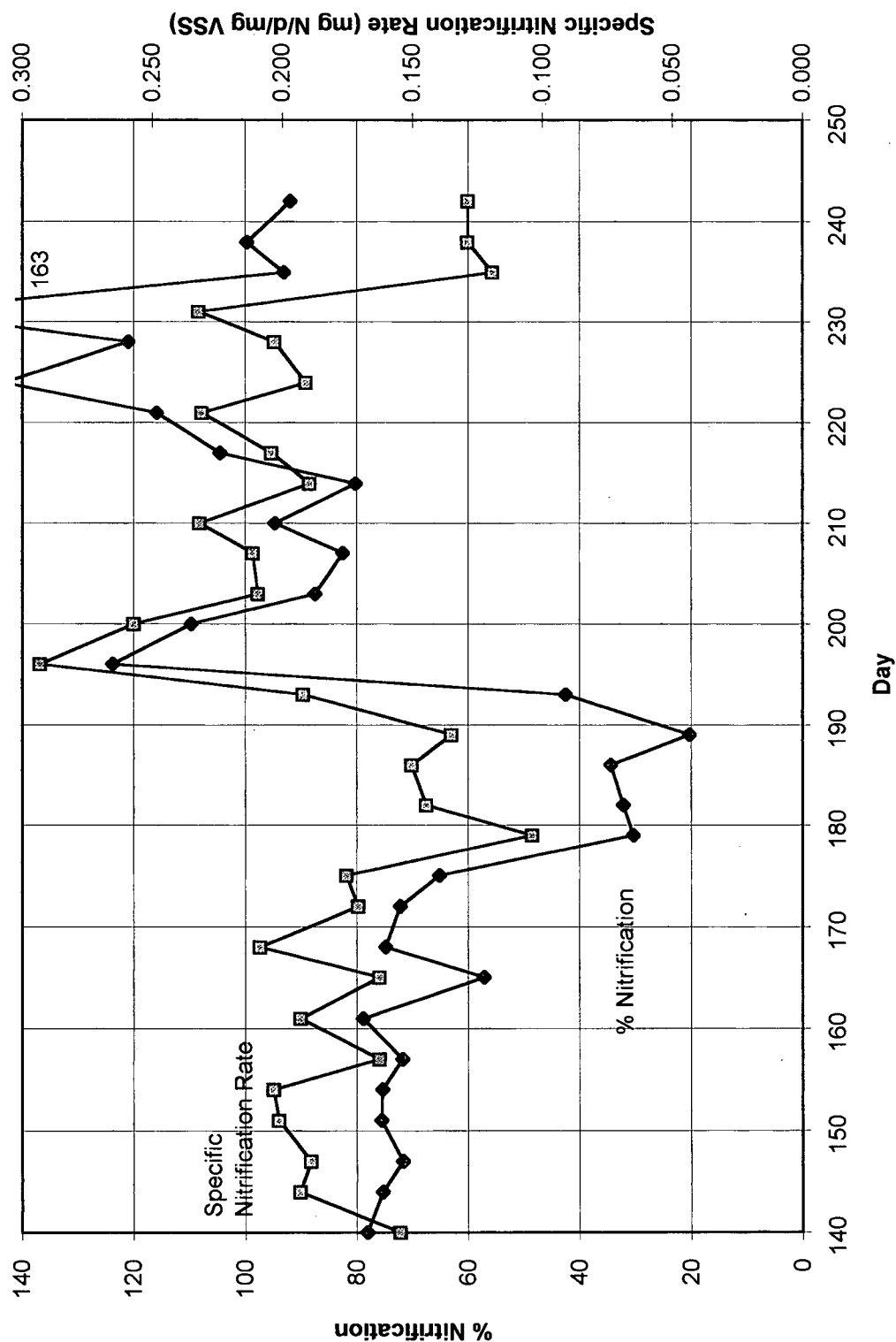


Figure 5.30: MLE Recycle Phase - System #2 ($r = 8:1$)
 % Nitrification and Specific Nitrification Rate



The specific nitrification rates of systems 1 and 2 are also shown in Figures 5.29 and 5.30. Both systems had similar rates, approximately 0.19 mg N/d/mg VSS, overall, before the clarifier recycle flows were increased on day 159. At the same time, aerobic VSS levels were slightly higher in System 1 than System 2 during the 6:1 recycle ratio period between days 140 and 157. Fluctuations in specific nitrification rates during periods of nitrification inhibition and NO_x accumulation were similar to those exhibited in % nitrification values, because the numerator in both calculations is the same.

After about day 203, once nitrification had recovered in the systems, System 1 consistently had larger specific nitrification rates than System 2. However, System 2 had aerobic VSS levels up to 1000 mg/L higher than those of System 1 after day 200, thus, resulting in expected lower specific nitrification rates. Aerobic VSS levels were increasing in both systems during this period; however, specific nitrification rates appeared to randomly fluctuate during this time. Average specific nitrification rates of 0.24 and 0.21 mg N/d/mg VSS for systems 1 and 2, respectively, occurred during the period from day 203 to 221. These values are similar to the 0.23 and 0.24 mg N/d/mg VSS values reported by Azevedo (1993) for 10 d and 20 d SRT systems, treating leachate containing 1000 mg N/L of ammonia.

As with the % nitrification data, similar difficulties exist when interpreting the specific nitrification rate data after the leachate ammonia concentrations were reduced on day 221, due to the effects that excess NO_x have on the calculations. However, by day 235, the specific nitrification rates in both systems dropped to about 0.13 mg N/d/mg VSS. The reduction in rates is the combined result of reduced ammonia loadings to the systems and increases in aerobic VSS levels, caused by boosts in methanol loading on day 231 (to remove accumulated NO_x).

Nitrification of ammonia results in the destruction of alkalinity due to production of hydrogen ions. The theoretical destruction ratio is 7.1 g CaCO₃ per g of ammonia-N (EPA 1993). However, denitrification produces bicarbonate alkalinity to the theoretical ratio of 3.57 g CaCO₃ per g of nitrate-N reduced to nitrogen gas (EPA 1975). Thus, approximately 3.5 g CaCO₃ are required per g ammonia-N nitrified (and subsequently denitrified).

Alkalinity consumption was somewhat erratic during the early stages of the recycle phase when ammonia was accumulating in the systems. Once nitrification was "stabilized", and complete denitrification restored by day 203, alkalinity consumption remained fairly constant until methanol shortages again resulted in decreased denitrification on day 231. The alkalinity consumption for System 1 ranged from 3.1 to 4.1 g CaCO_3 per g of ammonia-N nitrified between days 203 and 228. System 2 required slightly more alkalinity during this period and ranged from 3.7 to 4.3 g CaCO_3 per g of ammonia-N nitrified.

The total daily amount of alkalinity consumed during this period ranged from 41.8 to 46.6 g CaCO_3/d for System 1 and 44.0 to 56.4 g CaCO_3/d for System 2. System 2 should, in theory, have consumed slightly less alkalinity than System 1, due to its larger recycle ratio and greater potential for alkalinity generation during denitrification. However, differences in ammonia assimilation and actual NO_x available for denitrification, combined with slightly higher aerobic pH levels in System 2, appeared to have offset the potential for higher return of alkalinity in System 2. Aerobic pH levels in System 2 (Figure 5.22) were 0.1 to 0.2 units higher than levels in System 1 (Figure 5.21).

5.2.8 NO_x Levels

Nitrification of leachate in the aerobic reactor results in the oxidation of ammonia to nitrite (NO_2^-) and then nitrate (NO_3^-). " NO_x " is the sum of nitrite and nitrate. Nitrified sludge from the clarifier, produced during nitrification in the aerobic reactor, is returned to the anoxic reactor for denitrification in predenitrification systems, such as the MLE process.

Figures 5.31 and 5.32 show the reactor NO_x concentrations for systems 1 and 2, respectively. Both systems consistently removed all of the NO_x entering the anoxic reactors (providing sufficient methanol was available for denitrification) regardless of recycle ratio, anoxic AHRT or solids concentration. Elevated anoxic, and thus aerobic, NO_x values at around day 196 were the result of high NO_x production when nitrification was restored between days 189 and 196. Figures 5.19 and 5.20 indicated elevated reactor ammonia concentrations during this period. Not enough methanol was available for denitrification of the excess NO_x produced by nitrification of the "extra" ammonia during this period; therefore, some

Figure 5.31: MLE Recycle Phase - System #1 ($r = 7:1$)
Anoxic and Aerobic NOx Values

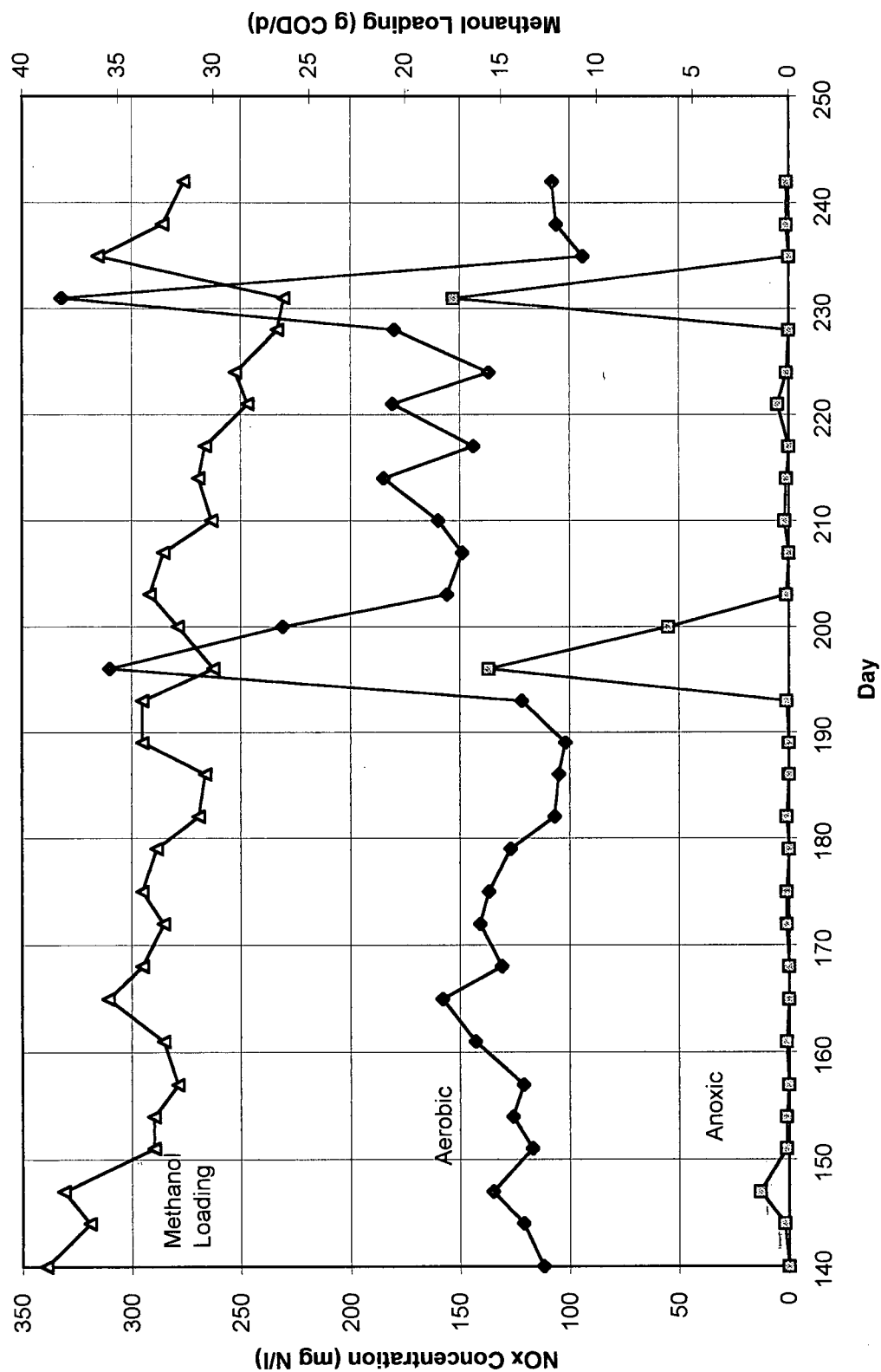
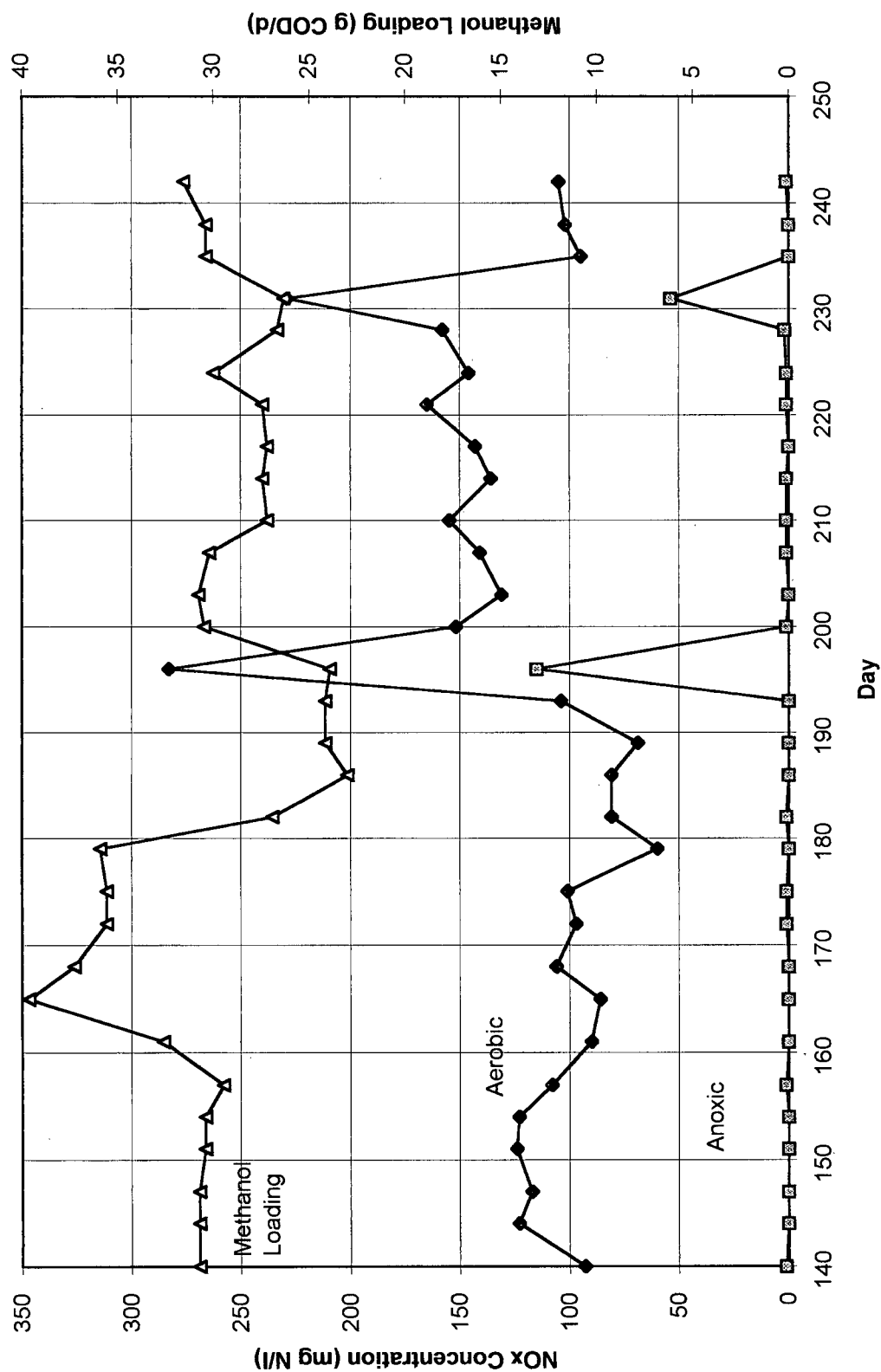


Figure 5.32: MLE Recycle Phase - System #2 ($r = 8:1$)
Anoxic and Aerobic NOx Values



accumulation of NO_x occurred in the systems. Figures 5.31 and 5.32 show that boosts in methanol loading resulted in rapid removal of excess NO_x. Elevated NO_x values in both systems on day 231 were also caused by methanol shortages. Reductions in NO_x concentrations after day 231 were the result of reduced ammonia loadings to the systems. Aerobic, and effluent, NO_x concentrations are specifically discussed in Section 5.2.10 entitled "System NO_x Removal".

The oxidation of nitrite to nitrate by *Nitrobacter* organisms normally proceeds at a much faster rate than the oxidation of ammonia to nitrite by *Nitrosomonas* bacteria; therefore, nitrite accumulation usually does not occur in biological systems (EPA 1993). However, *Nitrobacter* organisms can be inhibited to a greater extent than *Nitrosomonas* by several parameters, thus causing accumulation of nitrite in the system. Parameters suspected of inhibiting nitrite oxidation include "free" ammonia, nitrous acid, extreme temperatures, low concentrations of dissolved oxygen, metals, short sludge ages, high carbon loadings, and biologically available phosphorus deficiencies (Turk 1986).

Nitrite reactor concentrations are shown in Figure 5.33 for System 1 and Figure 5.34 for System 2. The ratio of aerobic nitrite to NO_x concentration is also shown on these figures. System 1 had a mean NO₂/NO_x ratio of 0.60 during the recycle phase from day 161 to 242; System 2 had a mean value of 0.62 during the same period. This compares closely to Azevedo (1993) who found NO₂/NO_x ratios of 0.59 (20 d SRT) to 0.68 (10 d SRT) when treating leachate containing 1000 to 1500 mg N/L of ammonia. High anoxic ammonia concentrations and pH levels were thought to have caused high anoxic "free" ammonia concentrations that inhibited *Nitrobacter* organisms, as they were recycled through the anoxic reactors.

The aerobic NO₂/NO_x ratios were higher in both systems during the period of nitrification inhibition from about day 179 to day 196, than for most of the remaining recycle phase. Aerobic reactor "free" ammonia concentrations increased during this period of rapid ammonia accumulation, with System 2 having much larger aerobic "free" ammonia levels than System 1 (Section 5.2.1). Anoxic "free" ammonia concentrations remained relatively constant and similar in both systems. It appears that *Nitrobacter* in

Figure 5.33: MLE Recycle Phase - System #1 ($r = 7:1$)
Anoxic and Aerobic NO₂ Values

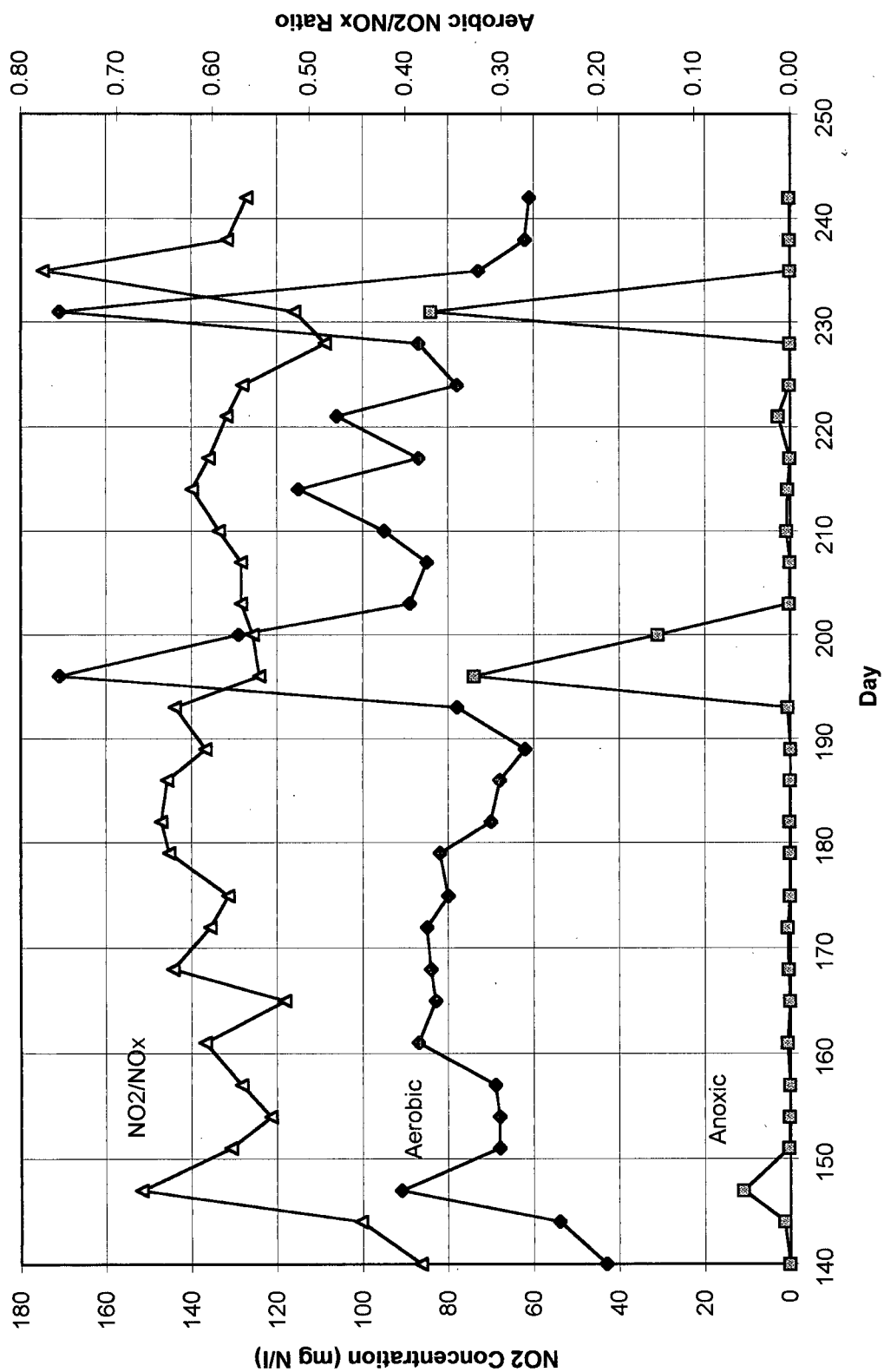
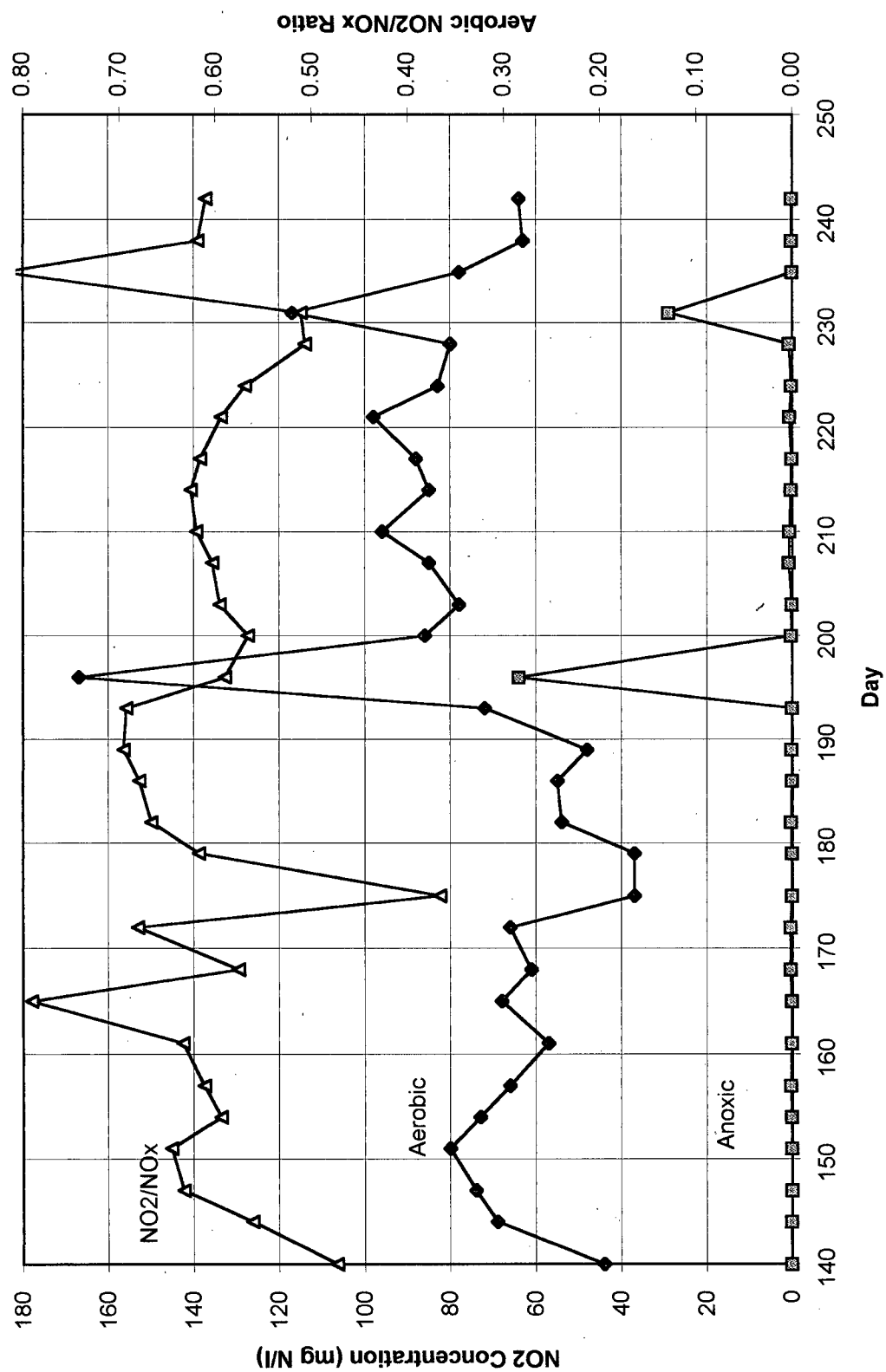


Figure 5.34: MLE Recycle Phase - System #2 ($r = 8:1$)
Anoxic and Aerobic NO₂ Values



System 2 were affected to a greater extent, as the difference between NO_2/NO_x ratios during this period and NO_2/NO_x ratios after day 196 were larger than differences in similar data for System 1. For System 2, the mean NO_2/NO_x ratio for days 179 to 196 was 0.66; for the period between days 200 and 221 it was 0.60. System 1 had average values of 0.63 and 0.59 for the same two periods, respectively. This may suggest that relatively low "free" ammonia concentrations in the aerobic reactor, compared to much higher levels in the anoxic reactor, can further inhibit *Nitrobacter*.

5.2.9 Denitrification

The % denitrification occurring in the anoxic reactor can be calculated by dividing the amount of NO_x removed in the anoxic reactor by the mass of NO_x entering the anoxic reactor. Figures 5.35 and 5.36 show the % denitrification achieved in systems 1 and 2. Both systems were able to consistently remove virtually 100% of the NO_x entering the anoxic reactors, providing sufficient methanol was available. Increases in recycle ratio from 6:1 to 7:1 and 8:1, with the corresponding reduction in anoxic AHRT's, did not result in decreased denitrification performance.

Elefsiniotis et al (1989) found that denitrification performance became very unstable when recycle ratios in identical systems were increased beyond 6:1 and anoxic AHRT's reduced below 1.71 hours; denitrification varied between almost 0 and 100%. The present study found that stable and complete NO_x removal could be achieved with anoxic AHRT's as low as 1.43 hours, with a recycle ratio of 8:1. The large fraction of nitrite in the return sludge (i.e. $\text{NO}_2/\text{NO}_x = 0.6$) may have contributed to consistent denitrification in the current study. Turk (1986) also found evidence to support this hypothesis; he found that nitrite reduction rates were 63% higher than nitrate reduction rates. Aerobic nitrite accumulation, caused by "free" ammonia inhibition of *Nitrobacter*, likely did not occur in the earlier study (Elefsiniotis et al 1989), since the leachate being treated contained only about 250 mg N/L of ammonia.

Specific denitrification rates are also shown in Figures 5.35 and 5.36. These rates vary in an almost identical manner as the specific nitrification rates shown in Figures 5.29 and 5.30. The reason for the similarity is that the denitrification rate is a function of the anoxic NO_x load, which, in turn is dependent

Figure 5.35: MLE Recycle Phase - System #1 ($r = 7:1$)
 % Denitrification and Specific Denitrification Rate

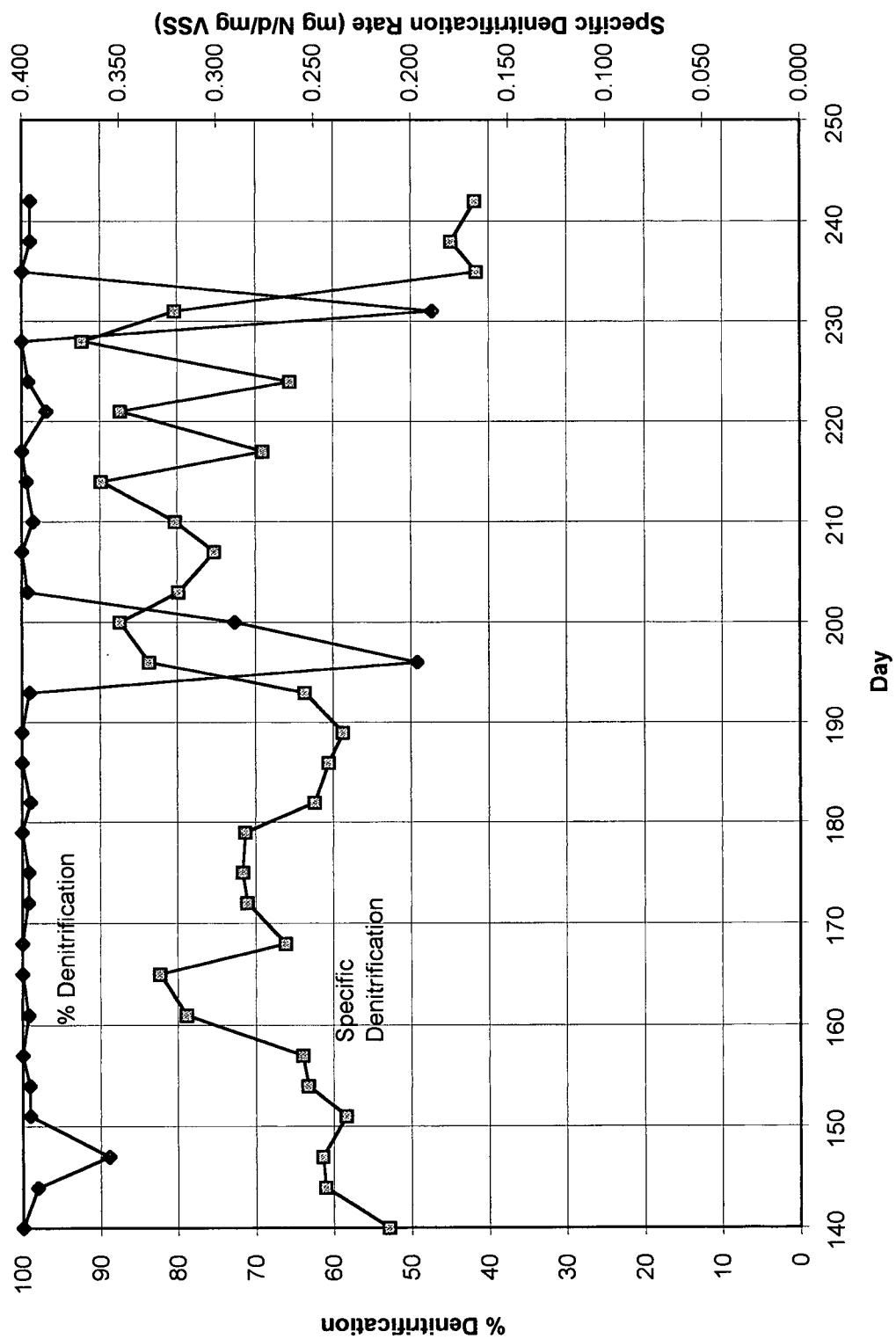
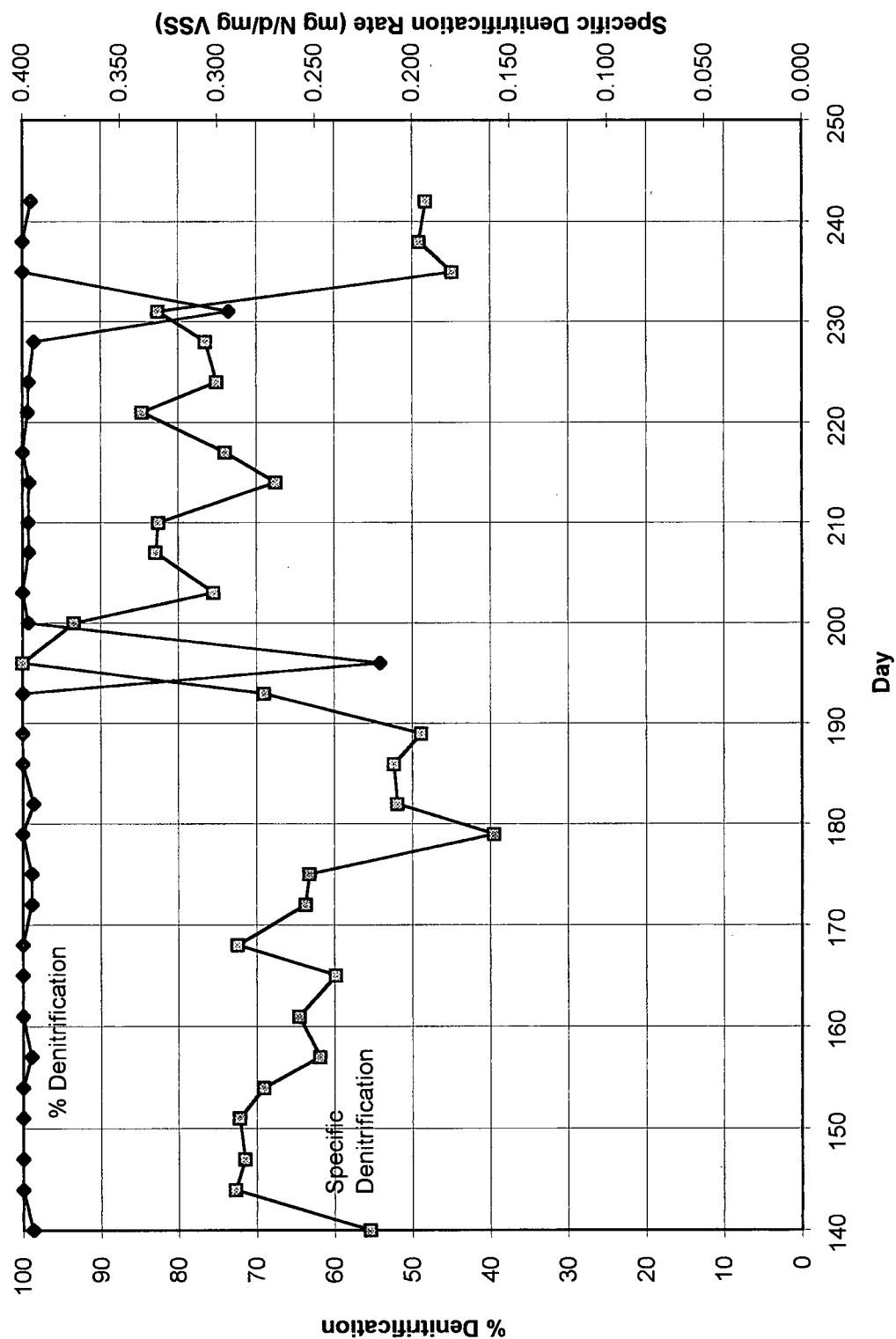


Figure 5.36: MLE Recycle Phase - System #2 ($r = 8:1$)
 % Denitrification and Specific Denitrification Rate



on the % nitrification. The specific nitrification rate is related to the % nitrification, since they share the same numerator. Between days 140 and 157, when both systems were operating with a recycle ratio of 6:1, the specific denitrification rate for System 1 (average of 0.25 mg N/d/mg VSS) was slightly lower than System 2 (average of 0.29 mg N/d/mg VSS), since System 1 had anoxic VSS concentrations that were about 1000 mg/L higher than those of System 2.

Between days 203 and 221, when nitrification had been restored and denitrification was 100%, both systems had specific denitrification rates of about 0.32 mg N/d/mg VSS, on average. The specific denitrification rates, as with the specific nitrification rates discussed earlier, displayed random fluctuations even though anoxic VSS levels were increasing during this period. By comparison, Azevedo (1993) found rates of 0.46 and 0.40 mg N/d/mg VSS, when treating leachate containing 1000 mg N/L of ammonia in systems with SRT's of 10 and 20 days.

Specific denitrification rates in both systems dropped sharply after day 231, to about 0.18 mg N/d/mg VSS. Reductions in anoxic NO_x loads resulting from reduced leachate ammonia concentrations were partly responsible for the reduction in the specific denitrification rates. Increases in methanol loading to remove excess NO_x also increased anoxic VSS levels and, therefore, also contributed to lowering the specific denitrification rates.

The denitrification of nitrified sludge returned from the clarifier to the anoxic reactor requires biodegradable organic carbon. Heterotrophic denitrifying bacteria need organic carbon to act as an electron donor for energy production and a carbon source for cell synthesis. The leachate used in this study contained low concentrations of biodegradable organic carbon (i.e. BOD₅ < 40 mg O₂/L); therefore, methanol was used as a carbon supplement. Methanol was selected because an earlier study at the University of British Columbia (Carley and Mavinic 1991) found that methanol resulted in "effective and trouble free" denitrification compared to some other organic carbon sources (e.g. glucose, brewer's yeast). Methanol is also the most commonly used external carbon source used in denitrification systems (EPA 1993).

The amount of organic carbon required to denitrify the return sludge can be expressed as the ratio of methanol added to the anoxic reactors, in terms of COD, divided by the amount of NO_x removed (i.e. COD:NO_x). The COD of the leachate is not included in this calculation because of the insignificant amount of biodegradable organic carbon contained within this particular leachate. The complete reduction of nitrate to nitrite, and then to nitrogen gas, theoretically requires 3.7 mg COD/mg NO₃-N (Azevedo 1993). Nitrite reduction alone requires 2.3 mg COD/mg NO₂-N.

Methanol loadings to the systems were usually slightly higher than actually required for complete denitrification, to ensure that any potential deficiencies in denitrification performance were due to the increased recycle ratios and decreased anoxic AHRT's, and not the result of carbon shortages. Methanol loadings were gradually reduced after complete denitrification was restored in both systems by day 203. Between days 203 and 228, an average COD:NO_x ratio of 2.9 mg COD/mg NO_x-N resulted in the removal of virtually 100% of the NO_x entering the anoxic reactor in System 1. Similarly, a mean 2.7 mg COD/mg NO_x-N ratio resulted in 100% anoxic NO_x removal in System 2. Further reductions in methanol loadings caused a loss of complete denitrification in both systems on day 231, when methanol loadings were less than 2.3 mg COD/NO_x-N.

The average NO₂/NO_x ratios for mixed liquor in the aerobic reactors (Section 5.2.8), hence return sludge, during this period was about 0.60 in both systems. Therefore, the theoretical COD:NO_x requirement for denitrification can be calculated to be $(3.7 \text{ mg COD/mg NO}_3\text{-N})(0.40) + (2.3 \text{ mg COD/mg NO}_2\text{-N})(0.60) = 2.9 \text{ mg COD/mg NO}_x\text{-N removed}$. The theoretical value compares closely to those obtained in this study. The amount of methanol required for complete denitrification in this study was found to be slightly less than the amount determined by Azevedo (1993). He found COD:NO_x ratios of 3.5 mg COD/mg NO_x-N were necessary to denitrify similar leachate containing 1000 mg N/L when using identical systems with recycle ratios of 6:1. Turk and Mavinic (1986) determined methanol requirements of 2.80 mg COD/mg NO₂-N for nitrite reduction and 4.95 mg COD/mg NO₃-N for nitrate reduction.

The higher rate of clarifier recycle flow in System 2 should theoretically require more methanol to denitrify the extra NO_x returned to the anoxic reactor. However, subtle differences in system performance (i.e. ammonia assimilation and actual NO_x available for denitrification) negated any notable differences in methanol requirements between the systems.

Anoxic pH levels, shown earlier in Figures 5.21 and 5.22, remained fairly constant during the recycle phase and were in the range of 8.3 to 8.5 the majority of the time in both systems. The approximate 1.0 increase above aerobic pH levels, which were maintained at about 7.5 using pH/pump controllers, was due to alkalinity production during denitrification in the anoxic reactors. Interestingly, anoxic pH levels in System 2 decreased noticeably during the period of nitrification inhibition between days 175 and 196. Reduced NO_x production during this period would have reduced the amount of alkalinity returned to the anoxic mixed liquor during denitrification, thus resulting in lower pH values. Nitrification inhibition was less severe in System 1; hence anoxic pH levels were not as greatly affected.

5.2.10 System NO_x Removal

As indicated in the previous section, nitrified sludge from the clarifier is returned to the anoxic reactor for denitrification in the MLE process. The effluent from such systems still contains NO_x because only some fraction of the nitrified sludge can be returned to the anoxic reactor. The effluent NO_x concentration can be estimated using the following equation (EPA 1993):

$$\text{effluent NO}_x \text{ (mg N/L)} = (\text{leachate ammonia, mg N/L}) / (Q + r \cdot Q)$$

where:

Q = leachate flow
r = clarifier recycle ratio

Actual effluent NO_x levels will be slightly lower than those estimated using the above equation because some of the leachate ammonia is assimilated by bacteria for cell synthesis and is not available for conversion into NO_x. Similarly, some ammonia may be "stripped" from the leachate in the aerobic reactor and is not available for nitrification.

The above equation illustrates that higher rates of clarifier recycle flow, hence larger "r" values, theoretically result in lower effluent NO_x concentrations, all else being equal in a well operated system. For a given leachate ammonia concentration, increasing the recycle ratio from 6:1 to 7:1 would result in a 13% reduction in effluent NO_x levels; an increase from 6:1 to 8:1 would yield a 22% reduction, and so on. An 8:1 recycle ratio should produce effluent with NO_x levels 11% lower than those of a 7:1 system.

The purpose of the MLE Recycle Phase was to determine if larger recycle ratios actually result in lower effluent NO_x concentrations, when treating leachate containing approximately 1200 mg N/L of ammonia. However, the presence of ammonia in effluents from both systems makes this determination very difficult, since not all of the NO_x that could potentially be produced was actually available for denitrification. Larger effluent ammonia concentrations result in lower effluent NO_x levels, and vice versa, for a given recycle ratio.

One way to compare effluent quality of the two systems is to calculate the total amount of inorganic nitrogen in the effluents. Total inorganic nitrogen is the sum of ammonia and NO_x concentrations. This calculation approximates the total amount of NO_x that would be in the effluent if the residual effluent ammonia would have been converted to NO_x (i.e. complete nitrification). Once complete denitrification was reestablished on day 203, and omitting data from day 231, the mean total effluent inorganic nitrogen concentration for System 1 (days 203 to 242) was 192 mg N/L; the mean value for System 2 was 171 mg N/L. The effluent nitrogen concentrations were "corrected" to account for small dilution effects caused by addition of various chemicals to the systems. Day 231 was omitted because of elevated NO_x values caused by methanol shortages in both systems. A t-test conducted on the mean differences in the data (Appendix C) concluded that there was a significant difference in the amount of inorganic nitrogen contained in the effluents. A similar test (Appendix C) concluded that differences in ammonia loadings to the systems were insignificant during this period.

The results of this analysis are difficult to interpret. Figures 5.31 and 5.32 indicate that System 2 almost always had lower aerobic, hence effluent, NO_x concentrations than System 1. In addition, Figures 5.19

and 5.20 show that, after nitrification was reestablished on day 196, System 2 usually had much lower aerobic ammonia concentrations than System 1. Higher VSS levels in System 2, compared to System 1, may have been able to assimilate a greater mass of ammonia, thus lowering the actual amount of NO_x produced during nitrification and, therefore, resulting in lower effluent NO_x concentrations. A t-test conducted on the mean differences in the anoxic NO_x load data (Appendix C) concluded that there was not a significant difference in the amount of NO_x entering the anoxic reactors for denitrification. Hence, the higher recycle rate used in System 2 may not have contributed directly to the lower effluent inorganic nitrogen concentrations as predicted by the above equation, but may have produced indirect benefits, through ammonia reduction and less NO_x production.

Further difficulties with data interpretation become apparent when examining data prior to the period when the clarifier recycle flows were increased. When System 1 was using a 6:1 recycle ratio and achieving complete denitrification (days 140 to 157), the mean total effluent inorganic nitrogen concentration was 156 mg N/L. Under similar conditions (days 130 to 157), System 2 produced effluent containing a mean concentration of 140 mg N/L. Lower recycle ratios are theoretically expected to result in higher, and not lower, effluent nitrogen concentrations. Therefore, based on the above findings, no evidence exists to support the theory that increasing recycle ratios from 6:1 to 7 or 8:1 automatically results in lower effluent NO_x concentrations. It appears that several operational variables are at play when using an MLE - type process to treat high ammonia wastes, to achieve maximum ammonia reductions and lowest possible NO_x levels in the final effluent.

5.3 Bardenpho Phase

This section presents and discusses data collected during the Bardenpho Phase (Day 1 - March 8, 1995 to Day 31 - April 7, 1995). The objective of this phase was to verify the ability of a pre and postdenitrification system (i.e. 4 stage Bardenpho Process) to remove essentially 100% of the inorganic nitrogen from leachate containing approximately 1100 mg N/L of ammonia.

5.3.1 System Operation

The Bardenpho Process for nitrogen removal consists of an anoxic reactor (Anoxic #1), aerobic reactor (Aerobic #1), a second anoxic reactor (Anoxic #2), a second aerobic reactor (Aerobic #2) and then a clarifier (Figure 1.2). Mixed liquor from Aerobic #1 was recycled to Anoxic #1 to provide a feed of nitrates/nitrites to the "predenitrification" part of the process. The mixed liquor recycle ratio, or Aerobic #1 recycle ratio, was maintained at 4:1 for the entire Bardenpho phase. Sludge from the clarifier was also returned to Anoxic #1 to prevent the accumulation of solids in the clarifier and maintain sufficient VSS concentrations throughout the system. The clarifier sludge recycle ratio was initially set a 2:1, however, accumulation of solids in the clarifier, as indicated by the rising sludge blanket, necessitated an increase in clarifier sludge recycle flow. Therefore, the clarifier sludge recycle flow was increased on day 12 to yield a recycle ratio of 3:1. The 3:1 clarifier recycle ratio was sufficient to stop the accumulation of solids and maintain a constant sludge blanket elevation within the clarifier. The recycle ratios were defined in this phase as:

$$\text{Aerobic \#1 Recycle Ratio} = (\text{Aerobic \#1 Recycle Flow})/(\text{"Simulated" Leachate Flow})$$

$$\text{Clarifier Recycle Ratio} = (\text{Clarifier Recycle Flow})/(\text{"Simulated" Leachate Flow})$$

where:

"Simulated" Leachate Flow = "base" leachate flow + NH_4Cl solution flow.

The recycle flows were set such that AHRT's in Anoxic #1 and Aerobic #1 were similar to those used during the MLE Recycle Phase. Table 5.6 contains the average reactor AHRT's for the period from day 13 to day 31 when the Aerobic #1 recycle ratio was 4:1 and clarifier recycle ratio was 3:1.

Table 5.6 Bardenpho Reactor Actual Hydraulic Retention Times

Reactor	Mean AHRT (hr)
Anoxic #1	1.64
Aerobic #1	3.17
Anoxic #2	3.25
Aerobic #2	6.34
Clarifier	2.54

The "post denitrification" reactors (i.e. Anoxic #2, Aerobic #2) were the same size as their "predenitrification" counterparts because the two, identical MLE systems were combined to form the

Bardenpho system. The lack of an internal recycle in the "postdenitrification" section results in much longer AHRT's compared to those in the first part of the system. Aerobic #2 is normally a reaeration zone used to strip nitrogen gas from the mixed liquor prior to clarification. Thus, AHRT's in this reactor can be as low as 0.5 hr and still be effective (EPA 1993).

Wasting from Aerobic #1 was conducted at the rate of 0.5 L/d. This resulted in an Aerobic #1 SRT of 20 days and, therefore, was comparable to the wasting rate used during the latter part of MLE Recycle Phase. Similarly, a "simulated" ammonia concentration of about 1100 mg N/L was maintained during the Bardenpho Phase.

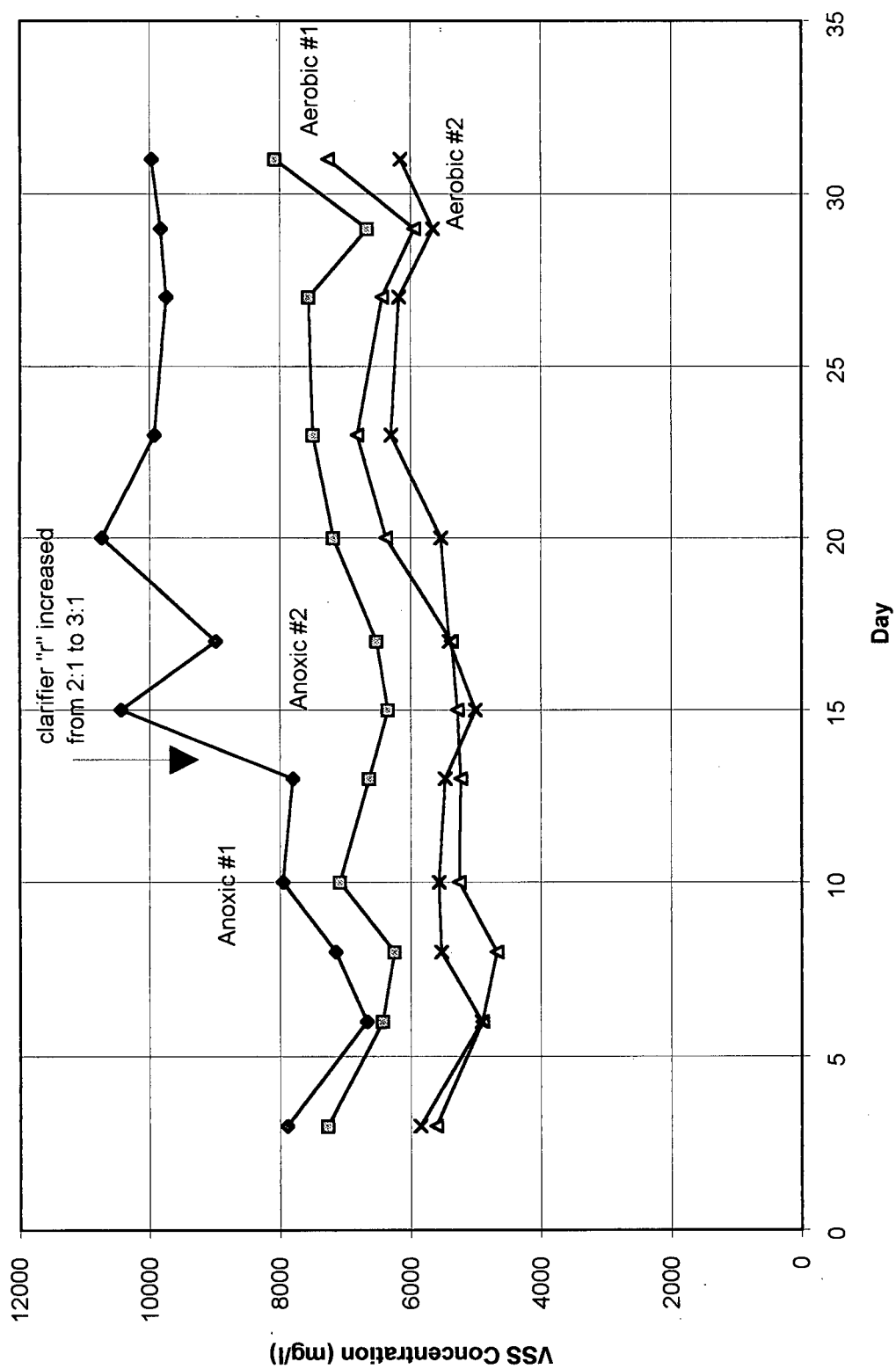
5.3.2 Solids Levels

Reactor VSS levels are shown in Figure 5.37. The effect of increasing the clarifier sludge recycle ratio from 2:1 to 3:1 on day 12 is clearly evident in Anoxic #1; VSS levels increased from about 8000 mg/L to 10000 mg/L, after the clarifier recycle flow was increased. Smaller increases in VSS concentrations also occurred in the other reactors.

Aerobic VSS levels for the Bardenpho system were comparable to those of the MLE systems. NO_x and methanol loadings to Anoxic #1 were about 40% smaller than those received by the anoxic reactors of the MLE systems, due to the smaller amount of returned nitrified mixed liquor/sludge (i.e. recycle ratio of 4:1 versus 7:1 and 8:1). However, VSS levels in Anoxic #1, after the clarifier sludge recycle flow was increased on day 12, were about 2000 mg/L higher than anoxic levels in the MLE systems.

Section 5.2.2 discussed how differences in anoxic and aerobic VSS levels may have been partly due to retention of solids within the overflow tubing connecting the reactors. A Masterflex pump was used to pump mixed liquor from Aerobic #1 to Anoxic #2 in the Bardenpho system. Hence, the amount of solids retained within the pump tubing was extremely small. Figure 5.37 indicates that Anoxic #2 VSS levels were 700 to 1500 mg/L larger than those of Aerobic #1. Rapid growth of heterotrophic denitrifying bacteria within Anoxic #2 was probably responsible for the increase in VSS levels between these two

**Figure 5.37: Bardenpho System
Anoxic and Aerobic VSS Values**



reactors. Anoxic #2 VSS levels were usually about 1300 mg/L larger than those of Aerobic #2. The difference in VSS concentrations between Anoxic #2 and Aerobic #2 may be partly due to retention of solids in the overflow tubing; however, endogenous respiration by heterotrophic bacteria in the carbon limited aerobic reactors may have also contributed to the reduction in VSS levels between anoxic and aerobic reactors.

The VSS/TSS ratios remained essentially constant in all reactors and ranged from 0.85 to 0.88. All reactors had a mean VSS/TSS ratio of 0.86.

Effluent TSS and VSS levels are shown in Figure 5.38. Consistent effluent solids concentrations of between 10 and 20 mg/L were achieved once the system stabilized after the increase in clarifier recycle flow on day 12. Interestingly, similar clarifier performance was achieved with the 7:1 MLE system during the MLE Recycle Phase, even though the clarifier AHRT was 1.27 hrs versus 2.54 hrs for the Bardenpho system.

5.3.3 Ammonia Levels and Removal

Reactor ammonia levels, shown in Figure 5.39, remained relatively constant during the Bardenpho phase. Anoxic #1 levels decreased slightly after day 12, in response to the greater dilution of incoming leachate by the larger amount of clarifier sludge recycle flow.

As with the MLE systems, complete ammonia removal was not achieved in the first aerobic reactor. Aerobic #1 ammonia levels varied from about 15 mg N/L to 25 mg N/L. The amount of ammonia removal in Aerobic #1, shown in Figure 5.40, varied between about 80% and 90% during the Bardenpho phase. The ammonia levels and % ammonia removals in Aerobic #1 were very similar to those of the aerobic reactor of the 7:1 MLE system, when treating leachate also containing about 1100 mg N/L of ammonia. Both systems had virtually identical AHRT's in their respective aerobic reactors, since they shared the same "overall" recycle ratio (i.e. $4:1 + 3:1 = 7:1$).

Figure 5.38: Bardenpho System
Effluent TSS and VSS Values

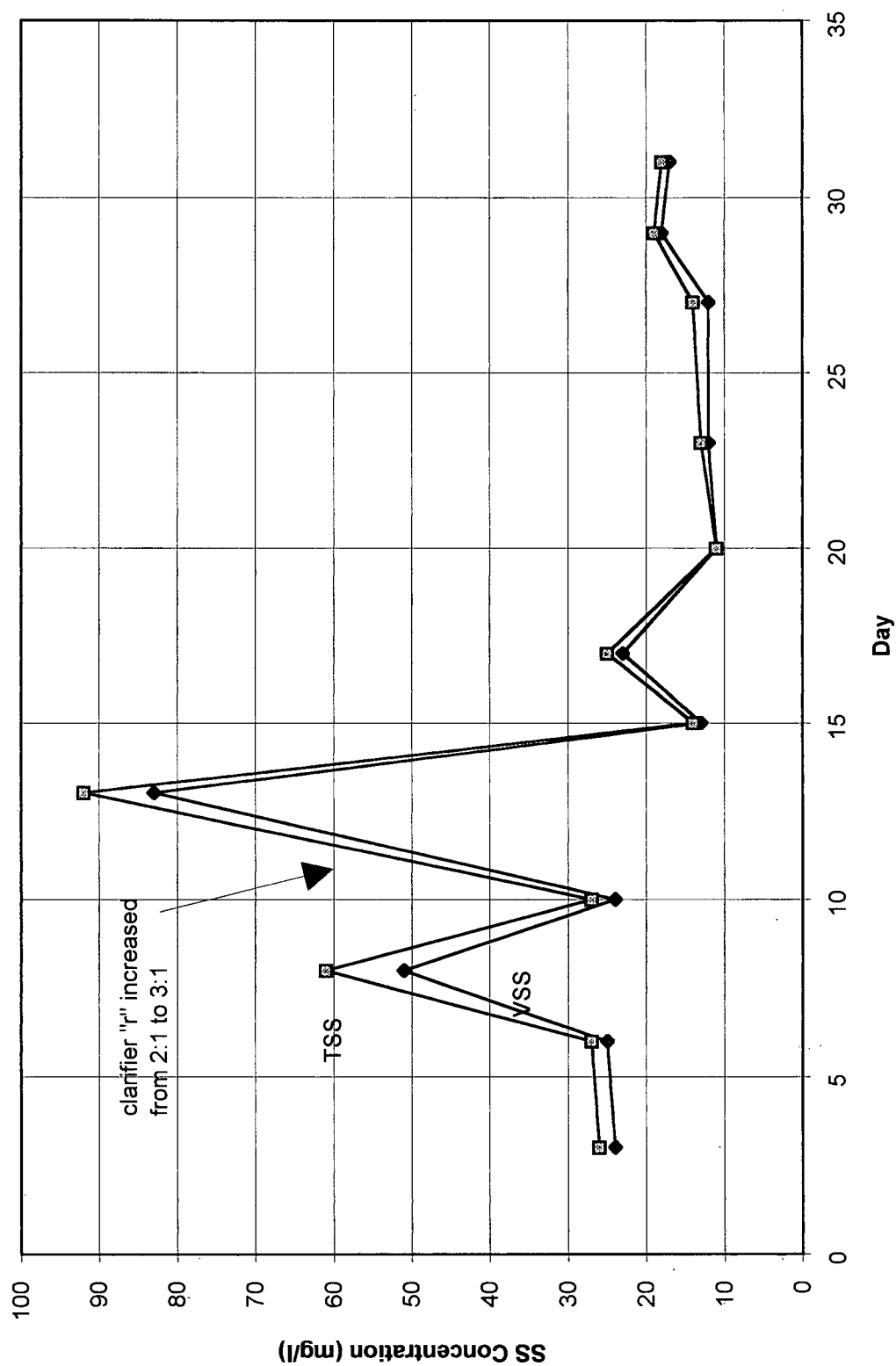


Figure 5.39: Bardenpho System
Anoxic and Aerobic Ammonia Values

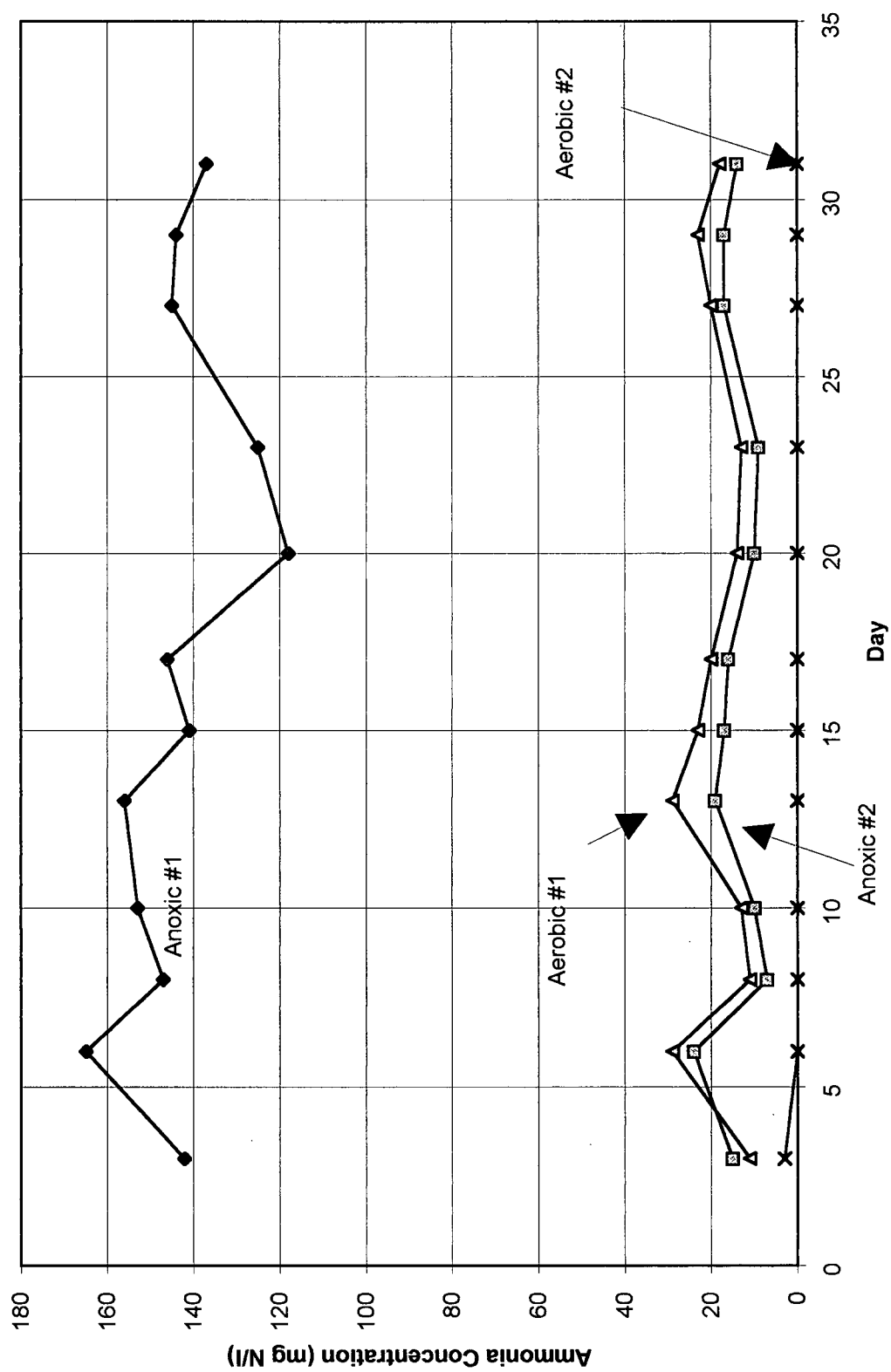
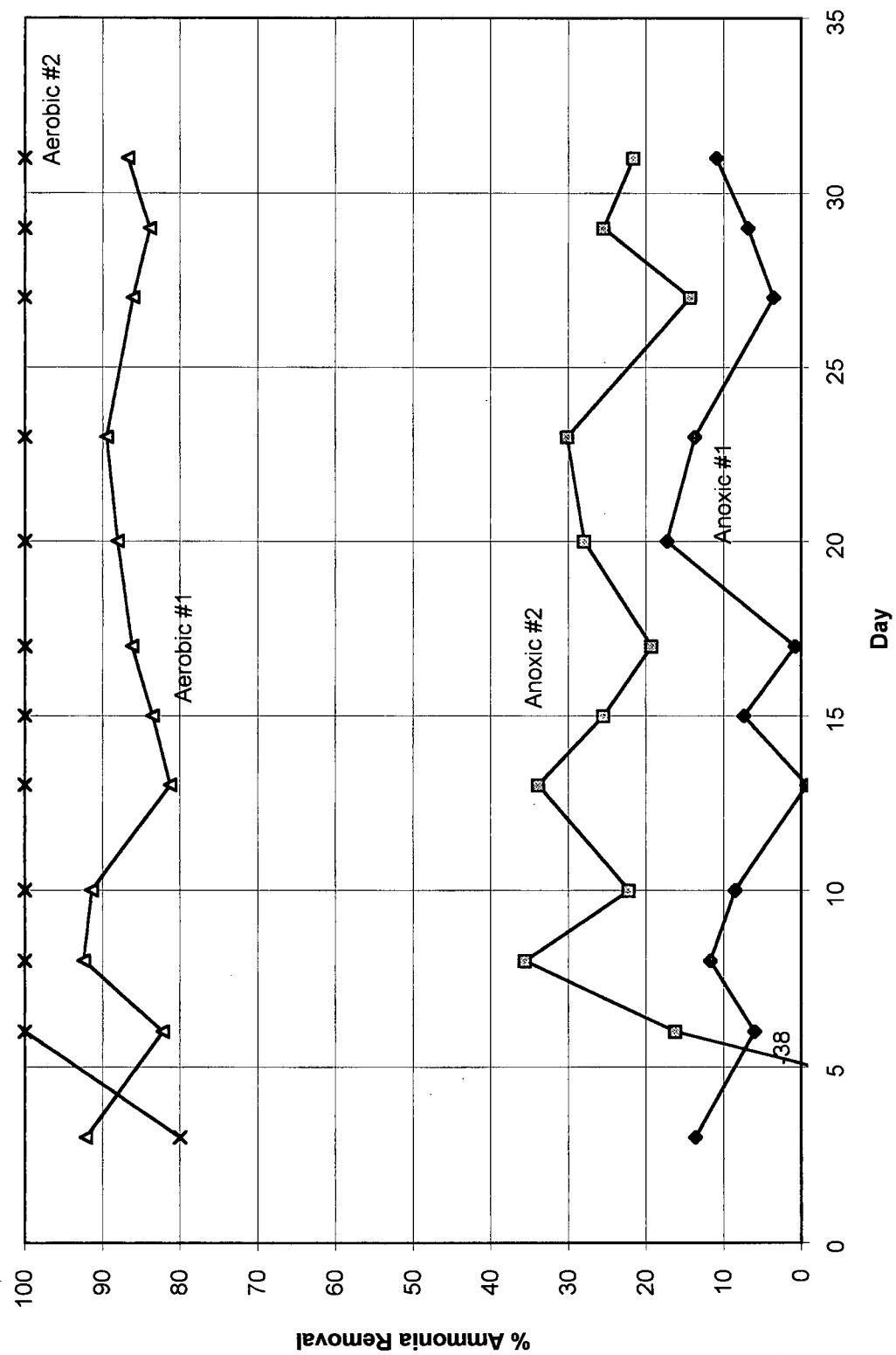


Figure 5.40: Bardenpho System
Anoxic and Aerobic % Ammonia Removal



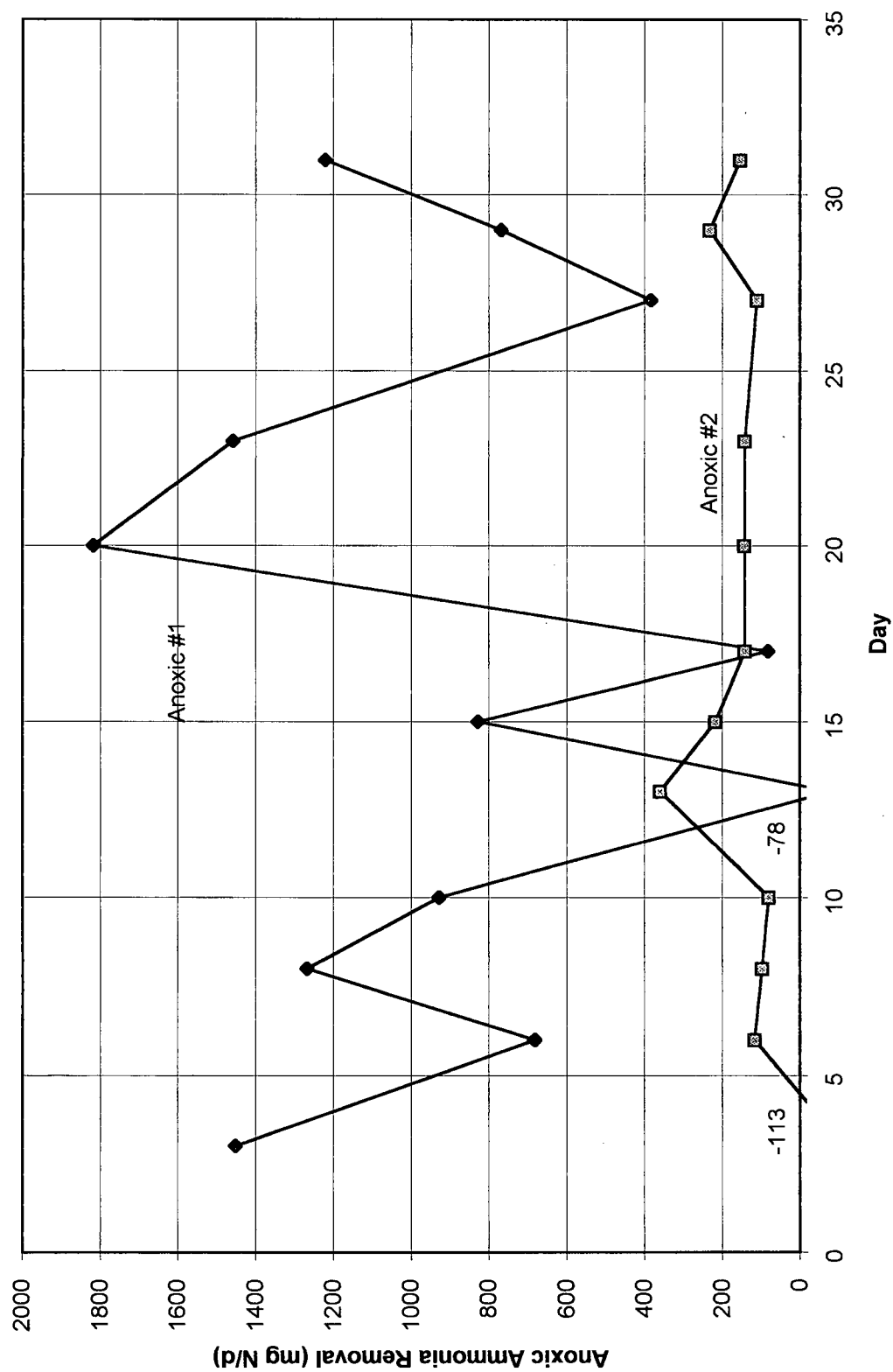
Ammonia levels in Aerobic #2, and thus effluent levels, were essentially zero during the Bardenpho phase. Therefore, Aerobic #2 ammonia removal and thus system ammonia removal was 100%

Figure 5.40 shows that the % ammonia removal in Anoxic #2 was much larger than that of Anoxic #1. Part of the difference can be attributed to the way the % ammonia removal data are calculated. Figure 5.39 indicates that Anoxic #1 ammonia levels were always in excess of 120 mg N/L; Anoxic #2 ammonia levels ranged from about 10 to 20 mg N/L. Therefore, for a given mass of ammonia removed, the calculated % ammonia removal would be significantly different since the calculation is formulated relative to the mass of ammonia entering the reactors.

The actual daily mass of ammonia removed in the anoxic reactors, shown in Figure 5.41, is of greater interest. Ammonia removal in Anoxic #1 was much greater than that of Anoxic #2, although more erratic. Assuming the removal of ammonia in the anoxic reactors is the result of assimilation by heterotrophic denitrifying organisms, similar amounts of ammonia removal would be expected for similar amounts of denitrification. The daily NO_x loads to the anoxic reactors were almost equal, after the clarifier recycle flow was increased on day 12. The mean NO_x load entering Anoxic #1, between days 13 and 31, was 5260 mg N/d; Anoxic #2 was receiving an average of 5031 mg N/d. Hence, methanol loadings to the anoxic reactors were identical during this period. The actual amount of anoxic denitrification (i.e. mg NO_x-N/d removed) was also very similar between days 13 and 31 with mean values of 5093 mg N/d and 4970 mg N/d for Anoxic #1 and Anoxic #2, respectively. A t-test conducted on the mean difference in the removal rates (Appendix C) found no significant difference in the values.

A possible explanation for the large differences in ammonia removal rates may be related to the differences in the AHRT's of the anoxic reactors. The AHRT of Anoxic #2 was essentially twice as long as the AHRT for Anoxic #1. Section 5.2.2 previously illustrated how decreases in AHRT require increases in reactor VSS concentrations to consume the same amount of substrate. Anoxic #1 had an average VSS concentration of 9686 mg/L between days 13 and 31; the mean value for Anoxic #2 was

Figure 5.41: Bardenpho System
Anoxic Ammonia Removal



7062 mg/L. Larger VSS levels in Anoxic #1, compared to those of Anoxic #2, may have caused a greater amount of ammonia assimilation.

5.3.4 Nitrification

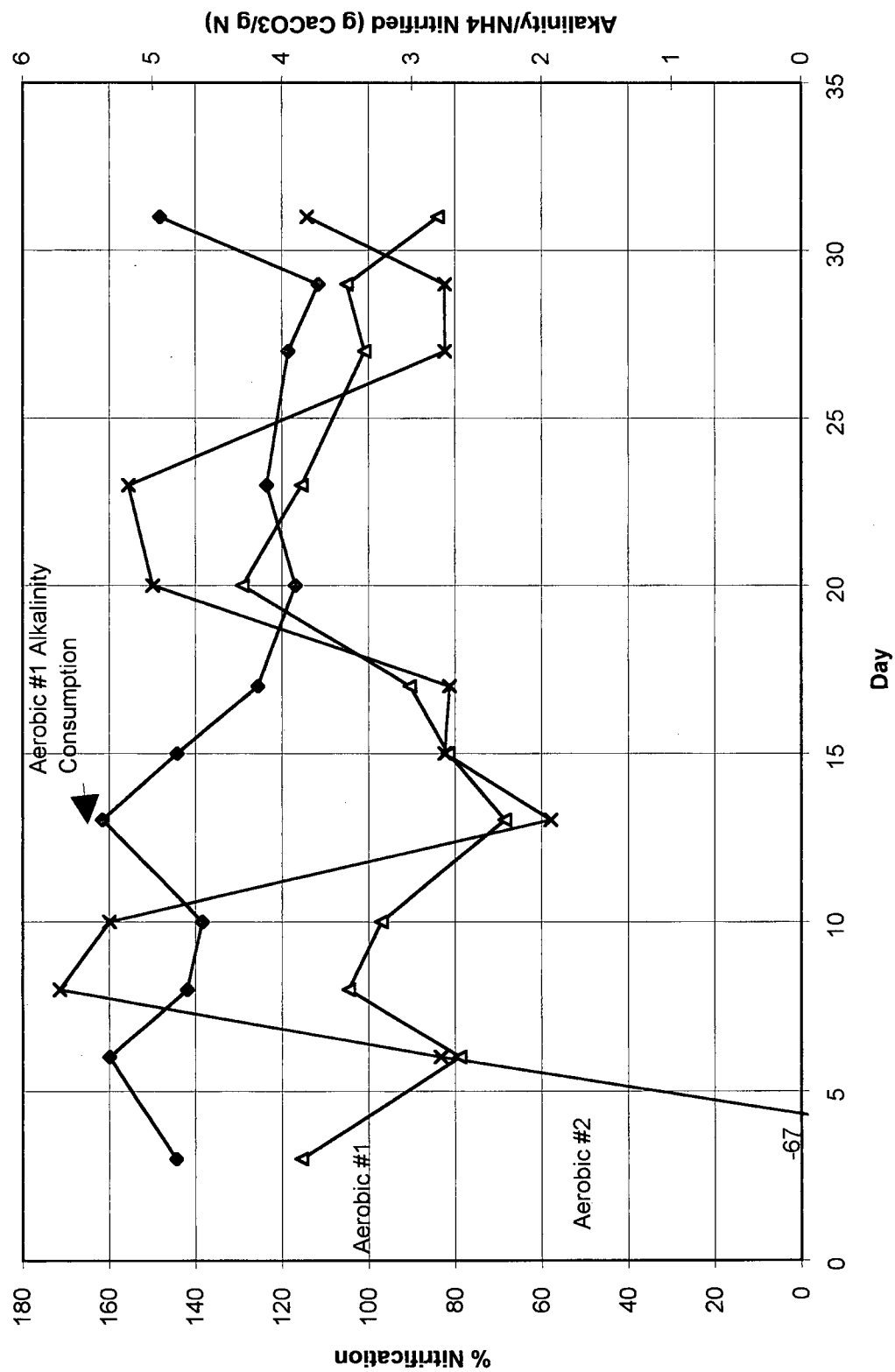
Nitrification performance of the aerobic reactors, expressed as % nitrification, is shown in Figure 5.42. Both reactors displayed fluctuating % nitrification data, even though % ammonia removals (Figure 5.40) were relatively constant. As discussed in Section 5.2.7, % nitrification values exceeding 100% may be due to the conversion of organic nitrogen, released by lysing cells, to ammonia and then nitrified to produce additional NO_x. Wasting from Aerobic #1 (0.5 L/d) yielded an Aerobic #1 SRT of 20 days. However, the system SRT (SSRT), defined by the amount of time solids spend in the entire system, had a mean value of about 71 days during the Bardenpho phase. The long SSRT may have contributed to cell lysing, release of organic nitrogen and ultimately an increase in the amount of NO_x produced during nitrification of the resulting "extra" ammonia.

Figure 5.42 also shows that Aerobic #2 occasionally had much higher % nitrification values than Aerobic #1. The concentration of ammonia entering Aerobic #2 (i.e. 20 mg N/L) was much smaller than that entering Aerobic #1 (i.e. 140 mg N/L); therefore, Aerobic #2 % nitrification values would be more sensitive to the effects of any additional NO_x resulting from conversion of organic nitrogen.

Fluctuations in % nitrification in Aerobic #1 of the Bardenpho system were of similar magnitude to those of the "stabilized" MLE systems. The low aerobic AHRT in the three systems may explain the similar nitrification "instability".

The alkalinity consumed during nitrification in Aerobic #1 is also shown in Figure 5.42. External alkalinity addition was not required for nitrification in Aerobic #2; therefore, alkalinity consumption was not calculated for this reactor. After the clarifier recycle flow was increased on day 12, alkalinity consumption remained fairly constant from day 17 to 29, with values around 4.0 g CaCO₃ per g ammonia-N nitrified. These values are similar to those required by the MLE Systems. The Bardenpho

Figure 5.42: Bardenpho System
% Nitrification and Alkalinity Consumption



system should require less total alkalinity than MLE systems to nitrify similar leachate, since the Bardenpho system has a larger denitrification "potential" that, in turn, can return more alkalinity to the mixed liquor during denitrification. Comparable data between the systems were not available to verify this hypothesis.

The specific nitrification rates of the aerobic reactors are shown in Figure 5.43. Aerobic #1 values were much higher than those of Aerobic #2, because of the higher ammonia concentrations entering Aerobic #1 versus Aerobic #2 (i.e. 140 mg N/L versus 20 mg N/L). In addition, both reactors had similar VSS concentrations. Between days 13 and 31, average VSS levels of 6091 mg/L and 5713 mg/L were present in Aerobic #1 and Aerobic #2, respectively. Therefore, the mass of ammonia removed compared to the mass of solids, was much smaller in Aerobic #2 than Aerobic #1. The average specific nitrification rate for Aerobic #1, for the period from day 13 to day 31, was 0.16 mg N/d/mg VSS; the mean value for Aerobic #2 was 0.01 mg N/d/mg VSS.

5.3.5 NO_x Levels and Removal

Reactor NO_x concentrations are shown in Figure 5.44. Anoxic NO_x concentrations were very low (i.e. < 5 mg N/L), thus indicating essentially complete denitrification of mixed liquor entering the anoxic reactors.

The presence of NO_x in Aerobic #2 indicates nitrification of some of the ammonia leaving Anoxic #2. Aerobic #2 (hence effluent) NO_x concentrations were in the range of 10 to 15 mg N/L. The absence of ammonia in the effluent, combined with almost complete removal of NO_x, meant that the Bardenpho system removed 99% of the total inorganic nitrogen contained within the leachate. The MLE systems, by comparison, were unable to remove all of the ammonia from the leachate and produced effluents containing greater than about 150 mg N/L of total inorganic nitrogen, regardless of recycle ratio utilized in this study. Total inorganic nitrogen removal efficiencies of the MLE systems were in the range of about 80% to 90%.

Figure 5.43: Bardenpho System
Specific Nitrification Rate

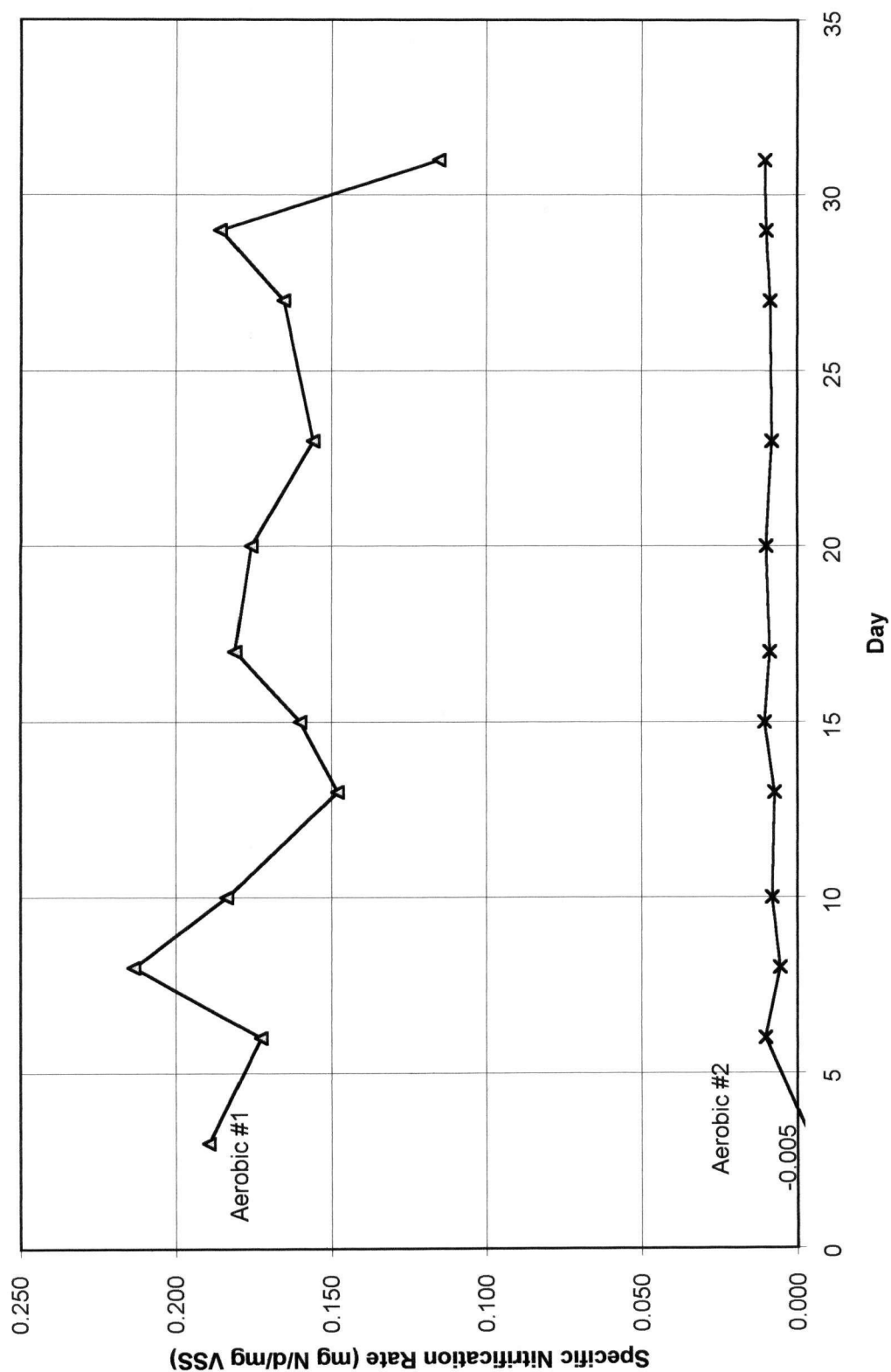
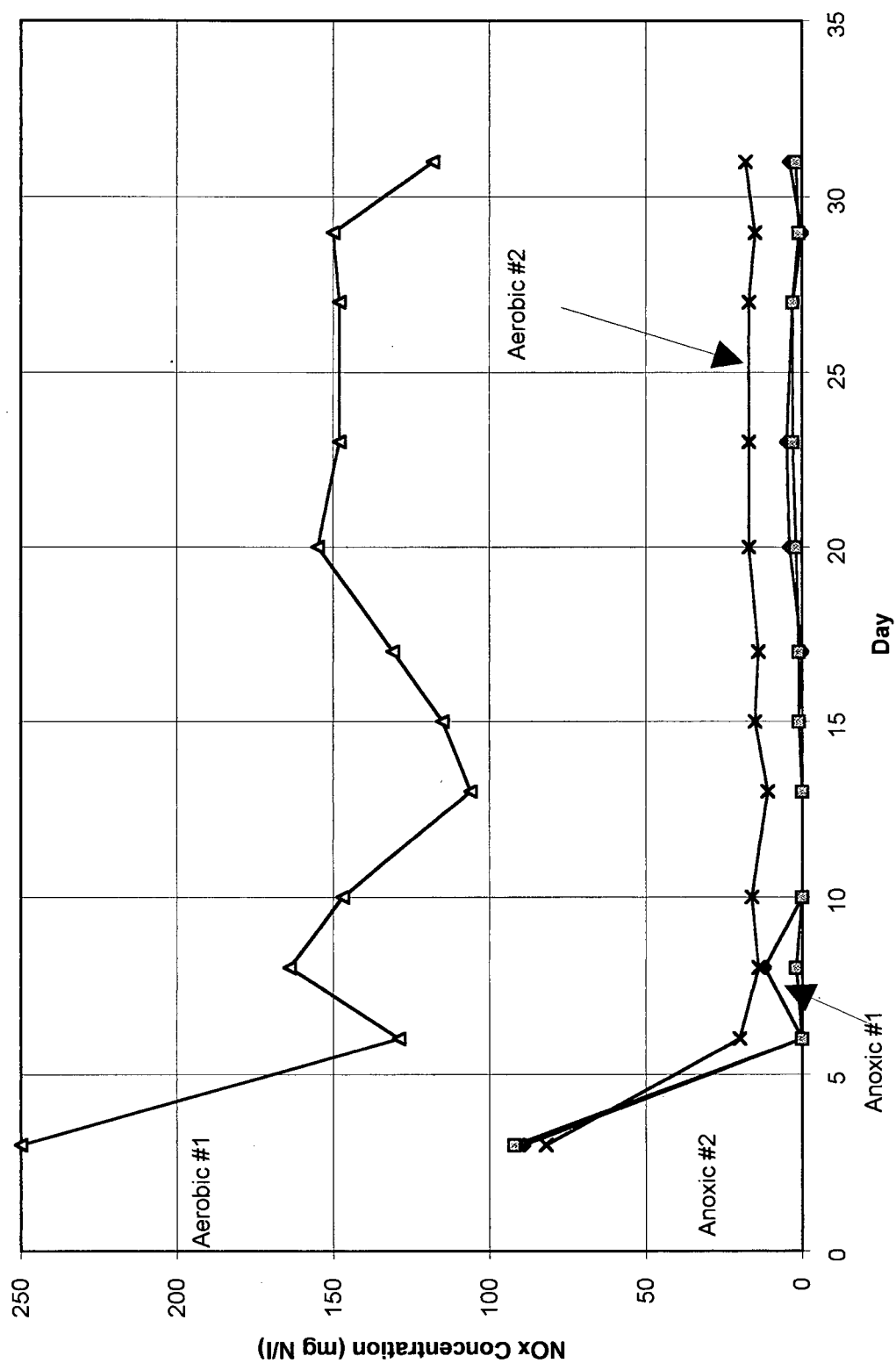


Figure 5.44: Bardenpho System
Anoxic and Aerobic NOx Values



Complete NO_x removal in the Bardenpho system may be attainable, if complete nitrification of the leachate occurred within Aerobic #1, thereby eliminating the production of NO_x in Aerobic #2. This could likely be accomplished by increasing the AHRT of Aerobic #1 by decreasing its recycle flow, or increasing reactor volume. However, ammonia is required by the heterotrophic denitrifying bacteria in Anoxic #2 for cell synthesis. Figure 5.39 shows differences in ammonia concentrations between Aerobic #1 and Anoxic #2 of about 4 to 5 mg N/L. Therefore, a small residual amount of ammonia in Aerobic #1 would be desirable to ensure that denitrification in Anoxic #2 was not "ammonia limited".

Reactor NO₂ levels are shown in Figure 5.45. Similar to the NO_x data, virtually all NO₂ was removed in the anoxic reactors. The presence of significant amounts of NO₂ in Aerobic #1 indicates inhibition of *Nitrobacter* due to recycling of these bacteria through the high "free" ammonia concentrations present in Anoxic #1. The ratio of NO₂ to NO_x in Aerobic #1, also shown in Figure 5.45, remained around 0.60 after the clarifier recycle flow was increased on day 12. Slightly larger NO₂/NO_x ratios before day 17 may be due to higher ammonia (thus "free" ammonia) concentrations present in Anoxic #1, because of less dilution of the leachate provided by the lower clarifier recycle flow. Aerobic NO₂/NO_x ratios of around 0.60 were also found in both MLE systems.

Figure 5.45 indicates that NO₂ levels in Aerobic #2, and the effluent, were also very low (i.e. 1 mg N/L). Aerobic #2 NO₂/NO_x ratios were always less than 0.09. The AHRT of Aerobic #2 was twice that of Aerobic #1; therefore, inhibitory effects on *Nitrobacter* may have been offset by the longer time available for nitrite oxidation. In addition, *Nitrobacter* may have been able to recover from their "inhibition" in the time it took the mixed liquor to travel from Aerobic #1, through Anoxic #2 and into Aerobic #2.

5.3.6 Denitrification

Denitrification performance of the anoxic reactors is shown in Figure 5.46. Percent denitrification in both anoxic reactors was greater than about 95% most of the time. More complete NO_x removal (i.e. 100% denitrification) could have been attained; however, methanol loadings were "finely tuned" in order to

Figure 5.45: Bardenpho System
Anoxic and Aerobic NO₂ Values

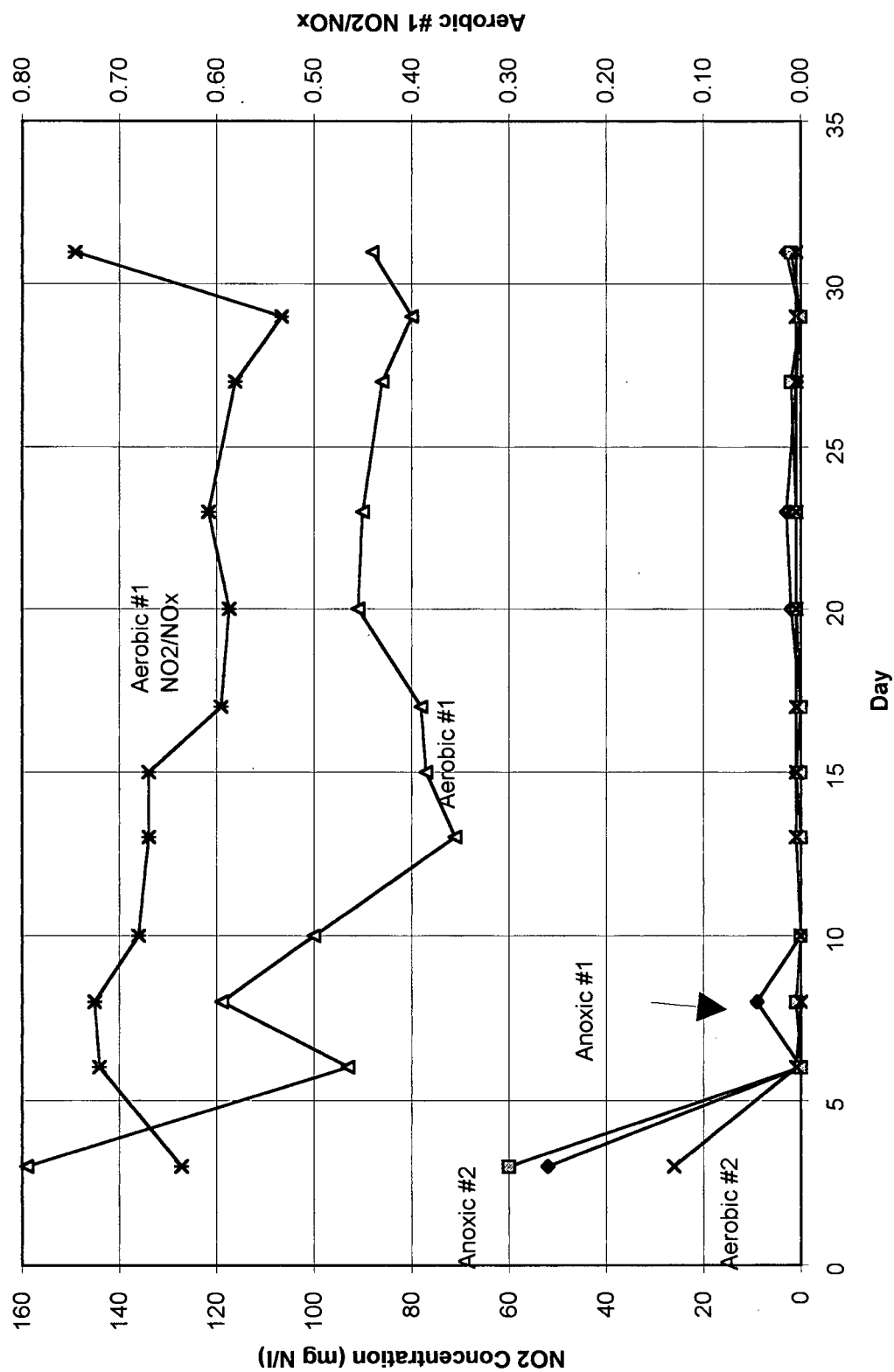
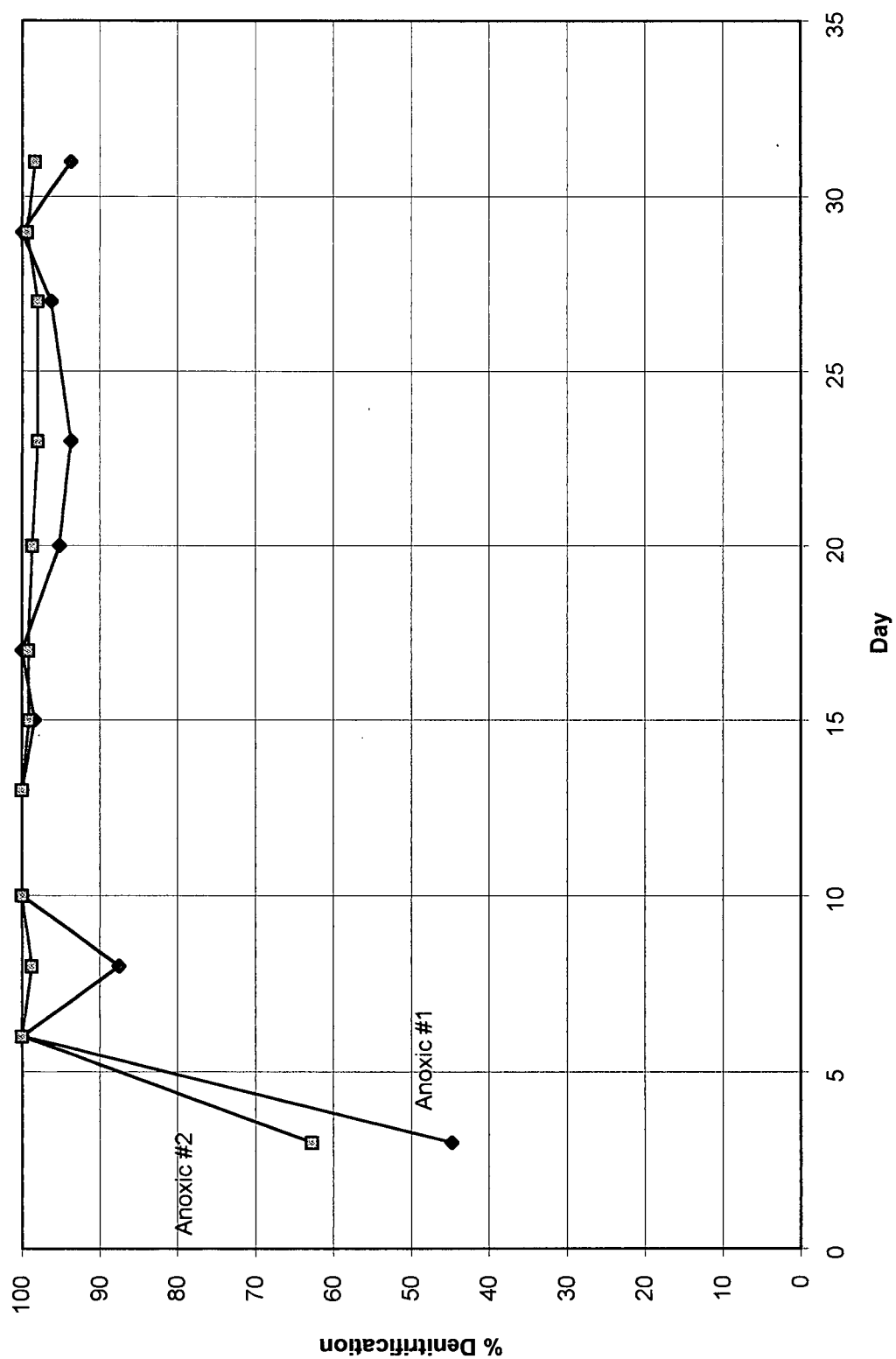


Figure 5.46: Bardenpho System
% Denitrification



determine minimum organic carbon requirements for denitrification. Therefore, there were small methanol shortages that sometimes caused residual NO_x to remain in the anoxic reactors.

Methanol loadings were essentially at their minimum between days 15 and 31. During this period the mean Anoxic #1 COD:NO_x requirement for basically "complete" denitrification was 3.7 mg COD/mg NO_x removed; Anoxic #2 had a average requirement of 3.8 mg COD/mg NO_x removed. These values are notably larger than the COD:NO_x requirements determined for the MLE systems: System 1 = 2.8 mg COD/mg NO_x removed; System 2 = 2.7 mg COD/mg NO_x removed. Both the Bardenpho and MLE systems had NO₂/NO_x ratios of about 0.60 in the nitrified return sludge/mixed liquor; thus similar unit methanol demands were expected. Therefore, the higher methanol requirements for the Bardenpho system was probably related to the introduction of oxygen into the anoxic reactors. The MLE systems had nitrified sludge from the clarifiers returned to the anoxic reactors for denitrification. The dissolved oxygen concentration of this return sludge was close to zero, given the "anoxic" conditions that exist at the bottom of a clarifier. However, nitrified mixed liquor entering both anoxic reactors in the Bardenpho system came directly from Aerobic #1. Dissolved oxygen concentrations in Aerobic #1 were always maintained above 2 mg O₂/L, to ensure nitrification was not inhibited. Therefore, residual oxygen originating in Aerobic #1 was entering both anoxic reactors. The dissolved oxygen concentrations in the anoxic reactors themselves were occasionally checked with a D.O. probe and always found to be < 0.3 mg O₂/L.

The presence of oxygen in a denitrification environment has a direct impact on the heterotrophic bacteria responsible for denitrification. These bacteria have the ability to use either oxygen, nitrate or nitrite as electron acceptors in the production of energy, by means of an electron transport chain (EPA 1993). Energy production is higher (i.e. more efficient) when oxygen is the electron acceptor. Therefore, bacteria will preferentially utilize oxygen over nitrate or nitrite. This results in the consumption of methanol beyond that required to denitrify the NO_x because the oxygen is utilized prior to the NO_x. Hence, COD:NO_x requirements would be larger than those strictly required for the reduction of NO_x. In

addition, the larger methanol requirements, due to the presence of both oxygen and NO_x, would result in higher reactor solids levels.

The specific denitrification rates for the anoxic reactors are shown in Figure 5.47. Anoxic #1 initially had larger specific denitrification rates than Anoxic #2, because Anoxic #1 NO_x loads (shown in Figure 5.48) were larger than those for Anoxic #2, prior to the increase in clarifier recycle flow on day 12. In addition, Anoxic #1 VSS levels were only about 500 to 1000 mg/L greater than those of Anoxic #2 during this time. However, after day 12 anoxic NO_x loads to both reactors were very similar and within about 4% of each other. Anoxic #1 VSS levels were up to about 2500 mg/L larger than those of Anoxic #2 after day 12 (Figure 5.37). Therefore, the specific denitrification rates of Anoxic #2 increased above those of Anoxic #1 between days 13 and 31. Once the anoxic NO_x loads stabilized after day 20, Anoxic #1 had an average specific denitrification rate of 0.11 mg N/d/mg VSS between days 20 and 31; the mean value for Anoxic #2 was 0.15 mg N/d/mg VSS.

5.3.7 pH Levels

pH levels, shown in Figure 5.49, varied considerably between reactors. The pH in Aerobic #1 was maintained at approximately 7.5 by the addition of sodium bicarbonate, using a pH/pump controller. The pH in Anoxic #1 varied from 8.1 to 8.3 after the clarifier recycle flow was increased on day 12. Similar to the MLE systems (anoxic pH's of 8.3 to 8.5), the increase in pH between Aerobic #1 and Anoxic #1 was due to the return of alkalinity to the mixed liquor during denitrification in Anoxic #1. Figure 5.49 also indicates that slight pH variations in Aerobic #1, due to minor instability in the pH/pump controller, cause almost identical variations in Anoxic #1 pH levels.

The pH levels in Anoxic #2 were significantly higher than those of Anoxic #1, and ranged from 8.8 to 9.0. Alkalinity production in both reactors would have been similar after day 12, because the amount of anoxic denitrification (i.e. mg NO_x-N/d removed) occurring within the reactors was essentially identical (Section 5.3.3). However, nitrification, accompanied by the destruction of alkalinity, occurring within Aerobic #2 reduced the pH to between 7.8 and 8.1 from the higher pH's of Anoxic #2; hence, the clarifier sludge

Figure 5.47: Bardenpho System
Specific Denitrification Rate

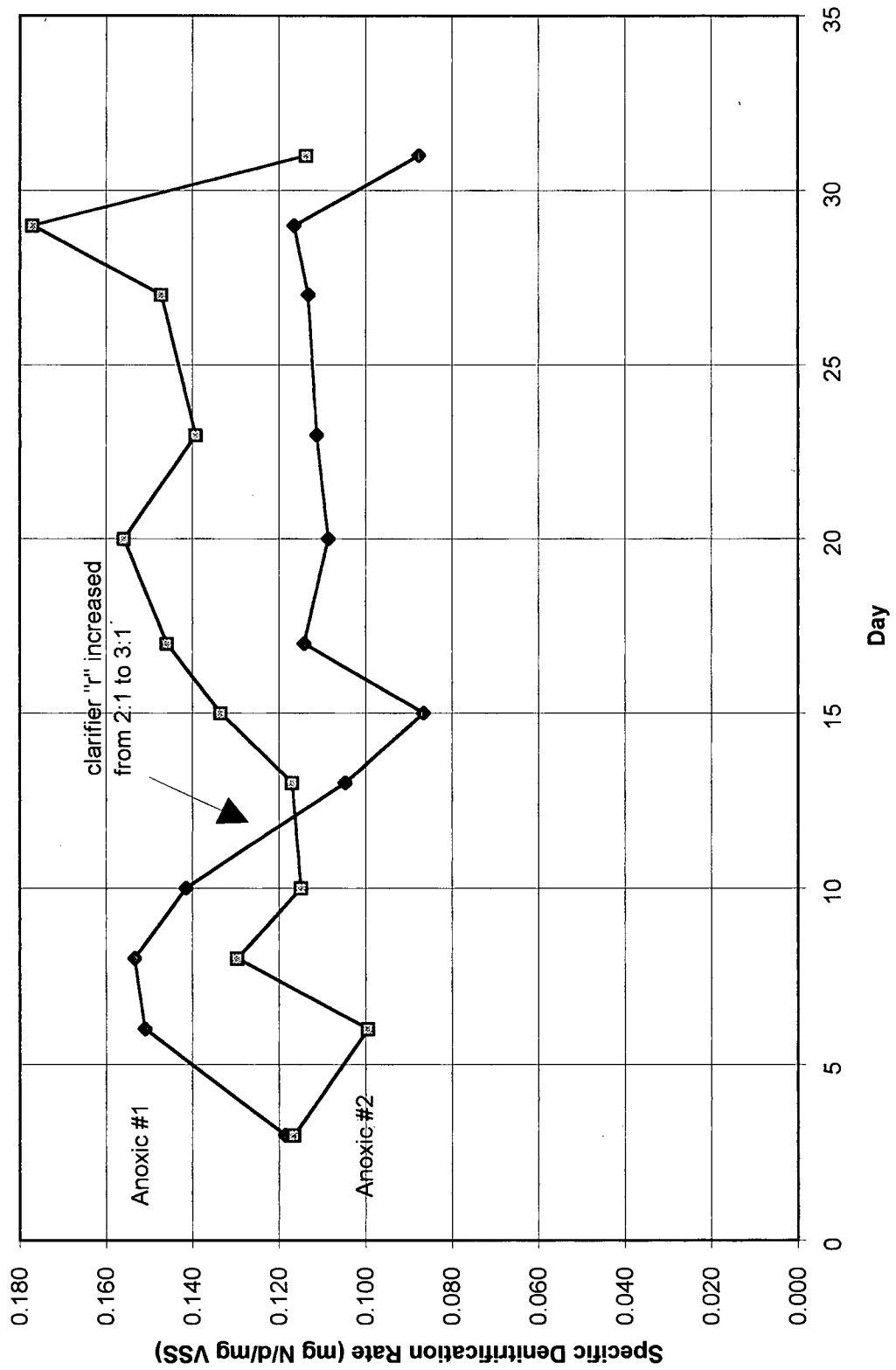


Figure 5.48: Bardenpho System
Anoxic NOx Load

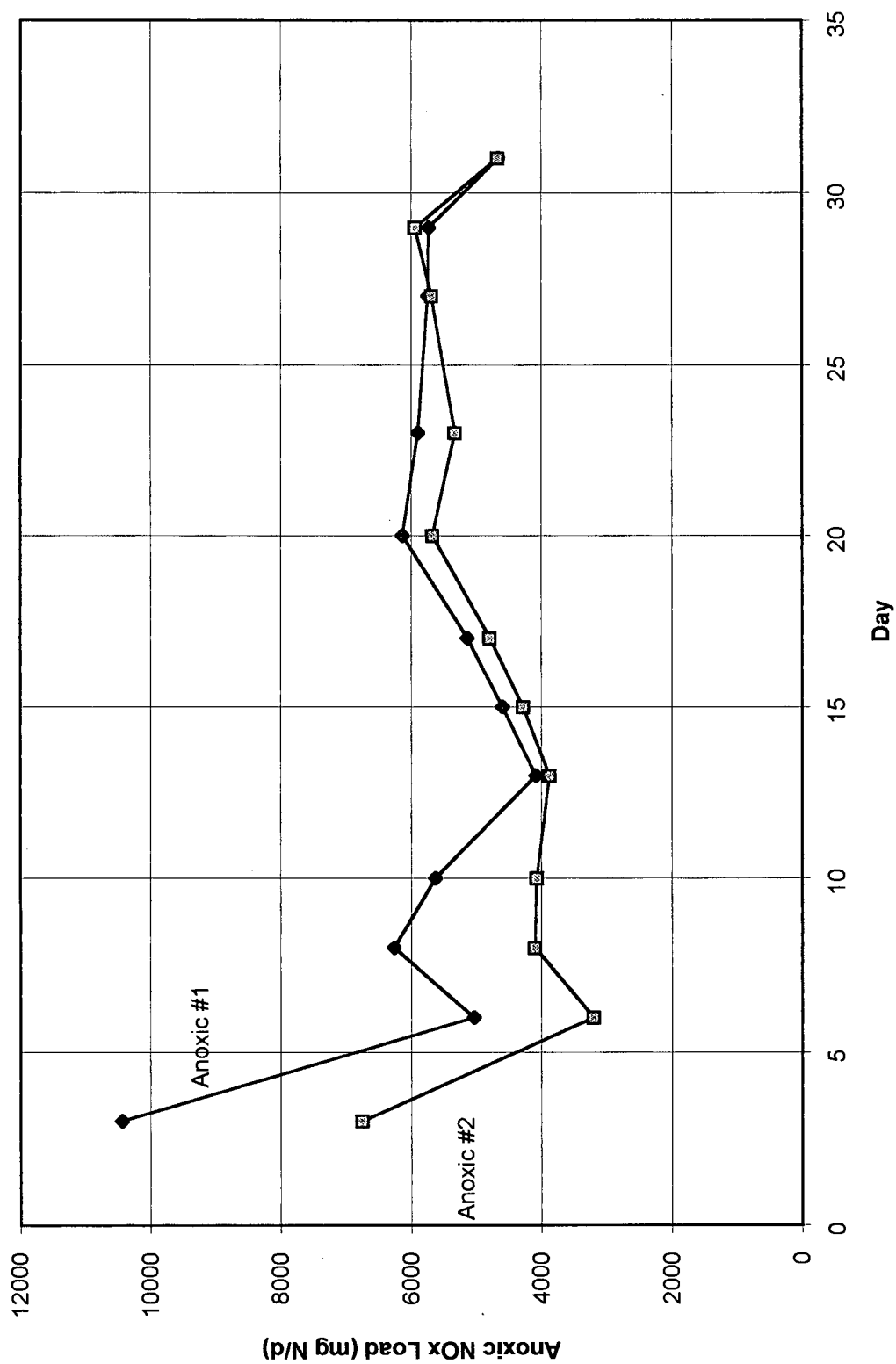
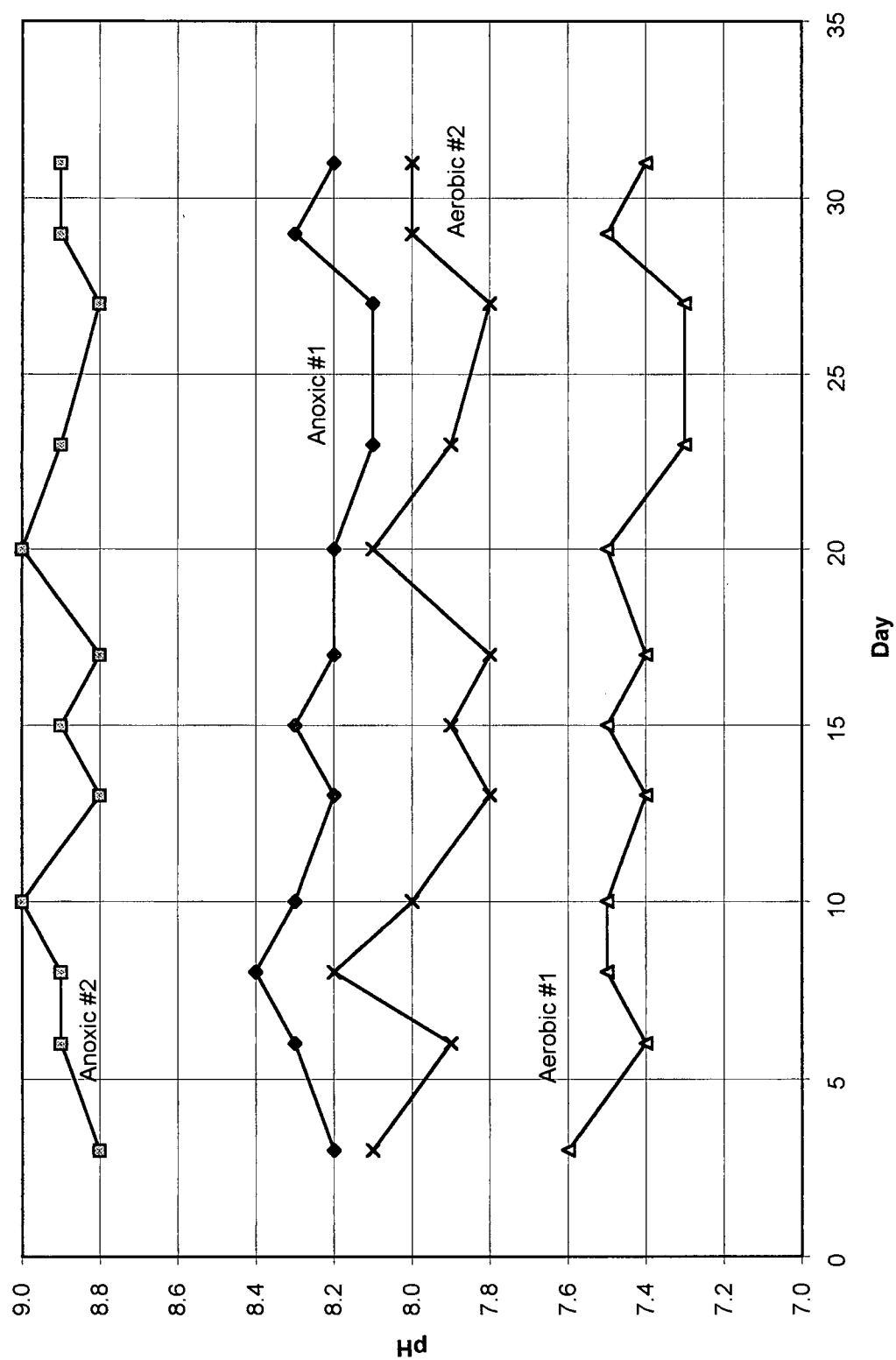


Figure 5.49: Bardenpho System
Anoxic and Aerobic pH Values



returned to Anoxic #1 may have contained less alkalinity than the mixed liquor recycled from Aerobic #1. Therefore, the clarifier return sludge may have "diluted" the contents of Anoxic #1, in terms of alkalinity concentrations, resulting in lower pH levels for similar levels of denitrification.

Anoxic pH values of 8.8 have been found to result in denitrification rates that were about 25% of the maximum rate; denitrification rates at pH levels of 8.2 were found to be 60% of the maximum rate (EPA 1993). However, specific denitrification rates, discussed in the previous section, were higher for Anoxic #2 than Anoxic #1. Therefore, the elevated pH within Anoxic #2 does not appear to have negatively impacted denitrification performance in this particular study.

Chapter 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The purpose of this research was to investigate the nitrogen removal capabilities of two different biological process configurations treating leachate containing up to approximately 1200 mg N/L of ammonia. The first configuration was a predenitrification system known as the Modified Ludzack-Ettinger (MLE) process. The MLE Startup Phase consisted of starting up two MLE systems treating "base" leachate containing about 230 mg N/L of ammonia, followed by incrementally increasing leachate ammonia concentrations to a "target" level of 1200 mg N/L. Aerobic SRT's of 13 days were used in both systems during the MLE Startup Phase. Increases in clarifier sludge recycle flows to yield recycle ratios of 7:1 (System 1) and 8:1 (System 2), from 6:1, were investigated as a means to reduce effluent NO_x concentrations during the MLE Recycle Phase. Aerobic SRT's of 10 days were initially used in both systems during the MLE Recycle Phase.

A pre and postdenitrification system, known as the Bardenpho process, was the second configuration evaluated. The Bardenpho Phase examined the overall nitrogen removal capabilities of this process when treating leachate containing about 1100 mg N/L of ammonia.

The following summarizes the results obtained from the different phases of this study:

6.1.1 MLE Startup Phase

1. Both MLE systems experienced nitrification failure, during the initial attempt at reaching the "target" leachate concentration, when leachate ammonia concentrations were increased from about 800 mg N/L to 1000 mg N/L and anoxic methanol loadings were held constant at levels required for complete denitrification of the "base" (i.e. 230 mg N/L ammonia) leachate.

2. Increases in anoxic methanol loading rates, implemented in order to remove excess NO_x from the anoxic reactors and thus assimilate additional ammonia, raised reactor pH levels due to the return of alkalinity from increased denitrification. Aerobic pH levels in System 1 increased from 7.5 to 8.3, resulting in an increase in the "free" ammonia fraction from 1.2% to 7.2%. Similarly, System 2 aerobic pH levels increased from 7.6 to 8.5 resulting in an increase in the "free" ammonia fraction from 1.5% to 11.0%. Increases in aerobic "free" ammonia concentrations appeared to have resulted in the inhibition of *Nitrosomonas* organisms responsible for ammonia oxidation.
3. The second attempt at reaching the "target" leachate ammonia concentration of 1200 mg N/L was successful in both systems. The length of time it took to increment the ammonia concentration from that of the "base" leachate to 1000 mg N/L was similar during both attempts. However, during the second attempt, anoxic methanol loadings were boosted at the same time leachate ammonia concentrations were increased. Anoxic ammonia removal efficiencies of up to 30% were achieved when methanol loadings were increased in similar proportions to leachate ammonia increases. Anoxic removal efficiencies were generally less than 10% during the initial attempt at reaching the "target" ammonia concentration. Increased ammonia assimilation during reduction of NO_x in the anoxic reactors helped to mitigate the rapid accumulation of ammonia, and "free" ammonia, in the systems, thus preventing apparent inhibition of *Nitrosomonas*.
4. Anoxic "free" ammonia values, after the second successful attempt at reaching the "target" leachate ammonia concentration, eventually reached levels higher than those present when nitrification basically "shut down" during the initial attempt. Therefore, recycling of *Nitrosomonas* bacteria, contained within the clarifier return sludge, through the anoxic reactors, does not appear to singly contribute to the inhibition of these organisms.

6.1.2 MLE Recycle Phase

1. Both MLE systems produced effluents containing between 10 and 20 mg N/L of ammonia when operated with a clarifier sludge recycle ratio of 6:1 and treating leachate containing approximately

1200 mg N/L of ammonia. Reactor and effluent ammonia levels rapidly rose in both systems approximately 2 weeks after clarifier sludge recycle ratios were increased from 6:1 to 7:1 and 8:1. Reductions in aerobic AHRT's from 3.42 hr ($r = 6:1$) to 3.18 hr ($r = 7:1$) and 2.84 hr ($r = 8:1$) may have caused insufficient contact time for stable nitrification. An increase in aerobic SRT from 10 days to 15 days quickly reduced ammonia levels in both systems. A further increase in aerobic SRT to 20 days did not remove the residual ammonia remaining in the effluents. System 1 effluent contained an average of about 60 mg N/L of ammonia; the mean ammonia concentration in effluent from System 2 was about 40 mg N/L.

2. Reactor VSS levels, particularly aerobic, increased more rapidly in System 2 ($r = 8:1$) than in System 1 ($r = 7:1$) when the aerobic SRT's were increased from 10 to 20 days. Actual VSS concentrations were also significantly greater in System 2 compared to System 1. Shorter reactor AHRT's in System 2 (i.e. kinetic influences) combined with a higher clarifier recycle flow, taking a larger mass of solids out of "storage" from the clarifier and into the reactors, may have caused the difference in solids levels between the two systems.
3. Reductions in leachate ammonia concentration by between 70 and 80 mg N/L lowered effluent ammonia concentrations in System 1 to about 20 mg N/L and 10 mg N/L in System 2. Further reductions in leachate ammonia concentrations, for a total reduction of approximately 200 mg N/L, did not reduce effluent ammonia concentrations in either system.
4. Stable and complete (i.e. 100%) anoxic denitrification was consistently achieved, provided adequate methanol was available for denitrification, in both MLE systems regardless of recycle ratio (up to 8:1) or anoxic AHRT (as low as 1.43 hr). COD:NO_x requirements for complete denitrification were found to be, on average, 2.9 mg COD/mg NO_x-N for System 1 ($r = 7:1$) and 2.7 mg COD/mg NO_x-N for System 2 ($r = 8:1$). Aerobic NO₂/NO_x ratios were around 0.60 in both systems.

5. System 2 ($r = 8:1$) effluent total inorganic nitrogen concentrations, determined using effluent ammonia and NO_x data, were found to be statistically different (i.e. lower) than those of System 1 ($r = 7:1$). However, no statistical difference was found in the anoxic NO_x loads. Therefore, lower effluent inorganic nitrogen concentrations found in System 2 may have been caused by greater assimilation of ammonia, due to higher reactor VSS levels, and less production of NO_x , rather than more NO_x being denitrified (as suggested by the larger recycle ratio).
6. Systems 1 and 2, when operated with a 6:1 recycle ratio, produced effluents containing mean total inorganic nitrogen concentrations of about 160 mg N/L and 140 mg N/L, respectively. However, when System 1 was using $r = 7:1$ the mean effluent total inorganic nitrogen concentration was about 190 mg N/L; an average value of about 170 mg N/L was achieved by System 2 using $r = 8:1$. Thus, increases in recycle ratios did not correspond to decreased effluent total inorganic nitrogen concentrations.
7. Effluent suspended solids concentrations usually remained below 30 mg/L regardless of recycle ratio. However, shorter clarifier AHRT's associated with using a recycle ratio of 8:1 ($\text{AHRT} = 1.14$ hr) resulted in greater instability in clarifier performance.

6.1.3 Bardenpho Phase

1. The Bardenpho System was capable of producing effluent containing < 1 mg N/L of ammonia, between about 10 and 15 mg N/L of NO_x , and less than 20 mg/L of suspended solids when treating leachate containing 1100 mg N/L of ammonia. Aerobic #1 and clarifier sludge recycle ratios of 4:1 and 3:1, respectively, were used with an Aerobic #1 SRT of 20 days. Large Aerobic #2 SS levels (i.e. 6000 mg/L), combined with efficient solids separation in the clarifier, necessitated increasing the clarifier sludge recycle ratio from 2:1 to 3:1 to prevent accumulation of solids in the bottom of the clarifier.

2. Aerobic #2 (hence effluent) NO_2/NO_x ratios were always < 0.09 , even though Aerobic #1 ratios were around 0.60. An Aerobic #2 AHRT that was twice that of Aerobic #1, combined with possible "recovery" time between aerobic reactors, allowed *Nitrobacter* to more completely oxidize available nitrite.
3. Residual NO_x remaining in the effluent was the result of incomplete ammonia removal in Aerobic #1. Ammonia levels in Aerobic #1 were in the range of 15 to 20 mg N/L; however, approximately 5 mg N/L of ammonia was removed in Anoxic #2. Therefore, a small residual amount of ammonia remaining in Aerobic #1 would be desirable to ensure denitrification in Anoxic #2 was not ammonia limited.
4. Minimum COD: NO_x requirements for complete denitrification in both anoxic reactors was in the range of 3.7 to 3.8 mg COD/mg $\text{NO}_x\text{-N}$ removed. The presence of oxygen in mixed liquor entering the anoxic reactors likely caused larger COD: NO_x requirements than those determined for the MLE systems.

6.2 Conclusions

The following conclusions, in response to the objectives outlined in Section 1.5, can be made:

1. Increases in MLE clarifier recycle ratios to 7:1 and 8:1, from 6:1, resulted in higher effluent ammonia (i.e. 50 mg N/l) and total inorganic nitrogen concentrations (i.e. 180 mg N/l); ammonia and total inorganic nitrogen concentrations of < 20 mg N/l and < 160 mg N/l, respectively, were attained when clarifier recycle ratios were set at 6:1. Total inorganic nitrogen removal efficiencies ranged from 80% to 90% at the increased clarifier recycle ratios;
2. Increases in MLE aerobic SRT's from 10 days to 15 days restored ammonia removal "stability"; 20 day aerobic SRT's did not further remove residual ammonia from the effluents;

3. Reductions in MLE leachate ammonia concentrations resulted in lower effluent ammonia concentrations. However, actual reductions in leachate ammonia levels yielded much smaller reductions in effluent ammonia levels;
4. The Bardenpho system produced effluent containing less than 1 mg N/l of ammonia and 15 mg N/l of NO_x; total inorganic nitrogen removal efficiencies of 99% were consistently achieved.

6.3 Recommendations

The following recommendations can be made based on results obtained from the three phases of this study:

1. An investigation should be conducted regarding "free" ammonia toxicity of ammonia oxidizing *Nitrosomonas* bacteria under both anoxic and aerobic conditions, similar to those experienced in the present research. Relative "degrees" of inhibition, for given constant "free" ammonia concentrations, would be useful in the design and operation of such systems.
2. Further research examining the treatment of high ammonia (i.e. > 1000 mg N/L) leachate using the Bardenpho Process should be conducted. Reactor sizes, recycle rates and AHRT's should be investigated in order to minimize reactor volumes, while maximizing ammonia and NO_x removal as well as nitrite accumulation, so as to reduce methanol requirements for denitrification.
3. The effects of reduced operating temperatures on the Bardenpho Process should be investigated. In particular, the effects of SRT and anoxic methanol loading on system performance at low temperatures should be studied.
4. Recent landfill design and operations have resulted in leachates containing extremely high concentrations of organics (COD > 100,000 mg/L) and ammonia (> 6,000 mg N/L) (Robinson,

1995). The ability of a Bardenpho system to treat such highly concentrated leachates should be investigated.

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APPENDICIES

- Appendix A: Calculation Definitions
- Appendix B: Raw and Calculated Data
- Appendix C: Statistical Analyses

APPENDIX A

CALCULATION DEFINITIONS

MLE Process Calculations

$$\text{Anoxic Overflow (l/d)} = [(\text{leachate flow, l/d}) + (\text{clarifier recycle flow, l/d})] + [[(\text{NH}_4\text{Cl feed flow, ml/hr}) + (\text{methanol feed flow, ml/hr}) + (\text{PO}_4 \text{ feed flow, ml/hr})] * (24 \text{ hr/d})(1 \text{ l}/1000\text{ml})]$$

$$\text{Aerobic Overflow (l/d)} = (\text{Anoxic overflow, l/d}) + [(\text{NaHCO}_3 \text{ flow, ml/hr})(24 \text{ hr/d})(1 \text{ l}/1000\text{ml})]$$

$$\text{Anoxic AHRT (hr)} = [(5 \text{ l})/(\text{Anoxic overflow, l/d})](24 \text{ hr/d})$$

$$\text{Aerobic AHRT (hr)} = [(10 \text{ l})/(\text{Aerobic overflow, l/d})](24 \text{ hr/d})$$

$$\text{Clarifier AHRT (hr)} = [(4 \text{ l})/(\text{Aerobic overflow, l/d})](24 \text{ hr/d})$$

$$\text{O-PO}_4 \text{ Loading (g P/d)} = [(\text{PO}_4 \text{ feed conc, g P/l})(\text{PO}_4 \text{ feed flow, ml/hr})(24 \text{ hr/d})(1 \text{ l}/1000\text{ml})] + [(\text{leachate PO}_4 \text{ conc, mg P/l})(\text{leachate flow, l/d})(1 \text{ g}/1000 \text{ mg})]$$

$$\text{Anoxic Methanol Load (g COD/d)} = (\text{methanol feed conc, ml/l})(\text{methanol feed flow, ml/hr})(791.5 \text{ mg CH}_3\text{OH/ml CH}_3\text{OH})(1.5 \text{ mg COD/mg CH}_3\text{OH})(24 \text{ hr/d})(1 \text{ l}/1000\text{ml})(1 \text{ g}/1000\text{mg})$$

$$\text{Simulated Leachate Ammonia Concentration (mg N/l)} = [[(\text{NH}_4\text{Cl feed conc, g NH}_4\text{Cl/l})(\text{NH}_4\text{Cl feed flow, ml/hr})(24 \text{ hr/d})(1 \text{ l}/1000\text{ml})(14 \text{ g N}/53.5 \text{ g NH}_4\text{Cl})(1000 \text{ mg/g})] + [(\text{leachate NH}_4 \text{ conc, mg N/l})(\text{leachate flow, l/d})]] / [[(\text{NH}_4\text{Cl feed flow, ml/hr})(24 \text{ hr/d})(1 \text{ l}/1000\text{ml})] + (\text{leachate flow, l/d})]$$

$$\text{Ammonia Load (g N/d)} = [[(\text{NH}_4\text{Cl feed conc, g NH}_4\text{Cl/l})(\text{NH}_4\text{Cl feed flow, ml/hr})(24 \text{ hr/d})(1 \text{ l}/1000\text{ml})(14 \text{ g N}/53.5 \text{ g NH}_4\text{Cl})(1000 \text{ mg/g})] + [(\text{leachate NH}_4 \text{ conc, mg N/l})(\text{leachate flow, l/d})]] * (1 \text{ g}/1000\text{mg})$$

Anoxic NH₄ Removal Rate (mg N/d) = [(NH₄Cl feed conc, g NH₄Cl/l)(NH₄Cl feed flow, ml/hr)(24 hr/d)(1 l/1000ml)(14 g N/53.5 g NH₄Cl)(1000 mg/g)] + [(leachate NH₄ conc, mg N/l)(leachate flow, l/d)] + [(Aerobic NH₄ conc, mg N/l)(Clarifier Recycle Flow, l/d)] - [(Anoxic NH₄ conc, mg N/l)(Anoxic Overflow, l/d)]

Aerobic NH₄ Removal Rate (mg N/d) = [(Anoxic NH₄ conc, mg N/l)(Anoxic Overflow, l/d)] - [(Aerobic NH₄ conc, mg N/l)(Aerobic Overflow, l/d)]

% Anoxic NH₄ Removal = [Anoxic NH₄ Removal Rate, mg N/d] / [(NH₄Cl feed conc, g NH₄Cl/l)(NH₄Cl feed flow, ml/hr)(24 hr/d)(1 l/1000ml)(14 g N/53.5 g NH₄Cl)(1000 mg/g)] + [(leachate NH₄ conc, mg N/l)(leachate flow, l/d)] + [(Aerobic NH₄ conc, mg N/l)(Clarifier Recycle Flow, l/d)] * 100 %

% Aerobic NH₄ Removal = [(Anoxic NH₄ conc, mg N/l)(Anoxic Overflow, l/d)] - [(Aerobic NH₄ conc, mg N/l)(Aerobic Overflow, l/d)] / [(Anoxic NH₄ conc, mg N/l)(Anoxic Overflow, l/d)] * 100 %

% System NH₄ Removal = [(Simulated Leachate Ammonia Conc, mg N/l) - (Effluent NH₄ conc, mg N/l)] / [Simulated Leachate Ammonia Conc, mg N/l] * 100 %

Anoxic NO_x Load (mg N/d) = [(Leachate flow, l/d)(Leachate NO_x conc, mg N/l) + [(Clarifier recycle flow, l/d)(Aerobic NO_x conc, mg N/l)]

Anoxic Denitrification Rate (mg N/d) = [Anoxic NO_x Load, mg N/d] - [(Anoxic overflow, l/d)(Anoxic NO_x conc, mg N/l)]

Anoxic Specific Denitrification Rate (mg N/d/mg VSS) = [Anoxic Denitrification Rate, mg N/d] / [(Anoxic VSS conc, mg/l)(5 l)]

$$\text{Anoxic \% Denitrification} = \left[\frac{[\text{Anoxic Denitrification Rate, mg N/d}]}{[\text{Anoxic NOx Load, mg N/d}]} \right] * 100 \%$$

$$\text{Aerobic Nitrification Rate (mg N/d)} = [(\text{Aerobic Overflow, l/d})(\text{Aerobic NOx conc, mg N/l})] - [(\text{Anoxic overflow, l/d})(\text{Anoxic NOx conc, mg N/l})]$$

$$\text{Aerobic Specific Nitrification Rate (mg N/d/mg VSS)} = [\text{Aerobic Nitrification Rate, mg N/d}] / [(\text{Aerobic VSS conc, mg/l})(10 \text{ l})]$$

$$\text{Aerobic \% Nitrification} = \left[\frac{[\text{Aerobic Nitrification Rate, mg N/d}]}{[(\text{Anoxic overflow, l/d})(\text{Anoxic NH}_4 \text{ conc, mg N/l})]} \right] * 100 \%$$

$$\text{Anoxic COD:NOx Entering (mg COD/mg NOx-N)} = \frac{[(\text{Anoxic Methanol Load, g COD/d})(1000 \text{ mg/g})]}{[\text{Anoxic NOx Load, mg N/d}]}$$

$$\text{Anoxic COD:NOx Removed (mg COD/mg NOx-N)} = \frac{[(\text{Anoxic Methanol Load, g COD/d})(1000 \text{ mg/g})]}{[(\text{Anoxic NOx Load, mg N/d}) - [(\text{Anoxic overflow, l/d})(\text{Anoxic NOx conc, mg N/l})]]}$$

$$\text{Aerobic SRT (d)} = [10 \text{ l}] / [\text{Aerobic Wasting, l/d}]$$

$$\text{System SRT (d)} = \frac{[(\text{Anoxic VSS conc, mg/l})(5 \text{ l}) + (\text{Aerobic VSS conc, mg/l})(15 \text{ l})]}{[(\text{Aerobic VSS conc, mg/l})(\text{Aerobic Wasting, l/d}) + (\text{Effluent VSS conc, mg/l}) * [(\text{Aerobic overflow, l/d}) - (\text{Clarifier recycle flow, l/d})]}$$

$$\text{NaHCO}_3 \text{ Load (g CaCO}_3\text{/d)} = [(\text{NaHCO}_3 \text{ feed conc, g NaHCO}_3\text{/l})(\text{NaHCO}_3 \text{ feed flow, ml/hr})(24 \text{ hr/d})(1 \text{ l}/1000\text{ml})(50 \text{ g CaCO}_3\text{/84 g NaHCO}_3)] + [(\text{leachate conc, mg CaCO}_3\text{/l})(\text{leachate flow, l/d})(1 \text{ g}/1000 \text{ mg})]$$

$$\text{Alkalinity / NH}_4 \text{ Added (g CaCO}_3\text{/g N)} = [\text{NaHCO}_3 \text{ load, g CaCO}_3\text{/d}] / [\text{Ammonia load, g N/d}]$$

$$\text{Alkalinity / NH}_4 \text{ Nitrified (g CaCO}_3\text{/g N)} = [\text{NaHCO}_3 \text{ load, g CaCO}_3\text{/d}] / [(\text{Nitrification Rate, mg N/d})(1 \text{ g/1000 mg})]$$

$$\text{Simulated Leachate Flow (l/d)} = [\text{Leachate flow, l/d}] + [(\text{NH}_4\text{Cl feed flow, ml/hr})(24 \text{ hr/d})(1 \text{ l/1000ml})]$$

$$\text{Chemical Flow (l/d)} = [(\text{PO}_4 \text{ feed flow, ml/hr}) + (\text{methanol feed flow, ml/hr}) + (\text{NaHCO}_3 \text{ feed flow, ml/hr})] * [(24 \text{ hr/d})(1 \text{ l/1000ml})]$$

$$\text{Total Flow (l/d)} = [\text{Simulated Leachate Flow, l/d}] + [\text{Chemical Flow, l/d}]$$

$$\text{Clarifier Recycle Ratio} = [\text{Clarifier recycle flow, l/d}] / [\text{Simulated Leachate Flow, l/d}]$$

$$\text{Corrected Effluent NO}_x \text{ Concentration (mg N/l)} = [(\text{Effluent NO}_x \text{ conc, mg N/l})(\text{Total Flow, l/d})] / [\text{Simulated Leachate Flow, l/d}]$$

$$\text{Corrected Effluent NH}_4 \text{ Concentration (mg N/l)} = [(\text{Effluent NH}_4 \text{ conc, mg N/l})(\text{Total Flow, l/d})] / [\text{Simulated Leachate Flow, l/d}]$$

$$\text{Total Effluent Inorganic Nitrogen (mg N/l)} = [\text{Corrected Effluent NO}_x \text{ Concentration, mg N/l}] + [\text{Corrected Effluent NH}_4 \text{ Concentration, mg N/l}]$$

$$\text{Total Inorganic Nitrogen Removal (\%)} = [\text{Ammonia Load, g N/d}] - [(\text{Effluent NO}_x \text{ conc, mg N/l}) + (\text{Effluent NH}_4 \text{ conc, mg N/l}) * (\text{Total Flow, l/d})(1 \text{ g/1000mg})]$$

Bardenpho Process Calculations

Anoxic #1 Overflow (l/d) = [(Leachate flow, l/d) + (Aerobic #1 recycle flow, l/d) + (Clarifier recycle flow, l/d)] + [[(NH₄Cl feed flow, ml/hr) + (methanol #1 feed flow, ml/hr) + (PO₄ #1 feed flow, ml/hr)] * [(24 hr/d)(1 l/1000ml)]]

Anoxic #2 Overflow (l/d) = [Post flow, l/d] + [[(methanol #2 feed flow, ml/hr) + (PO₄ #2 feed flow, ml/hr)] * [(24 hr/d)(1 l/1000ml)]]

Aerobic #1 Overflow (l/d) = [Anoxic #1 overflow, l/d] + [(NaHCO₃ #1 feed flow, ml/hr)(24 hr/d)(1 l/1000ml)]

Aerobic #2 Overflow (l/d) = [Anoxic #2 overflow, l/d]

Anoxic #1 AHRT (hr) = [(5 l)/(Anoxic #1 overflow, l/d)](24 hr/d)

Anoxic #2 AHRT (hr) = [(5 l)/(Anoxic #2 overflow, l/d)](24 hr/d)

Aerobic #1 AHRT (hr) = [(10 l)/(Aerobic #1 overflow, l/d)](24 hr/d)

Aerobic #2 AHRT (hr) = [(10 l)/(Aerobic #2 overflow, l/d)](24 hr/d)

Clarifier AHRT (hr) = [(4 l)/(Aerobic #2 overflow, l/d)](24 hr/d)

Anoxic #1 NH₄ Removal Rate (mg N/d) = [(Ammonia load, g N/d)(1000 mg/g)] + [(Aerobic #1 recycle flow, l/d)(Aerobic #1 NH₄ conc, mg N/l)] + [(Clarifier recycle flow, l/d)(Aerobic #2 NH₄ conc, mg N/l)] - [(Anoxic #1 overflow, l/d)(Anoxic #1 NH₄ conc, mg N/l)]

Anoxic #2 NH4 Removal Rate (mg N/d) = [(Post flow, l/d)(Aerobic #1 NH4 conc, mg N/l)] - [(Anoxic #2 overflow, l/d)(Anoxic #2 NH4 conc, mg N/l)]

Aerobic #1 NH4 Removal Rate (mg N/d) = [(Anoxic #1 overflow, l/d)(Anoxic #1 NH4 conc, mg N/l)] - [(Aerobic #1 overflow, l/d)(Aerobic #1 NH4 conc, mg N/l)]

Aerobic #2 NH4 Removal Rate (mg N/d) = [(Anoxic #2 overflow, l/d)(Anoxic #2 NH4 conc, mg N/l)] - [(Aerobic #2 overflow, l/d)(Aerobic #2 NH4 conc, mg N/l)]

% Anoxic #1 NH4 Removal = [(Anoxic #1 NH4 Removal Rate, mg N/d) / [(Ammonia load, g N/d)(1000 mg/g) + (Aerobic #1 recycle flow, l/d)(Aerobic #1 NH4 conc, mg N/l) + (Clarifier recycle flow, l/d)(Aerobic #2 NH4 conc, mg N/l)]] * 100 %

% Anoxic #2 NH4 Removal = [(Anoxic #2 NH4 Removal Rate, mg N/d) / [(Post flow, l/d)(Aerobic #1 NH4 conc, mg N/l)]] * 100 %

% Aerobic #1 NH4 Removal = [(Anoxic #1 overflow, l/d)(Anoxic #1 NH4 conc, mg N/l) - (Aerobic #1 overflow, l/d)(Aerobic #1 NH4 conc, mg N/l)] / [(Anoxic #1 overflow, l/d)(Anoxic #1 NH4 conc, mg N/l)] * 100 %

% Aerobic #2 NH4 Removal = [(Anoxic #2 overflow, l/d)(Anoxic #2 NH4 conc, mg N/l) - (Aerobic #2 overflow, l/d)(Aerobic #2 NH4 conc, mg N/l)] / [(Anoxic #2 overflow, l/d)(Anoxic #2 NH4 conc, mg N/l)] * 100 %

% System NH4 Removal = [(Simulated Leachate Ammonia Conc, mg N/l) - (Effluent NH4 conc, mg N/l)] / [Simulated Leachate Ammonia Conc, mg N/l] * 100 %

Anoxic #1 NOx Load (mg N/d) = (Leachate flow, l/d)(Leachate NOx conc, mg N/l) + (Aerobic #1 recycle flow, l/d)(Aerobic #1 NOx conc, mg N/l) + (Clarifier recycle flow, l/d)(Effluent NOx conc, mg N/l)

Anoxic #2 NOx Load (mg N/d) = (Post flow, l/d)(Aerobic #1 NOx conc, mg N/l)

Anoxic #1 Denitrification Rate (mg N/d) = [Anoxic #1 NOx Load, mg N/d] - [(Anoxic #1 overflow, l/d)(Anoxic #1 NOx conc, mg N/l)]

Anoxic #2 Denitrification Rate (mg N/d) = [Anoxic #2 NOx Load, mg N/d] - [(Anoxic #2 overflow, l/d)(Anoxic #2 NOx conc, mg N/l)]

Anoxic #1 Specific Denitrification Rate (mg N/d/mg VSS) = [Anoxic #1 Denitrification Rate, mg N/d] / [(Anoxic #1 VSS conc, mg/l)(5 l)]

Anoxic #2 Specific Denitrification Rate (mg N/d/mg VSS) = [Anoxic #2 Denitrification Rate, mg N/d] / [(Anoxic #2 VSS conc, mg/l)(5 l)]

Anoxic #1 % Denitrification = [[Anoxic #1 Denitrification Rate, mg N/d] / [Anoxic #1 NOx Load, mg N/d]] * 100 %

Anoxic #2 % Denitrification = [[Anoxic #2 Denitrification Rate, mg N/d] / [Anoxic #2 NOx Load, mg N/d]] * 100 %

Aerobic #1 Nitrification Rate (mg N/d) = [(Aerobic #1 overflow, l/d)(Aerobic #1 NOx conc, mg N/l)] - [(Anoxic #1 overflow, l/d)(Anoxic #1 NOx conc, mg N/l)]

Aerobic #2 Nitrification Rate (mg N/d) = [(Aerobic #2 overflow, l/d)(Aerobic #2 NOx conc, mg N/l)] - [(Anoxic #2 overflow, l/d)(Anoxic #2 NOx conc, mg N/l)]

$$\text{Aerobic \#1 Specific Nitrification Rate (mg N/d/mg VSS)} = [\text{Aerobic \#1 Nitrification Rate, mg N/d}] / [(\text{Aerobic \#1 VSS conc, mg/l})(10 \text{ l})]$$

$$\text{Aerobic \#2 Specific Nitrification Rate (mg N/d/mg VSS)} = [\text{Aerobic \#2 Nitrification Rate, mg N/d}] / [(\text{Aerobic \#2 VSS conc, mg/l})(10 \text{ l})]$$

$$\text{Aerobic \#1 \% Nitrification} = [[\text{Aerobic \#1 Nitrification Rate, mg N/d}] / [(\text{Anoxic \#1 overflow, l/d})(\text{Anoxic \#1 NH}_4 \text{ conc, mg N/l})]] * 100 \%$$

$$\text{Aerobic \#2 \% Nitrification} = [[\text{Aerobic \#2 Nitrification Rate, mg N/d}] / [(\text{Anoxic \#2 overflow, l/d})(\text{Anoxic \#2 NH}_4 \text{ conc, mg N/l})]] * 100 \%$$

$$\text{Anoxic \#1 COD:NO}_x \text{ Entering (mg COD/mg NO}_x\text{-N)} = [(\text{Anoxic \#1 Methanol Load, g COD/d})(1000 \text{ mg/g})] / [\text{Anoxic \#1 NO}_x \text{ Load, mg N/d}]$$

$$\text{Anoxic \#2 COD:NO}_x \text{ Entering (mg COD/mg NO}_x\text{-N)} = [(\text{Anoxic \#2 Methanol Load, g COD/d})(1000 \text{ mg/g})] / [\text{Anoxic \#2 NO}_x \text{ Load, mg N/d}]$$

$$\text{Anoxic \#1 COD:NO}_x \text{ Removed (mg COD/mg NO}_x\text{-N)} = [(\text{Anoxic \#1 Methanol Load, g COD/d})(1000 \text{ mg/g})] / [(\text{Anoxic \#1 NO}_x \text{ Load, mg N/d}) - [(\text{Anoxic \#1 overflow, l/d})(\text{Anoxic \#1 NO}_x \text{ conc, mg N/l})]]$$

$$\text{Anoxic \#2 COD:NO}_x \text{ Removed (mg COD/mg NO}_x\text{-N)} = [(\text{Anoxic \#2 Methanol Load, g COD/d})(1000 \text{ mg/g})] / [(\text{Anoxic \#2 NO}_x \text{ Load, mg N/d}) - [(\text{Anoxic \#2 overflow, l/d})(\text{Anoxic \#2 NO}_x \text{ conc, mg N/l})]]$$

$$\text{Aerobic \#1 SRT (d)} = [10 \text{ l}] / [\text{Aerobic \#1 Wasting, l/d}]$$

$$\text{System SRT (d)} = \frac{[(\text{Anoxic \#1 VSS conc, mg/l})(5 \text{ l}) + (\text{Anoxic \#2 VSS conc, mg/l})(5 \text{ l}) + (\text{Aerobic \#1 VSS conc, mg/l})(10 \text{ l}) + (\text{Aerobic \#2 VSS conc, mg/l})(15 \text{ l})]}{[(\text{Aerobic \#1 VSS conc, mg/l})(\text{Aerobic \#1 Wasting, l/d}) + (\text{Effluent VSS conc, mg/l}) * [(\text{Aerobic \#2 overflow, l/d}) - (\text{Clarifier recycle flow, l/d})]}$$

$$\text{Aerobic \#1 Recycle Ratio} = \frac{[\text{Aerobic \#1 recycle flow, l/d}]}{[\text{Simulated Leachate flow, l/d}]}$$

$$\text{Clarifier Recycle Ratio} = \frac{[\text{Clarifier recycle flow, l/d}]}{[\text{Simulated Leachate flow, l/d}]}$$

APPENDIX B
RAW AND CALCULATED DATA

MLE Startup and Recycle Phases

Leachate (Influent) Data

MLE System #1

MLE System #2

Bardenpho Phase

Leachate (Influent) Data

Bardenpho System

Leachate (Influent) Data

Date	Day	NH4 (mg N/l)	NOx (mg N/l)	NO2 (mg N/l)	O-PO4 (mp P/l)	pH
Jul 12/94	5					
Jul 14/94	7	232				
Jul 15/94	8		0.6		0.63	7.6
Jul 18/94	11	282	0.4		0.39	7.6
Jul 20/94	13	276	0.4		0.41	7.6
Jul 22/94	15	269	0.4		0.37	7.7
Jul 25/94	18	322	0.3		0.35	
Jul 27/94	20	274	0.3		0.34	7.7
Aug 1/94	24	273	0.8		0.55	7.7
Aug 3/94	26	272	0.3		0.69	7.7
Aug 5/94	28	260	0.4	0.1	0.42	7.8
Aug 8/94	31	269	0.3		0.60	7.7
Aug 10/94	33	253	0.5	0.3	0.79	7.7
Aug 12/94	35	253	0.4	0.0	0.46	7.7
Aug 15/94	38	260	0.3	0.1	0.36	7.7
Aug 17/94	40	281	0.2		0.83	7.7
Aug 19/94	42	295	0.8	0.3	0.63	7.6
Aug 22/94	45	392	0.2	0.0	0.75	7.6
Aug 24/94	47	338	0.1		0.91	7.6
Aug 26/94	49	300	1.3	0.3	0.74	7.6
Aug 29/94	52	278	0.2	0.0	0.82	7.5
Aug 31/94	54	280	0.2		0.82	7.6
Sep 2/94	56	273	0.6	0.1	0.59	7.7
Sep 6/94	60	280	1.6	0.5	0.89	7.6
Sep 9/94	63	266	0.5	0.1	0.87	7.7
Sep 12/94	66	315	0.2	0.1	0.89	7.7
Sep 14/94	68	253	0.2		0.96	7.6
Sep 16/94	70	230	0.3	0.1	0.91	7.7
Sep 19/94	73	262	0.2	0.1	1.03	7.7
Sep 21/94	75	229	0.1	0.0	0.99	7.6
Sep 23/94	77	217	1.3	0.4	0.06	7.6
Sep 26/94	80	206	0.5	0.0	0.81	7.5
Sep 28/94	82	266	1.1	0.0	0.69	7.6
Sep 30/94	84	277	1.2	0.1	0.79	7.6
Oct 3/94	87	337	0.7	0.0	0.38	7.6
Oct 7/94	91	266	0.8	0.0	0.77	7.6
Oct 11/94	95	246	0.6	0.0	0.70	7.6
Oct 14/94	98	243	0.5	0.0	0.86	7.6
Oct 17/94	101	238	0.9	0.1	0.72	7.6
Oct 19/94	103	267	1.6	0.4	0.85	7.6
Oct 21/94	105	249	0.3	0.1	0.57	7.5
Oct 23/94	107	249				
Oct 25/94	109	259	0.5	0.0	0.62	7.7
Oct 28/94	112	233	0.3	0.0	0.59	7.6
Nov 1/94	116	195	0.3	0.0	0.47	7.5
Nov 4/94	119	167	0.3	0.1	0.42	7.5
Nov 8/94	123	149	0.3	0.0	0.41	7.4
Nov 11/94	126	141	0.4	0.1	0.30	7.3
Nov 15/94	130	115	0.3	0.1	0.24	7.3

Leachate (Influent) Data

Date	Day	NH4 (mg N/l)	NOx (mg N/l)	NO2 (mg N/l)	O-PO4 (mp P/l)	pH
Nov 18/94	133	86	1.1	0.1	0.20	7.3
Nov 22/94	137	98	0.3	0.1	0.14	7.3
Nov 25/94	140	103	0.6	0.1	0.15	7.2
Nov 29/94	144	139	0.2	0.1	0.14	7.3
Dec 2/94	147	151	0.3	0.0	0.18	7.2
Dec 6/94	151	119	0.2	0.1	0.10	7.2
Dec 9/94	154	89	0.2	0.0	0.15	7.1
Dec 12/94	157	83	0.2	0.0	0.11	7.1
Dec 16/94	161	122	0.2	0.0	0.08	7.3
Dec 20/94	165	148	0.4	0.0	0.04	7.3
Dec 23/94	168	147	0.3	0.0	0.05	7.3
Dec 27/94	172	125	0.2	0.0	0.07	7.1
Dec 30/94	175	107	0.2	0.0	0.07	7.1
Jan 3/95	179	94	0.5	0.1	0.04	6.9
Jan 6/95	182	80	0.7	0.1	0.17	6.8
Jan 10/95	186	123	0.2	0.0	0.02	7.2
Jan 13/95	189	160	0.3	0.0	0.09	7.3
Jan 17/95	193	157	0.2	0.0	0.20	7.3
Jan 20/95	196	138	0.3	0.0	0.28	7.2
Jan 24/95	200	121	0.3	0.0	0.24	7.1
Jan 27/95	203	113	0.3	0.1	0.23	7.1
Jan 31/95	207	134	0.2	0.1	0.18	7.1
Feb 3/95	210	163	0.5	0.1	0.21	7.2
Feb 7/95	214	132	0.2	0.0	0.28	7.1
Feb 10/95	217	104	0.2	0.0	0.34	7.1
Feb 14/95	221	135	0.3	0.1	0.15	7.1
Feb 17/95	224	149	0.3	0.0	0.29	7.2
Feb 21/95	228	195	0.4	0.1	0.21	7.4
Feb 24/95	231	175	0.2	0.0	0.18	7.2
Feb 28/95	235	136	0.3	0.1	0.11	7.2
Mar 3/95	238	122	0.3	0.0	0.17	7.1
Mar 7/95	242	132	0.2	0.0	0.21	7.1

Leachate (Influent) Data

Date	Day	Akalinity (mg CaCO3/l)	TSS (mg/l)	VSS (mg/l)	BOD5 (mg/l)	COD (mg/l)
Jul 12/94	5		69	43		
Jul 14/94	7					
Jul 15/94	8		63	30		
Jul 18/94	11	1790				
Jul 20/94	13					
Jul 22/94	15					
Jul 25/94	18	2030	79	43		
Jul 27/94	20					499
Aug 1/94	24	2180				
Aug 3/94	26					513
Aug 5/94	28		89	48		
Aug 8/94	31	2120				
Aug 10/94	33					
Aug 12/94	35					
Aug 15/94	38	2160	37	17		466
Aug 17/94	40				31	
Aug 19/94	42					565
Aug 22/94	45	2260	71	16		549
Aug 24/94	47					
Aug 26/94	49					596
Aug 29/94	52		52	12		579
Aug 31/94	54					
Sep 2/94	56					438
Sep 6/94	60	2280	30	16		592
Sep 9/94	63				34	549
Sep 12/94	66	2080	32	20		532
Sep 14/94	68					
Sep 16/94	70					417
Sep 19/94	73		43	22		417
Sep 21/94	75					
Sep 23/94	77					445
Sep 26/94	80		37	18		398
Sep 28/94	82					
Sep 30/94	84	2300				
Oct 3/94	87	2260				525
Oct 7/94	91					509
Oct 11/94	95					509
Oct 14/94	98					493
Oct 17/94	101	2080	69	33		
Oct 19/94	103					
Oct 21/94	105					545
Oct 23/94	107					
Oct 25/94	109					536
Oct 28/94	112	1980				457
Nov 1/94	116	1480	25	13		457
Nov 4/94	119					360
Nov 8/94	123	1520	35	21		378
Nov 11/94	126					429
Nov 15/94	130	1260				359

Leachate (Influent) Data

Date	Day	Alkalinity (mg CaCO3/l)	TSS (mg/l)	VSS (mg/l)	BOD5 (mg/l)	COD (mg/l)
Nov 18/94	133					
Nov 22/94	137	1340	41	23		
Nov 25/94	140					281
Nov 29/94	144	1520	47	27		313
Dec 2/94	147				38	320
Dec 6/94	151	1180	53	33		288
Dec 9/94	154				41	233
Dec 12/94	157	1380				200
Dec 16/94	161					
Dec 20/94	165	1380	61	38		407
Dec 23/94	168					303
Dec 27/94	172	1160	54	30	28	407
Dec 30/94	175					289
Jan 3/95	179	750	28	20		250
Jan 6/95	182					205
Jan 10/95	186	1480	46	23	30	205
Jan 13/95	189					260
Jan 17/95	193	1370	42	24		216
Jan 20/95	196					
Jan 24/95	200	1200	27	16	36	
Jan 27/95	203					250
Jan 31/95	207	1540	34	18	32	250
Feb 3/95	210					
Feb 7/95	214	1200	43	23		
Feb 10/95	217				33	
Feb 14/95	221	1460	34	15	50	
Feb 17/95	224					356
Feb 21/95	228	1470	41	19	19	375
Feb 24/95	231					291
Feb 28/95	235	1290	60	33		253
Mar 3/95	238				21	272
Mar 7/95	242	1540	59	31		260

MLE System #1

Date	Day	PO4 Feed Flow (ml/hr)	CH3OH Feed Flow (ml/hr)	NH4Cl Feed Flow (ml/hr)	NaHCO3 Feed Flow (ml/hr)	Leachate (l/d)	Clarifier Recycle (l/d)	Anoxic Overflow (l/d)
Jul 12/94	5	11.3	0	0	0			
Jul 14/94	7	11.4	0	0	0			
Jul 15/94	8	11.4	0	0	0	9.8	59.4	
Jul 18/94	11	11.7	0	0	0	9.9	59.4	
Jul 20/94	13	11.4	0	0	0	9.8	59.4	
Jul 22/94	15	11.6	0	0	0	9.8	59.4	
Jul 25/94	18	11.4	0	0	0	9.8	60.3	
Jul 27/94	20	11.4	0	0	0	9.8	60.3	
Aug 1/94	24	11.7	0	0	0	9.8	61.2	
Aug 3/94	26	11.5	0	0	0	9.8	63.0	
Aug 5/94	28	11.5	0	0	0	9.9	63.9	
Aug 8/94	31	5.8	0	0	0	9.9	63.0	
Aug 10/94	33	5.2	0	0	0	9.9	63.0	
Aug 12/94	35	5.6	4.7	0	0	9.8	63.0	72.9
Aug 15/94	38	5.7	4.2	0	0	3.9	63.0	67.0
Aug 17/94	40	4.6	4.1	0	0	10.2	62.1	72.4
Aug 19/94	42	5.2	4.5	0	0	10.1	63.0	73.2
Aug 22/94	45	5.4	4.0	0	0	10.2	62.1	72.4
Aug 24/94	47	5.0	3.8	0	0	10.2	61.2	71.5
Aug 26/94	49	4.6	7.0	0	0	10.4	61.2	71.7
Aug 29/94	52	4.9	6.7	0	0	10.4	61.2	71.7
Aug 31/94	54	4.8	6.8	0	0	10.4	61.2	71.7
Sep 2/94	56	5.0	6.9	0	0	10.4	61.2	71.7
Sep 6/94	60	5.1	6.9	0	0	9.6	61.2	70.9
Sep 9/94	63	5.1	7.1	0	0	9.8	61.2	71.1
Sep 12/94	66	5.1	7.0	0	0	9.6	62.1	71.8
Sep 14/94	68	5.0	7.3	0	0	9.6	60.3	70.0
Sep 16/94	70	5.2	7.4	0	0	9.8	59.4	69.3
Sep 19/94	73	4.9	7.5	8.4	0	9.8	60.3	70.6
Sep 21/94	75	4.8	7.1	8.0	8.8	9.9	59.4	69.8
Sep 23/94	77	5.2	7.1	8.1	12.1	9.6	59.4	69.5
Sep 26/94	80	5.2	7.7	8.2	25.0	9.9	59.4	69.8
Sep 28/94	82	5.5	7.3	8.3	25.7	9.2	59.4	69.1
Sep 30/94	84	4.8	7.5	8.1	25.4	9.2	59.4	69.1
Oct 3/94	87	4.7	7.4	8.5	29.2	9.2	59.4	69.1
Oct 7/94	91	4.4	7.5	8.4	26.2	9.2	59.4	69.1
Oct 11/94	95	5.0	7.6	8.4	31.8	9.2	59.4	69.1
Oct 14/94	98	5.5	7.7	8.6	29.5	9.2	60.3	70.0
Oct 17/94	101	4.9	7.5	8.5	31.8	9.2	60.3	70.0
Oct 19/94	103	4.7	7.8	8.5	17.1	9.1	58.5	68.1
Oct 21/94	105	4.9	8.0	8.7	0.0	9.1	58.5	68.1
Oct 23/94	107	4.9	8.0	8.7	0.0	9.1	58.5	68.1
Oct 25/94	109	4.9	8.1	0.0	0.0	9.1	57.6	66.8
Oct 28/94	112	4.9	7.9	0.0	0.0	8.9	58.5	67.5
Nov 1/94	116	5.1	7.8	8.8	8.8	8.9	58.5	67.9
Nov 4/94	119	4.8	7.6	8.3	15.7	8.9	57.6	67.0
Nov 8/94	123	4.9	7.6	8.9	18.4	9.1	57.6	67.2
Nov 11/94	126	5.2	8.5	9.0	21.8	8.9	57.6	67.1
Nov 15/94	130	4.9	8.2	8.8	26.3	9.1	56.7	66.3

MLE System #1

Date	Day	PO4 Feed Flow (ml/hr)	CH3OH Feed Flow (ml/hr)	NH4Cl Feed Flow (ml/hr)	NaHCO3 Feed Flow (ml/hr)	Leachate (l/d)	Clarifier Recycle (l/d)	Anoxic Overflow (l/d)
Nov 18/94	133	4.9	8.6	8.9	25.6	9.1	56.7	66.3
Nov 22/94	137	5.2	8.0	9.2	28.4	9.1	56.7	66.4
Nov 25/94	140	4.7	8.5	9.0	27.0	9.1	56.7	66.3
Nov 29/94	144	5.0	8.0	8.7	27.2	9.1	63.0	72.6
Dec 2/94	147	5.5	8.3	8.8	27.0	9.1	62.1	71.8
Dec 6/94	151	4.8	8.3	8.9	28.9	8.9	62.1	71.5
Dec 9/94	154	5.0	8.3	9.0	29.2	9.1	62.1	71.8
Dec 12/94	157	4.9	8.6	8.9	32.9	9.1	62.1	71.7
Dec 16/94	161	5.0	8.8	9.2	27.9	9.1	65.7	75.4
Dec 20/94	165	5.6	8.9	9.2	28.2	9.1	64.8	74.5
Dec 23/94	168	4.9	9.1	9.4	29.7	9.2	64.8	74.6
Dec 27/94	172	5.0	8.8	9.2	29.4	9.1	64.8	74.5
Dec 30/94	175	5.7	9.1	9.1	29.2	9.1	64.8	74.5
Jan 3/95	179	4.8	8.9	9.6	29.2	9.1	64.8	74.5
Jan 6/95	182	5.7	9.0	9.0	30.9	9.1	64.8	74.5
Jan 10/95	186	4.9	8.9	9.7	29.3	9.1	64.8	74.5
Jan 13/95	189	5.0	9.1	9.0	24.5	9.1	64.8	74.5
Jan 17/95	193	5.6	9.1	9.4	23.1	9.1	64.8	74.5
Jan 20/95	196	5.3	8.1	9.5	34.8	9.1	64.8	74.5
Jan 24/95	200	5.5	8.6	9.4	32.9	9.1	64.8	74.5
Jan 27/95	203	5.2	9.0	9.4	30.0	9.2	65.7	75.5
Jan 31/95	207	5.4	8.8	9.1	27.4	9.2	65.7	75.5
Feb 3/95	210	5.1	8.8	9.1	28.3	9.2	65.7	75.5
Feb 7/95	214	5.1	9.0	9.6	28.3	8.9	65.7	75.2
Feb 10/95	217	5.0	8.9	9.1	30.1	8.8	65.7	75.1
Feb 14/95	221	5.5	9.0	9.3	29.5	8.8	64.8	74.2
Feb 17/95	224	5.0	8.1	9.4	25.2	8.9	65.7	75.2
Feb 21/95	228	5.3	7.8	9.4	25.7	8.9	65.7	75.2
Feb 24/95	231	5.0	7.7	9.2	28.6	8.9	65.7	75.2
Feb 28/95	235	5.1	7.9	9.2	33.1	8.9	64.8	74.3
Mar 3/95	238	5.1	7.9	9.2	24.1	8.9	64.8	74.3
Mar 7/95	242	5	8.2	9.2	25.4	8.9	64.8	74.3

MLE System #1

Date	Day	Aerobic Overflow (l/d)	Aerobic Wasting (l/d)	Anoxic AHRT (hr)	Aerobic AHRT (hr)	Clarifier AHRT (hr)
Jul 12/94	5		0			
Jul 14/94	7		0			
Jul 15/94	8	69.5	0		3.45	1.38
Jul 18/94	11	69.6	0		3.45	1.38
Jul 20/94	13	69.5	0		3.45	1.38
Jul 22/94	15	69.5	0		3.45	1.38
Jul 25/94	18	70.4	0		3.41	1.36
Jul 27/94	20	70.4	0		3.41	1.36
Aug 1/94	24	71.3	1		3.37	1.35
Aug 3/94	26	73.1	1		3.28	1.31
Aug 5/94	28	74.1	0		3.24	1.30
Aug 8/94	31	73.0	1		3.29	1.31
Aug 10/94	33	73.0	1		3.29	1.31
Aug 12/94	35	72.9	0	1.65	3.29	1.32
Aug 15/94	38	67.0	0	1.79	3.58	1.43
Aug 17/94	40	72.4	0	1.66	3.31	1.33
Aug 19/94	42	73.2	0.5	1.64	3.28	1.31
Aug 22/94	45	72.4	0.5	1.66	3.31	1.33
Aug 24/94	47	71.5	0.5	1.68	3.36	1.34
Aug 26/94	49	71.7	0.5	1.67	3.35	1.34
Aug 29/94	52	71.7	0.5	1.67	3.35	1.34
Aug 31/94	54	71.7	0.5	1.67	3.35	1.34
Sep 2/94	56	71.7	0.5	1.67	3.35	1.34
Sep 6/94	60	70.9	0.5	1.69	3.38	1.35
Sep 9/94	63	71.1	0.5	1.69	3.37	1.35
Sep 12/94	66	71.8	0.5	1.67	3.34	1.34
Sep 14/94	68	70.0	0.75	1.71	3.43	1.37
Sep 16/94	70	69.3	0.75	1.73	3.46	1.38
Sep 19/94	73	70.6	0.75	1.70	3.40	1.36
Sep 21/94	75	70.0	0.75	1.72	3.43	1.37
Sep 23/94	77	69.8	0.75	1.73	3.44	1.38
Sep 26/94	80	70.4	0.75	1.72	3.41	1.36
Sep 28/94	82	69.7	0.75	1.74	3.44	1.38
Sep 30/94	84	69.7	0.75	1.74	3.44	1.38
Oct 3/94	87	69.8	0.75	1.74	3.44	1.37
Oct 7/94	91	69.7	0.75	1.74	3.44	1.38
Oct 11/94	95	69.9	0.75	1.74	3.43	1.37
Oct 14/94	98	70.8	0.75	1.71	3.39	1.36
Oct 17/94	101	70.8	0.75	1.71	3.39	1.36
Oct 19/94	103	68.5	0.75	1.76	3.50	1.40
Oct 21/94	105	68.1	0.75	1.76	3.52	1.41
Oct 23/94	107	68.1	0.75			
Oct 25/94	109	66.8	0.75	1.80	3.59	1.44
Oct 28/94	112	67.5	0.75	1.78	3.55	1.42
Nov 1/94	116	68.2	0.75	1.77	3.52	1.41
Nov 4/94	119	67.4	0.75	1.79	3.56	1.42
Nov 8/94	123	67.7	0.75	1.78	3.55	1.42
Nov 11/94	126	67.6	0.75	1.79	3.55	1.42
Nov 15/94	130	67.0	0.75	1.81	3.58	1.43

MLE System #1

Date	Day	Aerobic Overflow (l/d)	Aerobic Wasting (l/d)	Anoxic AHRT (hr)	Aerobic AHRT (hr)	Clarifier AHRT (hr)
Nov 18/94	133	67.0	0.75	1.81	3.58	1.43
Nov 22/94	137	67.0	0.75	1.81	3.58	1.43
Nov 25/94	140	67.0	0.75	1.81	3.58	1.43
Nov 29/94	144	73.3	1	1.65	3.27	1.31
Dec 2/94	147	72.4	1	1.67	3.31	1.33
Dec 6/94	151	72.2	1	1.68	3.32	1.33
Dec 9/94	154	72.5	1	1.67	3.31	1.33
Dec 12/94	157	72.5	1	1.67	3.31	1.32
Dec 16/94	161	76.0	1	1.59	3.16	1.26
Dec 20/94	165	75.2	1	1.61	3.19	1.28
Dec 23/94	168	75.3	1	1.61	3.19	1.28
Dec 27/94	172	75.2	1	1.61	3.19	1.28
Dec 30/94	175	75.2	1	1.61	3.19	1.28
Jan 3/95	179	75.2	1	1.61	3.19	1.28
Jan 6/95	182	75.2	1	1.61	3.19	1.28
Jan 10/95	186	75.2	1	1.61	3.19	1.28
Jan 13/95	189	75.0	0.67	1.61	3.20	1.28
Jan 17/95	193	75.0	0.67	1.61	3.20	1.28
Jan 20/95	196	75.3	0.67	1.61	3.19	1.27
Jan 24/95	200	75.3	0.67	1.61	3.19	1.28
Jan 27/95	203	76.2	0.5	1.59	3.15	1.26
Jan 31/95	207	76.1	0.5	1.59	3.15	1.26
Feb 3/95	210	76.1	0.5	1.59	3.15	1.26
Feb 7/95	214	75.9	0.5	1.60	3.16	1.27
Feb 10/95	217	75.8	0.5	1.60	3.17	1.27
Feb 14/95	221	74.9	0.5	1.62	3.20	1.28
Feb 17/95	224	75.8	0.5	1.60	3.17	1.27
Feb 21/95	228	75.8	0.5	1.60	3.17	1.27
Feb 24/95	231	75.8	0.5	1.60	3.16	1.27
Feb 28/95	235	75.1	0.5	1.62	3.20	1.28
Mar 3/95	238	74.8	0.5	1.62	3.21	1.28
Mar 7/95	242	74.9	0.5	1.62	3.21	1.28

MLE System #1

Date	Day	PO4 Feed Conc (g P/l)	CH3OH Feed Conc (ml/l)	NH4Cl Feed Conc (g NH4CL/l)	NaHCO3 Feed Conc (g/l)
Jul 12/94	5	0.692	0	0	0
Jul 14/94	7	0.692	0	0	0
Jul 15/94	8	0.692	0	0	0
Jul 18/94	11	0.675	0	0	0
Jul 20/94	13	0.675	0	0	0
Jul 22/94	15	0.675	0	0	0
Jul 25/94	18	0.672	0	0	0
Jul 27/94	20	0.672	0	0	0
Aug 1/94	24	0.656	0	0	0
Aug 3/94	26	0.656	0	0	0
Aug 5/94	28	0.656	0	0	0
Aug 8/94	31	0.644	0	0	0
Aug 10/94	33	0.644	0	0	0
Aug 12/94	35	0.644	15	0	0
Aug 15/94	38	0.644	10	0	0
Aug 17/94	40	0.644	10	0	0
Aug 19/94	42	0.644	20	0	0
Aug 22/94	45	0.536	20	0	0
Aug 24/94	47	0.536	30	0	0
Aug 26/94	49	0.536	30	0	0
Aug 29/94	52	0.536	30	0	0
Aug 31/94	54	0.536	40	0	0
Sep 2/94	56	0.536	50	0	0
Sep 6/94	60	0.539	60	0	0
Sep 9/94	63	0.539	65	0	0
Sep 12/94	66	0.875	65	0	0
Sep 14/94	68	0.875	65	0	0
Sep 16/94	70	0.875	65	0	0
Sep 19/94	73	0.875	65	24	80
Sep 21/94	75	0.865	65	62	80
Sep 23/94	77	0.865	65	62	80
Sep 26/94	80	0.865	65	110	80
Sep 28/94	82	0.865	65	110	80
Sep 30/94	84	0.865	65	138	80
Oct 3/94	87	0.865	65	138	80
Oct 7/94	91	0.865	65	138	80
Oct 11/94	95	0.902	65	138	80
Oct 14/94	98	0.902	75	138	80
Oct 17/94	101	0.902	75	138	80
Oct 19/94	103	0.902	85	138	80
Oct 21/94	105	0.902	100	138	80
Oct 23/94	107	0.902	100	138	0
Oct 25/94	109	0.911	50	0	0
Oct 28/94	112	0.911	25	0	0
Nov 1/94	116	0.911	43	44	80
Nov 4/94	119	0.911	55	92	80
Nov 8/94	123	0.911	83	95	80
Nov 11/94	126	0.842	109	131	80
Nov 15/94	130	0.842	130	151	80

MLE System #1

Date	Day	PO4 Feed Conc (g P/l)	CH3OH Feed Conc (ml/l)	NH4Cl Feed Conc (g NH4Cl/l)	NaHCO3 Feed Conc (g/l)
Nov 18/94	133	0.842	145	160	80
Nov 22/94	137	0.842	145	174	80
Nov 25/94	140	0.842	160	174	80
Nov 29/94	144	1.000	160	174	80
Dec 2/94	147	1.000	160	174	80
Dec 6/94	151	1.000	140	174	80
Dec 9/94	154	1.000	140	174	80
Dec 12/94	157	1.000	130	174	80
Dec 16/94	161	1.032	130	174	80
Dec 20/94	165	1.032	140	174	80
Dec 23/94	168	1.032	130	174	80
Dec 27/94	172	1.032	130	174	80
Dec 30/94	175	0.989	130	174	80
Jan 3/95	179	0.989	130	174	80
Jan 6/95	182	0.989	120	174	80
Jan 10/95	186	0.989	120	174	80
Jan 13/95	189	0.989	130	174	80
Jan 17/95	193	0.989	130	174	80
Jan 20/95	196	0.989	130	174	80
Jan 24/95	200	0.951	130	174	80
Jan 27/95	203	0.951	130	174	80
Jan 31/95	207	0.951	130	174	80
Feb 3/95	210	0.951	120	174	80
Feb 7/95	214	0.955	120	174	80
Feb 10/95	217	0.955	120	174	80
Feb 14/95	221	0.951	110	174	80
Feb 17/95	224	0.951	125	160	80
Feb 21/95	228	0.951	120	148	80
Feb 24/95	231	0.951	120	148	80
Feb 28/95	235	0.951	160	145	80
Mar 3/95	238	0.974	145	145	80
Mar 7/95	242	0.974	135	145	80

MLE System #1

Date	Day	O-PO4 Load (g P/d)	Anoxic Methanol COD Load (g COD/d)	Simulated Leachate Ammonia Con'c (mg N/l)	Ammonia Load (g N/d)	NaHCO3 g CaCO3/d)	Anoxic ORF (mV)
Jul 12/94	5		0				
Jul 14/94	7		0				
Jul 15/94	8	0.196	0				
Jul 18/94	11	0.193	0	282	2.79		
Jul 20/94	13	0.189	0	276	2.70		
Jul 22/94	15	0.192	0	269	2.64		
Jul 25/94	18	0.187	0	322	3.16		
Jul 27/94	20	0.187	0	274	2.69		
Aug 1/94	24	0.190	0	273	2.68		
Aug 3/94	26	0.188	0	272	2.67		
Aug 5/94	28	0.185	0	260	2.57		
Aug 8/94	31	0.096	0	269	2.66		
Aug 10/94	33	0.088	0	253	2.50		
Aug 12/94	35	0.091	2.01	253	2.48		
Aug 15/94	38	0.090	1.20	260	1.01		-65
Aug 17/94	40	0.080	1.17	281	2.87		-51
Aug 19/94	42	0.087	2.57	295	2.98		-49
Aug 22/94	45	0.077	2.28	392	4.00		-57
Aug 24/94	47	0.074	3.25	338	3.45		-72
Aug 26/94	49	0.067	5.99	300	3.12		-98
Aug 29/94	52	0.072	5.73	278	2.89		-119
Aug 31/94	54	0.070	7.75	280	2.91		-120
Sep 2/94	56	0.070	9.83	273	2.84		-125
Sep 6/94	60	0.075	11.80	280	2.69		-132
Sep 9/94	63	0.074	13.15	266	2.61		-130
Sep 12/94	66	0.116	12.97	315	3.02		-139
Sep 14/94	68	0.114	13.52	253	2.43		-166
Sep 16/94	70	0.118	13.71	230	2.25		-155
Sep 19/94	73	0.113	13.89	383	3.83		-128
Sep 21/94	75	0.109	13.15	533	5.38	30.66	-125
Sep 23/94	77	0.109	13.15	535	5.24	33.81	-200
Sep 26/94	80	0.116	14.26	763	7.70	49.19	-162
Sep 28/94	82	0.121	13.52	870	8.18	48.54	-127
Sep 30/94	84	0.107	13.89	1018	9.57	50.22	-117
Oct 3/94	87	0.101	13.71	1113	10.47	54.20	-95
Oct 7/94	91	0.098	13.89	1035	9.73	50.76	-109
Oct 11/94	95	0.115	14.08	1015	9.54	57.17	-123
Oct 14/94	98	0.127	16.46	1030	9.69	54.54	-148
Oct 17/94	101	0.113	16.03	1016	9.56	55.52	-163
Oct 19/94	103	0.109	18.90	1053	9.80	38.49	-127
Oct 21/94	105	0.111	22.80	1053	9.81		-138
Oct 23/94	107	0.106	11.54	1053	9.81		
Oct 25/94	109	0.113	11.54	259	2.36		-249
Oct 28/94	112	0.112	5.63	233	2.07		-113
Nov 1/94	116	0.116	9.56	457	4.17	23.24	-103
Nov 4/94	119	0.109	11.91	690	6.28	31.13	-98
Nov 8/94	123	0.111	17.98	716	6.67	34.88	-132
Nov 11/94	126	0.108	26.41	950	8.66	38.47	-158
Nov 15/94	130	0.101	30.38	1009	9.39	41.55	-164

MLE System #1

Date	Day	O-PO4 Load (g P/d)	Anoxic Methanol COD Load (g COD/d)	Simulated Leachate Ammonia Con'c (mg N/l)	Ammonia Load (g N/d)	NaHCO3 g CaCO3/d	Anoxic ORF (mV)
Nov 18/94	133	0.101	35.54	1044	9.73	40.75	-190
Nov 22/94	137	0.106	33.06	1174	10.94	44.68	-192
Nov 25/94	140	0.096	38.76	1156	10.77	43.08	-249
Nov 29/94	144	0.121	36.48	1157	10.77	44.95	-212
Dec 2/94	147	0.134	37.85	1180	10.99	44.72	-208
Dec 6/94	151	0.116	33.12	1183	10.78	43.56	-242
Dec 9/94	154	0.121	33.12	1143	10.64	44.14	-250
Dec 12/94	157	0.119	31.86	1125	10.48	50.20	-242
Dec 16/94	161	0.125	32.60	1198	11.16	44.48	-243
Dec 20/94	165	0.139	35.51	1223	11.40	44.82	-249
Dec 23/94	168	0.122	33.72	1233	11.62	46.67	-261
Dec 27/94	172	0.124	32.60	1201	11.19	44.19	-258
Dec 30/94	175	0.136	33.72	1172	10.92	43.96	-255
Jan 3/95	179	0.114	32.97	1216	11.35	40.23	-235
Jan 6/95	182	0.137	30.78	1134	10.56	42.17	-237
Jan 10/95	186	0.116	30.44	1256	11.72	46.99	-248
Jan 13/95	189	0.119	33.72	1212	11.29	41.50	-255
Jan 17/95	193	0.135	33.72	1255	11.70	38.89	-255
Jan 20/95	196	0.128	30.01	1247	11.64	52.28	-217
Jan 24/95	200	0.128	31.86	1220	11.37	48.56	-227
Jan 27/95	203	0.121	33.35	1200	11.31	45.36	-252
Jan 31/95	207	0.125	32.60	1187	11.18	45.51	-248
Feb 3/95	210	0.118	30.10	1215	11.44	46.54	-238
Feb 7/95	214	0.119	30.78	1278	11.66	43.06	-254
Feb 10/95	217	0.118	30.44	1204	10.86	44.99	-252
Feb 14/95	221	0.127	28.22	1258	11.35	46.60	-238
Feb 17/95	224	0.117	28.86	1180	10.77	41.82	-251
Feb 21/95	228	0.123	26.68	1148	10.47	42.48	-213
Feb 24/95	231	0.116	26.33	1108	10.11	45.80	-202
Feb 28/95	235	0.117	36.02	1051	9.59	49.35	-260
Mar 3/95	238	0.121	32.65	1038	9.46	39.05	-274
Mar 7/95	242	0.119	31.55	1047	9.55	42.76	-285

MLE System #1

Date	Day	Anoxic pH	Aerobic D.O. (mg/l)	Aerobic pH	Anoxic NH4 (mg N/l)	Anoxic Free Ammonia (mg N/l)	Aerobic NH4 (mg N/l)	Aerobic Free Ammonia (mg N/l)
Jul 12/94	5						32	
Jul 14/94	7		3.8					
Jul 15/94	8		3.5	7.5				
Jul 18/94	11		3.2	7.5		0.0	3	0.0
Jul 20/94	13		1.9	7.4		0.0	1	0.0
Jul 22/94	15		3.0	7.5		0.0	1	0.0
Jul 25/94	18		4.5			0.0	1	0.0
Jul 27/94	20		4.1	7.4		0.0	1	0.0
Aug 1/94	24		4.2	7.5		0.0	4	0.0
Aug 3/94	26		5.1	7.7		0.0	12	0.2
Aug 5/94	28		6.2	7.6		0.0	13	0.2
Aug 8/94	31		6.5	7.5		0.0	2	0.0
Aug 10/94	33		4.9	7.4		0.0	1	0.0
Aug 12/94	35	7.6	5.5	7.7	51	0.8	14	0.3
Aug 15/94	38	7.6	6.7	7.7	21	0.3	1	0.0
Aug 17/94	40	7.6	2.4	7.5	58	0.9	16	0.2
Aug 19/94	42	7.6	2.1	7.5	48	0.7	6	0.1
Aug 22/94	45	7.6	2.8	7.5	52	0.8	1	0.0
Aug 24/94	47	7.6	3.0	7.5	48	0.7	1	0.0
Aug 26/94	49	7.6	3.1	7.6	46	0.7	0	0.0
Aug 29/94	52	7.7	3.0	7.7	41	0.8	0	0.0
Aug 31/94	54	7.8	2.6	7.8	40	1.0	0	0.0
Sep 2/94	56	7.9	2.9	7.8	39	1.2	0	0.0
Sep 6/94	60	8.0	2.2	7.9	36	1.4	0	0.0
Sep 9/94	63	8.1	3.0	8.1	35	1.6	0	0.0
Sep 12/94	66	8.1	3.8	8.0	40	1.9	0	0.0
Sep 14/94	68	8.1	3.8	8.1	33	1.6	0	0.0
Sep 16/94	70	8.1	3.2	8.1	29	1.4	0	0.0
Sep 19/94	73	7.9	1.1	7.6	50	1.5	0	0.0
Sep 21/94	75	7.7	1.4	7.5	67	1.3	0	0.0
Sep 23/94	77	7.8	4.9	7.6	66	1.6	0	0.0
Sep 26/94	80	7.7	3.1	7.4	93	1.8	1	0.0
Sep 28/94	82	7.9	3.6	7.5	99	3.0	0	0.0
Sep 30/94	84	8.0	2.8	7.5	153	5.8	31	0.4
Oct 3/94	87	8.0	2.4	7.5	208	7.8	53	0.6
Oct 7/94	91	7.8	2.5	7.5	195	4.7	50	0.6
Oct 11/94	95	7.8	2.5	7.5	209	5.0	105	1.3
Oct 14/94	98	7.9	2.2	7.6	174	5.2	62	1.0
Oct 17/94	101	7.9	2.4	7.5	164	4.9	59	0.7
Oct 19/94	103	7.9	3.7	7.6	214	6.5	119	1.8
Oct 21/94	105	7.9	4.9	7.8	320	9.7	245	5.9
Oct 23/94	107	8.0		8.1	507	19.1	448	21.0
Oct 25/94	109	8.2	6.8	8.3	293	17.1	276	20.0
Oct 28/94	112	7.6	4.7	7.5	37	0.6	5	0.1
Nov 1/94	116	7.6	3.1	7.4	58	0.9	1	0.0
Nov 4/94	119	7.9	2.0	7.4	97	2.9	18	0.2
Nov 8/94	123	7.8	1.4	7.4	80	1.9	0	0.0
Nov 11/94	126	7.9	2.2	7.4	95	2.9	0	0.0
Nov 15/94	130	8.0	1.6	7.3	110	4.1	0	0.0

MLE System #1

Date	Day	Anoxic pH	Aerobic D.O. (mg/l)	Aerobic pH	Anoxic NH4 (mg N/l)	Anoxic Free Ammonia (mg N/l)	Aerobic NH4 (mg N/l)	Aerobic Free Ammonia (mg N/l)
Nov 18/94	133	8.1	2.2	7.3	116	5.4	1	0.0
Nov 22/94	137	8.2	3.4	7.4	131	7.7	20	0.2
Nov 25/94	140	8.2	3.2	7.4	127	7.4	12	0.1
Nov 29/94	144	8.3	3.9	7.5	155	11.2	16	0.2
Dec 2/94	147	8.2	4.1	7.4	156	9.1	17	0.2
Dec 6/94	151	8.4	4.3	7.5	155	13.9	19	0.2
Dec 9/94	154	8.4	4.1	7.4	148	13.3	14	0.1
Dec 12/94	157	8.4	4.9	7.5	123	11.0	10	0.1
Dec 16/94	161	8.5	3.3	7.5	116	12.8	8	0.1
Dec 20/94	165	8.5	4.5	7.5	150	16.5	9	0.1
Dec 23/94	168	8.4	3.6	7.5	146	13.1	9	0.1
Dec 27/94	172	8.4	3.5	7.5	136	12.2	4	0.0
Dec 30/94	175	8.5	4.6	7.5	133	14.7	7	0.1
Jan 3/95	179	8.5	4.3	7.4	144	15.9	18	0.2
Jan 6/95	182	8.3	4.3	7.5	142	10.3	26	0.3
Jan 10/95	186	8.4	3.0	7.6	154	13.8	37	0.6
Jan 13/95	189	8.2	3.5	7.5	248	14.5	111	1.4
Jan 17/95	193	8.3	3.7	7.5	190	13.8	69	0.8
Jan 20/95	196	8.4	4.0	7.6	139	12.4	18	0.3
Jan 24/95	200	8.4	3.8	7.4	139	12.4	14	0.1
Jan 27/95	203	8.4	3.3	7.4	153	13.7	30	0.3
Jan 31/95	207	8.3	2.8	7.4	181	13.1	61	0.6
Feb 3/95	210	8.4	2.7	7.5	186	16.7	65	0.8
Feb 7/95	214	8.3	2.4	7.4	178	12.9	62	0.6
Feb 10/95	217	8.3	2.3	7.4	171	12.4	56	0.5
Feb 14/95	221	8.4	2.4	7.4	191	17.1	71	0.7
Feb 17/95	224	8.3	2.7	7.5	157	11.4	30	0.4
Feb 21/95	228	8.4	3.0	7.4	167	15.0	12	0.1
Feb 24/95	231	8.2	2.3	7.3	149	8.7	29	0.2
Feb 28/95	235	8.3	2.9	7.5	144	10.4	19	0.2
Mar 3/95	238	8.3	2.6	7.5	146	10.6	29	0.4
Mar 7/95	242	8.3	3.3	7.5	140	10.1	21	0.3

MLE System #1

Date	Day	Effluent NH4 (mg N/l)	Anoxic NOx (mg N/l)	Aerobic NOx (mg N/l)	Effluent NOx (mg N/l)	Anoxic NO2 (mg N/l)	Aerobic NO2 (mg N/l)	Effluent NO2 (mg N/l)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8			217				
Jul 18/94	11			243				
Jul 20/94	13			240				
Jul 22/94	15			252				
Jul 25/94	18	1		245	250			
Jul 27/94	20	0		256	251		0.0	
Aug 1/94	24	1		283	297			
Aug 3/94	26	13		297	296		0.0	
Aug 5/94	28	14		235	222		35	40
Aug 8/94	31	0		240	239			
Aug 10/94	33	0		258	248		2.3	2.4
Aug 12/94	35	13	143	183	185	1.2	1.9	1.8
Aug 15/94	38		187	213		0.5	0.3	
Aug 17/94	40	15	176	213	213			
Aug 19/94	42	5	191	230	231	4.0	4.0	4.5
Aug 22/94	45	0	210	250	249	0.7	1.1	0.7
Aug 24/94	47	0	203	246	246			
Aug 26/94	49	0	173	212	212	1.9	0.6	0.2
Aug 29/94	52	0	155	195	195	0.5	0.6	0.1
Aug 31/94	54	0	132	168	169			
Sep 2/94	56	0	121	161	161	0.4	0.3	0.1
Sep 6/94	60	0	67	101	99	0.3	0.3	0.1
Sep 9/94	63	0	50	88	89	0.2	0.2	0.1
Sep 12/94	66	0	43	83	85	0.3	0.2	0.1
Sep 14/94	68	0	20	55	55			
Sep 16/94	70	0	6	36	37	0.2	0.3	0.1
Sep 19/94	73	0	63	109	112	0.6	0.3	0.1
Sep 21/94	75	0	105	157	151	0.1	0.4	0.2
Sep 23/94	77	0	163	224	222	0.2	0.1	0.0
Sep 26/94	80	0	249	361	368	0.3	1.3	1.4
Sep 28/94	82	1	303	386	425	0.5	11.3	12.8
Sep 30/94	84	32	335	434	431	1.0	23.3	24.7
Oct 3/94	87	51	339	458	457	2.5	30.2	31.9
Oct 7/94	91	49	404	467	463	0.6	18.5	20.2
Oct 11/94	95	105	381	489	484	0.3	15.6	16.8
Oct 14/94	98	60	375	481	480	0.2	13.9	15.2
Oct 17/94	101	60	377	498	415	0.6	20.4	21.6
Oct 19/94	103	109	269	343	352	0.1	8.0	8.1
Oct 21/94	105	241	71	131	132	0.1	9.5	9.4
Oct 23/94	107	448						
Oct 25/94	109	271	0	24	26	0.0	8.2	8.8
Oct 28/94	112	2	127	151	164	0.2	0.7	0.8
Nov 1/94	116	0	144	190	195	0.1	1.1	0.3
Nov 4/94	119	17	130	193	196	0.1	0.7	22.6
Nov 8/94	123	0	182	257	259	0.0	0.2	0.9
Nov 11/94	126	0	145	234	237	0.5	1.7	1.4
Nov 15/94	130	0	119	222	216	0.4	2.4	1.8

MLE System #1

Date	Day	Effluent NH4 (mg N/l)	Anoxic NOx (mg N/l)	Aerobic NOx (mg N/l)	Effluent NOx (mg N/l)	Anoxic NO2 (mg N/l)	Aerobic NO2 (mg N/l)	Effluent NO2 (mg N/l)
Nov 18/94	133	1	67	180	179	3	10.0	9.0
Nov 22/94	137	21	46	176	179	1.3	38	41
Nov 25/94	140	13	0	112	115	0.0	43	42
Nov 29/94	144	16	2	121	122	1.3	54	57
Dec 2/94	147	18	13	135	138	11	91	75
Dec 6/94	151	18	1	117	125	0.3	68	69
Dec 9/94	154	13	1	126	131	0.2	68	72
Dec 12/94	157	10	0	121	124	0.0	69	71
Dec 16/94	161	7	1	143	145	0.6	87	88
Dec 20/94	165	9	0	158	153	0.0	83	82
Dec 23/94	168	9	0	131	131	0.0	84	85
Dec 27/94	172	3	1	141	138	0.7	85	86
Dec 30/94	175	7	1	137	136	0.1	80	78
Jan 3/95	179	17	0	127	124	0.0	82	78
Jan 6/95	182	25	1	107	98	0.2	70	62
Jan 10/95	186	36	0	105	98	0.0	68	62
Jan 13/95	189	109	0	102	89	0.0	62	55
Jan 17/95	193	63	1	122	116	0.6	78	73
Jan 20/95	196	17	137	310	293	74.0	171	167
Jan 24/95	200	15	55	231	214	31.0	129	116
Jan 27/95	203	29	1	156	149	0.3	89	83
Jan 31/95	207	58	0	149	137	0.0	85	77
Feb 3/95	210	60	2	160	150	0.9	95	88
Feb 7/95	214	60	1	185	142	0.7	115	82
Feb 10/95	217	53	0	144	138	0.0	87	80
Feb 14/95	221	70	5	181	164	2.8	106	93
Feb 17/95	224	29	1	137	130	0.2	78	72
Feb 21/95	228	7	0	180	166	0.0	87	80
Feb 24/95	231	25	153	332	309	84.0	171	157
Feb 28/95	235	17	0	94	89	0.0	73	67
Mar 3/95	238	31	1	106	100	0.2	62	59
Mar 7/95	242	21	1	108	102	0.3	61	56

MLE System #1

Date	Day	Anoxic O-PO4 (mg P/l)	Aerobic O-PO4 (mg P/l)	Anoxic TSS (mg/l)	Aerobic TSS (mg/l)	Effluent TSS (mg/l)	Anoxic VSS (mg/l)	Aerobic VSS (mg/l)
Jul 12/94	5				2232			1632
Jul 14/94	7							
Jul 15/94	8				2408			1768
Jul 18/94	11				2576			1848
Jul 20/94	13				2528			1800
Jul 22/94	15				2828			2008
Jul 25/94	18				2724	45		1864
Jul 27/94	20				2640	43		1784
Aug 1/94	24		11.7		2712	36		1676
Aug 3/94	26		11.4					
Aug 5/94	28		10.6		2584	61		1576
Aug 8/94	31		6.9		2604	36		1644
Aug 10/94	33		7.0					
Aug 12/94	35	2.4	2.4	2944	1980	9	1980	1340
Aug 15/94	38	8.8	8.0	3148	2152	11	2116	1492
Aug 17/94	40	8.3	7.4	3376	1920	8	2244	1304
Aug 19/94	42	7.0	6.6	3548	1988	8	2384	1360
Aug 22/94	45	6.3	5.8	3336	2108	6	2212	1424
Aug 24/94	47	5.6	5.3	3064	2012	6	2044	1368
Aug 26/94	49	4.6	4.2	3236	1980	5	2184	1364
Aug 29/94	52	3.9	3.7	3308	2128	3	2304	1480
Aug 31/94	54	3.6	3.1	3248	2252	5	2240	1576
Sep 2/94	56	3.2	3.0	3256	2296	6	2288	1604
Sep 6/94	60	2.5	2.1	3884	2640	4	2796	1932
Sep 9/94	63	2.1	1.9	3792	2664	7	2796	1960
Sep 12/94	66	2.5	2.3	3836	2632	4	2908	2000
Sep 14/94	68	2.5	2.4	3704	2720	4	2804	2060
Sep 16/94	70	2.8	2.8	3620	2612	4	2720	1968
Sep 19/94	73	3.5	3.5	3592	2720	4	2756	2092
Sep 21/94	75	4.3	4.0	3584	2716	6	2780	2116
Sep 23/94	77	4.6	4.3	3836	2576	6	2980	2016
Sep 26/94	80	5.3	5.0	3784	2604	8	2984	2044
Sep 28/94	82	5.6	5.1	3816	2616	10	3036	2088
Sep 30/94	84	5.6	4.9	3896	2724	21	3092	2172
Oct 3/94	87	5.7	4.9	3900	2736	30	3144	2216
Oct 7/94	91	5.0	4.1	4228	2824	25	3328	2284
Oct 11/94	95	5.2	4.3	4120	2888	25	3360	2372
Oct 14/94	98	4.8	4.0	4032	2852	69	3300	2352
Oct 17/94	101	5.2	4.3	3932	2836	31	3228	2328
Oct 19/94	103	4.5	3.6	4316	3108	36	3596	2572
Oct 21/94	105	2.9	3.2	4212	3108	39	3492	2572
Oct 23/94	107							
Oct 25/94	109	4.7	4.1	3960	3440	42	3212	2804
Oct 28/94	112	7.3	8.8	3600	2848	30	2884	2300
Nov 1/94	116	7.7	7.1	3720	2908	11	2940	2332
Nov 4/94	119	7.5	6.6	4132	3356	27	3280	2648
Nov 8/94	123	6.3	5.9	4704	3496	38	3768	2800
Nov 11/94	126	4.0	3.6	5304	3908	15	4292	3148
Nov 15/94	130	3.6	3.1	5696	4336	49	4696	3576

MLE System #1

Date	Day	Anoxic O-PO4 (mg P/l)	Aerobic O-PO4 (mg P/l)	Anoxic TSS (mg/l)	Aerobic TSS (mg/l)	Effluent TSS (mg/l)	Anoxic VSS (mg/l)	Aerobic VSS (mg/l)
Nov 18/94	133	2.8	2.5	5916	4408	10	4932	3644
Nov 22/94	137	2.5	2.3	6404	4720	33	5396	3964
Nov 25/94	140	2.3	1.8	7020	4936	24	6008	4204
Nov 29/94	144	2.3		7218	5308	21	6128	4552
Dec 2/94	147	2.2	2.3	7036	5348	34	6068	4592
Dec 6/94	151	2.4	2.4	7068	5212	32	6164	4524
Dec 9/94	154	2.9	2.7	6992	5348	60	6128	4668
Dec 12/94	157	3.3	3.0	6704	5412	26	5876	4724
Dec 16/94	161	3.0	3.4	6732	4932	42	5912	4320
Dec 20/94	165	2.9	3.7	7036	4880	43	6220	4292
Dec 23/94	168	3.6	3.8	7248	4796	22	6420	4248
Dec 27/94	172	3.1	3.5	7224	5364	38	6376	4696
Dec 30/94	175	3.0	3.7	6944	5060	27	6148	4452
Jan 3/95	179	3.6	3.8	6500	5064	33	5772	4484
Jan 6/95	182	5.3	4.8	6172	5004	24	5504	4436
Jan 10/95	186	5.6	5.0	6264	4488	23	5616	4032
Jan 13/95	189	4.9	4.2	6268	4588	48	5628	4132
Jan 17/95	193	4.0	3.9	6880	5132	26	6156	4544
Jan 20/95	196	3.5	4.1	6652	5356	37	5912	4720
Jan 24/95	200	3.2	3.5	7016	5572	13	6224	4912
Jan 27/95	203	3.6	3.6	7120	5328	21	6376	4768
Jan 31/95	207	4.2	4.2	7248	5556	11	6504	4972
Feb 3/95	210	3.9	3.8	7196	5436	15	6460	4884
Feb 7/95	214	4.6	4.5	7520	5756	12	6728	5160
Feb 10/95	217	4.6	4.5	7652	5664	15	6856	5076
Feb 14/95	221	4.1	4.3	7304	5784	18	6504	5164
Feb 17/95	224	4.4	4.2	7656	6016	15	6816	5352
Feb 21/95	228	4.2	4.4	7188	6140	11	6412	5460
Feb 24/95	231	5.5	5.8	7208	6088	23	6420	5412
Feb 28/95	235	4.3	3.9	8244	6280	15	7336	5568
Mar 3/95	238	3.9	3.4	8512	6500	38	7584	5764
Mar 7/95	242	4.1	3.6	9356	6712	23	8304	5940

MLE System #1

Date	Day	Effluent VSS (mg/l)	Anoxic BOD5 (mg/l)	Aerobic BOD5 (mg/l)	Effluent BOD5 (mg/l)	Anoxic COD (mg/l)	Aerobic COD (mg/l)	Effluent COD (mg/l)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8							
Jul 18/94	11							
Jul 20/94	13							
Jul 22/94	15							
Jul 25/94	18	29						
Jul 27/94	20	27					403	390
Aug 1/94	24	23						
Aug 3/94	26						390	417
Aug 5/94	28	35						
Aug 8/94	31	24						
Aug 10/94	33							
Aug 12/94	35	8						
Aug 15/94	38	8				302	302	
Aug 17/94	40	7						
Aug 19/94	42	7		9		368	351	384
Aug 22/94	45	5				401	417	335
Aug 24/94	47	5						
Aug 26/94	49	4				446	429	412
Aug 29/94	52	3				446	429	429
Aug 31/94	54	4						
Sep 2/94	56	5				420	403	403
Sep 6/94	60	3				438	386	386
Sep 9/94	63	5	11	5	5	412	394	394
Sep 12/94	66	4				429	394	394
Sep 14/94	68	4						
Sep 16/94	70	4				333	317	300
Sep 19/94	73	4				333	267	350
Sep 21/94	75	6						
Sep 23/94	77	6				318	318	334
Sep 26/94	80	6				366	318	318
Sep 28/94	82	9						
Sep 30/94	84	17						
Oct 3/94	87	22				477	445	445
Oct 7/94	91	22				438	438	438
Oct 11/94	95	19				473	420	438
Oct 14/94	98	50				456	438	419
Oct 17/94	101	26						
Oct 19/94	103	30						
Oct 21/94	105	33				510	510	510
Oct 23/94	107							
Oct 25/94	109	39				579	516	526
Oct 28/94	112	24				377	417	397
Nov 1/94	116	9				356	316	377
Nov 4/94	119	23				309	267	303
Nov 8/94	123	32				326	275	309
Nov 11/94	126	15				341	288	306
Nov 15/94	130	44				341	320	320

MLE System #1

Date	Day	Effluent VSS (mg/l)	Anoxic BOD5 (mg/l)	Aerobic BOD5 (mg/l)	Effluent BOD5 (mg/l)	Anoxic COD (mg/l)	Aerobic COD (mg/l)	Effluent COD (mg/l)
Nov 18/94	133	8						
Nov 22/94	137	30						
Nov 25/94	140	21				281	281	281
Nov 29/94	144	18				281	248	248
Dec 2/94	147	28	29	16	15	243	188	173
Dec 6/94	151	30				288	180	180
Dec 9/94	154	56	36	17	14	200	158	120
Dec 12/94	157	23				233	91	89
Dec 16/94	161	36						
Dec 20/94	165	37				577	212	212
Dec 23/94	168	19				441	177	202
Dec 27/94	172	29	9	14	11	303	210	208
Dec 30/94	175	23				328	240	242
Jan 3/95	179	30						
Jan 6/95	182	22	10	11	8	400	177	137
Jan 10/95	186	23	114	12	19	352	82	137
Jan 13/95	189	41				433	235	243
Jan 17/95	193	17				346	174	180
Jan 20/95	196	16						
Jan 24/95	200	12	74	9	7			
Jan 27/95	203	16				333	194	201
Jan 31/95	207	8	94	10	9	333	199	207
Feb 3/95	210	15						
Feb 7/95	214	11						
Feb 10/95	217	13	35	12	12			
Feb 14/95	221	15	14	10	11			
Feb 17/95	224	13				413	250	238
Feb 21/95	228	9	11	11	7	317	202	268
Feb 24/95	231	21				255	140	137
Feb 28/95	235	14					268	254
Mar 3/95	238	32	86	14	14	384	204	207
Mar 7/95	242	19				336	223	168

MLE System #1

Date	Day	Anoxic VSS/TSS	Aerobic VSS/TSS	Effluent VSS/TSS	Anoxic NO2/NOx	Aerobic NO2/NOx	Effluent NO2/NOx
Jul 12/94	5		0.73				
Jul 14/94	7						
Jul 15/94	8		0.73				
Jul 18/94	11		0.72				
Jul 20/94	13		0.71				
Jul 22/94	15		0.71				
Jul 25/94	18		0.68	0.64			
Jul 27/94	20		0.68	0.63			
Aug 1/94	24		0.62	0.64			
Aug 3/94	26						
Aug 5/94	28		0.61	0.57		0.15	
Aug 8/94	31		0.63	0.67			
Aug 10/94	33					0.01	0.01
Aug 12/94	35	0.67	0.68	0.89	0.01	0.01	0.01
Aug 15/94	38	0.67	0.69	0.73	0.00	0.00	
Aug 17/94	40	0.66	0.68	0.88			
Aug 19/94	42	0.67	0.68	0.88	0.02	0.02	0.02
Aug 22/94	45	0.66	0.68	0.83	0.00	0.00	0.00
Aug 24/94	47	0.67	0.68	0.83			
Aug 26/94	49	0.67	0.69	0.80	0.01	0.00	0.00
Aug 29/94	52	0.70	0.70	1.00	0.00	0.00	0.00
Aug 31/94	54	0.69	0.70	0.80			
Sep 2/94	56	0.70	0.70	0.83	0.00	0.00	0.00
Sep 6/94	60	0.72	0.73	0.75	0.00	0.00	0.00
Sep 9/94	63	0.74	0.74	0.71	0.00	0.00	0.00
Sep 12/94	66	0.76	0.76	1.00	0.01	0.00	0.00
Sep 14/94	68	0.76	0.76	1.00			
Sep 16/94	70	0.75	0.75	1.00	0.03	0.01	0.00
Sep 19/94	73	0.77	0.77	1.00	0.01	0.00	0.00
Sep 21/94	75	0.78	0.78	1.00	0.00	0.00	0.00
Sep 23/94	77	0.78	0.78	1.00	0.00	0.00	0.00
Sep 26/94	80	0.79	0.78	0.75	0.00	0.00	0.00
Sep 28/94	82	0.80	0.80	0.90	0.00	0.03	0.03
Sep 30/94	84	0.79	0.80	0.81	0.00	0.05	0.06
Oct 3/94	87	0.81	0.81	0.73	0.01	0.07	0.07
Oct 7/94	91	0.79	0.81	0.88	0.00	0.04	0.04
Oct 11/94	95	0.82	0.82	0.76	0.00	0.03	0.03
Oct 14/94	98	0.82	0.82	0.72	0.00	0.03	0.03
Oct 17/94	101	0.82	0.82	0.84	0.00	0.04	0.05
Oct 19/94	103	0.83	0.83	0.83	0.00	0.02	0.02
Oct 21/94	105	0.83	0.83	0.85	0.00	0.07	0.07
Oct 23/94	107						
Oct 25/94	109	0.81	0.82	0.93	0.00	0.34	0.34
Oct 28/94	112	0.80	0.81	0.80	0.00	0.00	0.00
Nov 1/94	116	0.79	0.80	0.82	0.00	0.01	0.00
Nov 4/94	119	0.79	0.79	0.85	0.00	0.00	0.12
Nov 8/94	123	0.80	0.80	0.84	0.00	0.00	0.00
Nov 11/94	126	0.81	0.81	1.00	0.00	0.01	0.01
Nov 15/94	130	0.82	0.82	0.90	0.00	0.01	0.01

MLE System #1

Date	Day	Anoxic VSS/TSS	Aerobic VSS/TSS	Effluent VSS/TSS	Anoxic NO2/NOx	Aerobic NO2/NOx	Effluent NO2/NOx
Nov 18/94	133	0.83	0.83	0.80	0.04	0.06	0.05
Nov 22/94	137	0.84	0.84	0.91	0.03	0.22	0.23
Nov 25/94	140	0.86	0.85	0.88	0.00	0.38	0.37
Nov 29/94	144	0.85	0.86	0.86	0.65	0.45	0.47
Dec 2/94	147	0.86	0.86	0.82	0.85	0.67	0.54
Dec 6/94	151	0.87	0.87	0.94	0.30	0.58	0.55
Dec 9/94	154	0.88	0.87	0.93	0.20	0.54	0.55
Dec 12/94	157	0.88	0.87	0.88	0.00	0.57	0.57
Dec 16/94	161	0.88	0.88	0.86	0.60	0.61	0.61
Dec 20/94	165	0.88	0.88	0.86	0.00	0.53	0.54
Dec 23/94	168	0.89	0.89	0.86	0.00	0.64	0.65
Dec 27/94	172	0.88	0.88	0.76	0.70	0.60	0.62
Dec 30/94	175	0.89	0.88	0.85	0.10	0.58	0.57
Jan 3/95	179	0.89	0.89	0.91	0.00	0.65	0.63
Jan 6/95	182	0.89	0.89	0.92	0.20	0.65	0.63
Jan 10/95	186	0.90	0.90	1.00	0.00	0.65	0.63
Jan 13/95	189	0.90	0.90	0.85	0.00	0.61	0.62
Jan 17/95	193	0.89	0.89	0.65	0.60	0.64	0.63
Jan 20/95	196	0.89	0.88	0.43	0.54	0.55	0.57
Jan 24/95	200	0.89	0.88	0.92	0.56	0.56	0.54
Jan 27/95	203	0.90	0.89	0.76	0.30	0.57	0.56
Jan 31/95	207	0.90	0.89	0.73	0.00	0.57	0.56
Feb 3/95	210	0.90	0.90	1.00	0.45	0.59	0.59
Feb 7/95	214	0.89	0.90	0.92	0.70	0.62	0.58
Feb 10/95	217	0.90	0.90	0.87	0.00	0.60	0.58
Feb 14/95	221	0.89	0.89	0.83	0.56	0.59	0.57
Feb 17/95	224	0.89	0.89	0.87	0.20	0.57	0.55
Feb 21/95	228	0.89	0.89	0.82	0.00	0.48	0.48
Feb 24/95	231	0.89	0.89	0.91	0.55	0.52	0.51
Feb 28/95	235	0.89	0.89	0.93	0.00	0.78	0.75
Mar 3/95	238	0.89	0.89	0.84	0.20	0.58	0.59
Mar 7/95	242	0.89	0.88	0.83	0.30	0.56	0.55

MLE System #1

Date	Day	Anoxic NH4 Removal Rate (mg N/d)	Aerobic NH4 Removal Rate (mg N/d)	% Anoxic NH4 Removal	% Aerobic NH4 Removal	% System NH4 Removal	Anoxic NOx Load (mg N/d)
Jul 12/94	5						
Jul 14/94	7						
Jul 15/94	8						
Jul 18/94	11						
Jul 20/94	13						
Jul 22/94	15						
Jul 25/94	18					100	
Jul 27/94	20					100	
Aug 1/94	24					100	
Aug 3/94	26					95	
Aug 5/94	28					95	
Aug 8/94	31					100	
Aug 10/94	33					100	
Aug 12/94	35	-358	2699	-10.7	72.5	95	11533
Aug 15/94	38	-362	1374	-34.7	97.6	100	13420
Aug 17/94	40	-371	3077	-9.7	73.3	95	13229
Aug 19/94	42	-164	3083	-4.9	87.7	98	14498
Aug 22/94	45	288	3701	7.1	98.3	100	15527
Aug 24/94	47	45	3397	1.3	99.0	100	15056
Aug 26/94	49	-160	3277	-5.1	99.3	100	12988
Aug 29/94	52	-31	2919	-1.1	99.3	100	11936
Aug 31/94	54	56	2854	1.9	99.5	100	10284
Sep 2/94	56	48	2790	1.7	99.7	100	9859
Sep 6/94	60	141	2546	5.2	99.7	100	6197
Sep 9/94	63	124	2482	4.7	99.7	100	5391
Sep 12/94	66	157	2866	5.2	99.8	100	5156
Sep 14/94	68	124	2304	5.1	99.7	100	3318
Sep 16/94	70	250	2003	11.0	99.7	100	2141
Sep 19/94	73	315	3517	8.2	99.6	100	6575
Sep 21/94	75	717	4663	13.3	99.7	100	9327
Sep 23/94	77	655	4581	12.5	99.8	100	13318
Sep 26/94	80	1252	6444	16.2	99.2	100	21448
Sep 28/94	82	1355	6823	16.5	99.7	100	22939
Sep 30/94	84	849	8398	7.4	79.4	97	25791
Oct 3/94	87	-762	10677	-5.6	74.3	95	27212
Oct 7/94	91	-779	9989	-6.1	74.1	95	27747
Oct 11/94	95	1333	7109	8.4	49.2	90	29052
Oct 14/94	98	1240	7801	9.2	64.0	94	29009
Oct 17/94	101	1630	7308	12.4	63.6	94	30038
Oct 19/94	103	2180	6423	13.0	44.1	90	20080
Oct 21/94	105	2335	5110	9.7	23.4	77	7666
Oct 23/94	107	1487	4018	4.1	11.6	57	
Oct 25/94	109	-1323	1136	-7.2	5.8	-5	1387
Oct 28/94	112	-132	2161	-5.6	86.5	99	8836
Nov 1/94	116	285	3873	6.7	98.3	100	11118
Nov 4/94	119	818	5287	11.2	81.3	98	11119
Nov 8/94	123	1286	5380	19.3	100.0	100	14806
Nov 11/94	126	2289	6370	26.4	100.0	100	13482
Nov 15/94	130	2094	7297	22.3	100.0	100	12590

MLE System #1

Date	Day	Anoxic NH4 Removal Rate (mg N/d)	Aerobic NH4 Removal Rate (mg N/d)	% Anoxic NH4 Removal	% Aerobic NH4 Removal	% System NH4 Removal	Anoxic NOx Load (mg N/d)
Nov 18/94	133	2086	7629	21.3	99.1	100	10216
Nov 22/94	137	3385	7353	28.0	84.6	98	9982
Nov 25/94	140	3026	7622	26.4	90.5	99	6356
Nov 29/94	144	521	10086	4.4	89.6	99	7625
Dec 2/94	147	852	9963	7.1	89.0	98	8386
Dec 6/94	151	875	9717	7.3	87.6	98	7267
Dec 9/94	154	894	9605	7.8	90.4	99	7826
Dec 12/94	157	2277	8099	20.5	91.8	99	7516
Dec 16/94	161	2947	8134	25.2	93.0	99	9397
Dec 20/94	165	812	10495	6.8	93.9	99	10242
Dec 23/94	168	1320	10210	10.8	93.8	99	8492
Dec 27/94	172	1323	9826	11.6	97.0	100	9139
Dec 30/94	175	1466	9379	12.9	94.7	99	8879
Jan 3/95	179	1787	9371	14.3	87.4	99	8234
Jan 6/95	182	1673	8619	13.7	81.5	98	6940
Jan 10/95	186	2646	8689	18.7	75.7	97	6806
Jan 13/95	189	19	10135	0.1	54.9	91	6612
Jan 17/95	193	2019	8975	12.5	63.4	95	7907
Jan 20/95	196	2450	8997	19.1	86.9	99	20091
Jan 24/95	200	1927	9299	15.7	89.8	99	14972
Jan 27/95	203	1734	9262	13.1	80.2	98	10252
Jan 31/95	207	1525	9016	10.0	66.0	95	9791
Feb 3/95	210	1678	9086	10.7	64.7	95	10517
Feb 7/95	214	2356	8679	15.0	64.9	95	12156
Feb 10/95	217	1703	8591	11.7	66.9	96	9463
Feb 14/95	221	1783	8851	11.2	62.5	94	11731
Feb 17/95	224	940	9529	7.4	80.7	98	9004
Feb 21/95	228	-1294	11645	-11.5	92.8	99	11830
Feb 24/95	231	815	8999	6.8	80.4	98	21814
Feb 28/95	235	125	9268	1.2	86.7	98	6094
Mar 3/95	238	500	8672	4.4	80.0	97	6871
Mar 7/95	242	516	8824	4.7	84.9	98	7000

MLE System #1

Date	Day	Anoxic Denitr Rate (mg N/d)	Anoxic Specific Denitr Rate (mg N/d/ mg VSS)	% Anoxic Denitr	Aerobic Nitr Rate (mg N/d)	Aerobic Specific Nitr Rate (mg N/d/ mg VSS)	% Aerobic Nitr	Anoxic COD:NOx Entering (mg COD/ mg N)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8							
Jul 18/94	11							
Jul 20/94	13							
Jul 22/94	15							
Jul 25/94	18							
Jul 27/94	20							
Aug 1/94	24							
Aug 3/94	26							
Aug 5/94	28							
Aug 8/94	31							
Aug 10/94	33							
Aug 12/94	35	1103	0.111	9.6	2917	0.218	78.4	0.17
Aug 15/94	38	884	0.084	6.6	1743	0.117	123.8	0.09
Aug 17/94	40	485	0.043	3.7	2679	0.205	63.8	0.09
Aug 19/94	42	512	0.043	3.5	2856	0.210	81.3	0.18
Aug 22/94	45	317	0.029	2.0	2897	0.203	76.9	0.15
Aug 24/94	47	538	0.053	3.6	3075	0.225	89.6	0.22
Aug 26/94	49	582	0.053	4.5	2797	0.205	84.8	0.46
Aug 29/94	52	820	0.071	6.9	2869	0.194	97.6	0.48
Aug 31/94	54	817	0.073	7.9	2582	0.164	90.0	0.75
Sep 2/94	56	1181	0.103	12.0	2869	0.179	102.6	1.00
Sep 6/94	60	1445	0.103	23.3	2411	0.125	94.4	1.90
Sep 9/94	63	1834	0.131	34.0	2703	0.138	108.6	2.44
Sep 12/94	66	2068	0.142	40.1	2873	0.144	100.0	2.51
Sep 14/94	68	1918	0.137	57.8	2451	0.119	106.1	4.08
Sep 16/94	70	1725	0.127	80.6	2080	0.106	103.4	6.40
Sep 19/94	73	2126	0.154	32.3	3249	0.155	92.0	2.11
Sep 21/94	75	1998	0.144	21.4	3663	0.173	78.3	1.41
Sep 23/94	77	1987	0.133	14.9	4305	0.214	93.8	0.99
Sep 26/94	80	4064	0.272	18.9	8036	0.393	123.8	0.67
Sep 28/94	82	1992	0.131	8.7	5976	0.286	87.3	0.59
Sep 30/94	84	2641	0.171	10.2	7106	0.327	67.2	0.54
Oct 3/94	87	3780	0.240	13.9	8546	0.386	59.4	0.50
Oct 7/94	91	-173	-0.010	-0.6	4648	0.203	34.5	0.50
Oct 11/94	95	2716	0.162	9.3	7839	0.330	54.3	0.48
Oct 14/94	98	2742	0.166	9.5	7765	0.330	63.7	0.57
Oct 17/94	101	3638	0.225	12.1	8853	0.380	77.1	0.53
Oct 19/94	103	1756	0.098	8.7	5182	0.201	35.5	0.94
Oct 21/94	105	2829	0.162	36.9	4088	0.159	18.8	2.97
Oct 23/94	107							
Oct 25/94	109	1387	0.086	100.0	1604	0.057	8.2	8.32
Oct 28/94	112	261	0.018	3.0	1620	0.070	64.9	0.64
Nov 1/94	116	1334	0.091	12.0	3166	0.136	80.3	0.86
Nov 4/94	119	2408	0.147	21.7	4295	0.162	66.1	1.07
Nov 8/94	123	2567	0.136	17.3	5157	0.184	95.9	1.21
Nov 11/94	126	3759	0.175	27.9	6090	0.193	95.6	1.96
Nov 15/94	130	4696	0.200	37.3	6973	0.195	95.6	2.41

MLE System #1

Date	Day	Anoxic Denitr Rate (mg N/d/ mg VSS)	Anoxic Specific Denitr Rate (mg N/d/ mg VSS)	% Anoxic Denitr	Aerobic Nitr Rate (mg N/d)	Aerobic Specific Nitr Rate (mg N/d/ mg VSS)	% Aerobic Nitr	Anoxic COD:NOx Entering (mg COD/ mg N)
Nov 18/94	133	5771	0.234	56.5	7608	0.209	98.9	3.48
Nov 22/94	137	6929	0.257	69.4	8748	0.221	100.6	3.31
Nov 25/94	140	6356	0.212	100.0	7503	0.178	89.1	6.10
Nov 29/94	144	7480	0.244	98.1	8723	0.192	77.5	4.78
Dec 2/94	147	7453	0.246	88.9	8842	0.193	79.0	4.51
Dec 6/94	151	7196	0.233	99.0	8380	0.185	75.6	4.56
Dec 9/94	154	7755	0.253	99.1	9057	0.194	85.3	4.23
Dec 12/94	157	7516	0.256	100.0	8777	0.186	99.5	4.24
Dec 16/94	161	9322	0.315	99.2	10797	0.250	123.5	3.47
Dec 20/94	165	10242	0.329	100.0	11874	0.277	106.3	3.47
Dec 23/94	168	8492	0.265	100.0	9862	0.232	90.6	3.97
Dec 27/94	172	9064	0.284	99.2	10524	0.224	103.9	3.57
Dec 30/94	175	8805	0.286	99.2	10224	0.230	103.2	3.80
Jan 3/95	179	8234	0.285	100.0	9547	0.213	89.0	4.00
Jan 6/95	182	6866	0.249	98.9	7973	0.180	75.4	4.44
Jan 10/95	186	6806	0.242	100.0	7895	0.196	68.8	4.47
Jan 13/95	189	6612	0.235	100.0	7654	0.185	41.5	5.10
Jan 17/95	193	7833	0.254	99.1	9080	0.200	64.2	4.26
Jan 20/95	196	9887	0.334	49.2	13145	0.278	127.0	1.49
Jan 24/95	200	10875	0.349	72.6	13291	0.271	128.4	2.13
Jan 27/95	203	10176	0.319	99.3	11811	0.248	102.3	3.25
Jan 31/95	207	9791	0.301	100.0	11342	0.228	83.0	3.33
Feb 3/95	210	10366	0.321	98.6	12031	0.246	85.7	2.86
Feb 7/95	214	12081	0.359	99.4	13959	0.271	104.3	2.53
Feb 10/95	217	9463	0.276	100.0	10912	0.215	85.0	3.22
Feb 14/95	221	11361	0.349	96.8	13184	0.255	93.1	2.41
Feb 17/95	224	8928	0.262	99.2	10306	0.193	87.3	3.20
Feb 21/95	228	11830	0.369	100.0	13643	0.250	108.7	2.26
Feb 24/95	231	10314	0.321	47.3	13682	0.253	122.2	1.21
Feb 28/95	235	6094	0.166	100.0	7055	0.127	66.0	5.91
Mar 3/95	238	6797	0.179	98.9	7859	0.136	72.5	4.75
Mar 7/95	242	6926	0.167	98.9	8012	0.135	77.1	4.51

MLE System #1

Date	Day	Anoxic COD:NOx Removed (mg COD/ mg N)	Aerobic Alk:NH4 Added (g CaCO3/ g N)	Aerobic Alk:NH4 Nitrified (g CaCO3/ g N)	Aerobic SRT (days)	System SRT (days)	Simulated Leachate Flow (l/d)
Jul 12/94	5						
Jul 14/94	7						
Jul 15/94	8						9.8
Jul 18/94	11						9.9
Jul 20/94	13						9.8
Jul 22/94	15						9.8
Jul 25/94	18						9.8
Jul 27/94	20						9.8
Aug 1/94	24				10		9.8
Aug 3/94	26				10		9.8
Aug 5/94	28						9.9
Aug 8/94	31				10		9.9
Aug 10/94	33				10		9.9
Aug 12/94	35	1.82					9.8
Aug 15/94	38	1.35					3.9
Aug 17/94	40	2.41					10.2
Aug 19/94	42	5.01			20	43.0	10.1
Aug 22/94	45	7.20			20	42.5	10.2
Aug 24/94	47	6.04			20	41.8	10.2
Aug 26/94	49	10.28			20	43.3	10.4
Aug 29/94	52	6.99			20	43.7	10.4
Aug 31/94	54	9.49			20	42.0	10.4
Sep 2/94	56	8.32			20	41.5	10.4
Sep 6/94	60	8.17			20	43.2	9.6
Sep 9/94	63	7.17			20	42.1	9.8
Sep 12/94	66	6.27			20	42.9	9.6
Sep 14/94	68	7.05			13	28.4	9.6
Sep 16/94	70	7.95			13	28.4	9.8
Sep 19/94	73	6.54			13	28.0	10.0
Sep 21/94	75	6.58	5.70	8.37	13	27.6	10.1
Sep 23/94	77	6.62	6.46	7.85	13	28.7	9.8
Sep 26/94	80	3.51	6.39	6.12	13	28.5	10.1
Sep 28/94	82	6.79	5.93	8.12	13	28.0	9.4
Sep 30/94	84	5.26	5.25	7.07	13	26.6	9.4
Oct 3/94	87	3.63	5.18	6.34	13	25.9	9.4
Oct 7/94	91	-80.41	5.22	10.92	13	26.2	9.4
Oct 11/94	95	5.18	5.99	7.29	13	26.5	9.4
Oct 14/94	98	6.00	5.63	7.02	13	22.6	9.4
Oct 17/94	101	4.41	5.81	6.27	13	25.3	9.4
Oct 19/94	103	10.76	3.93	7.43	13	25.4	9.3
Oct 21/94	105	8.06			13	24.9	9.3
Oct 23/94	107						
Oct 25/94	109	8.32			13	23.6	9.1
Oct 28/94	112	21.53			13	25.2	8.9
Nov 1/94	116	7.17	5.58	7.34	13	27.1	9.1
Nov 4/94	119	4.95	4.96	7.25	13	25.4	9.1
Nov 8/94	123	7.00	5.23	6.76	13	25.1	9.3
Nov 11/94	126	7.03	4.44	6.32	13	27.4	9.1
Nov 15/94	130	6.47	4.42	5.96	13	24.6	9.3

MLE System #1

Date	Day	Anoxic COD:NOx Removed (mg COD/ mg N)	Aerobic Alk:NH4 Added (g CaCO3/ g N)	Aerobic Alk:NH4 Nitrified (g CaCO3/ g N)	Aerobic SRT (days)	System SRT (days)	Simulated Leachate Flow (l/d)
Nov 18/94	133	6.16	4.19	5.36	13	28.2	9.3
Nov 22/94	137	4.77	4.08	5.11	13	26.3	9.3
Nov 25/94	140	6.10	4.00	5.74	13	27.6	9.3
Nov 29/94	144	4.88	4.17	5.15	10	20.9	9.3
Dec 2/94	147	5.08	4.07	5.06	10	20.3	9.3
Dec 6/94	151	4.60	4.04	5.20	10	20.4	9.1
Dec 9/94	154	4.27	4.15	4.87	10	19.2	9.3
Dec 12/94	157	4.24	4.79	5.72	10	20.2	9.3
Dec 16/94	161	3.50	3.98	4.12	10	20.1	9.3
Dec 20/94	165	3.47	3.93	3.77	10	20.4	9.3
Dec 23/94	168	3.97	4.02	4.73	10	21.5	9.4
Dec 27/94	172	3.60	3.95	4.20	10	20.5	9.3
Dec 30/94	175	3.83	4.03	4.30	10	20.8	9.3
Jan 3/95	179	4.00	3.55	4.21	10	20.0	9.3
Jan 6/95	182	4.48	3.99	5.29	10	20.2	9.3
Jan 10/95	186	4.47	4.01	5.95	10	20.7	9.3
Jan 13/95	189	5.10	3.68	5.42	15	28.3	9.3
Jan 17/95	193	4.30	3.32	4.28	15	30.7	9.3
Jan 20/95	196	3.04	4.49	3.98	15	30.1	9.3
Jan 24/95	200	2.93	4.27	3.65	15	30.7	9.3
Jan 27/95	203	3.28	4.01	3.84	20	40.5	9.4
Jan 31/95	207	3.33	4.07	4.01	20	41.7	9.4
Feb 3/95	210	2.90	4.07	3.87	20	40.6	9.4
Feb 7/95	214	2.55	3.69	3.08	20	41.3	9.1
Feb 10/95	217	3.22	4.14	4.12	20	41.4	9.0
Feb 14/95	221	2.48	4.11	3.53	20	40.2	9.0
Feb 17/95	224	3.23	3.88	4.06	20	40.7	9.1
Feb 21/95	228	2.26	4.06	3.11	20	40.4	9.1
Feb 24/95	231	2.55	4.53	3.35	20	38.8	9.1
Feb 28/95	235	5.91	5.15	6.99	20	41.1	9.1
Mar 3/95	238	4.80	4.13	4.97	20	38.8	9.1
Mar 7/95	242	4.56	4.48	5.34	20	41.3	9.1

MLE System #1

Date	Day	Clarifier Recycle Flow (l/d)	Clarifier Recycle Ratio	Chemical Flow (l/d)	Total Flow (l/d)	Effluent NOx (mg/l)	Effluent Dilution Factor	Corrected Effluent NH4 (mg N/l)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8	59.4	6.1	0.27	10.1		1.03	
Jul 18/94	11	59.4	6.0	0.28	10.2		1.03	
Jul 20/94	13	59.4	6.1	0.27	10.1		1.03	
Jul 22/94	15	59.4	6.1	0.28	10.1		1.03	
Jul 25/94	18	60.3	6.2	0.27	10.1	250	1.03	
Jul 27/94	20	60.3	6.2	0.27	10.1	251	1.03	
Aug 1/94	24	61.2	6.2	0.28	10.1	297	1.03	
Aug 3/94	26	63.0	6.4	0.28	10.1	296	1.03	
Aug 5/94	28	63.9	6.5	0.28	10.2	222	1.03	
Aug 8/94	31	63.0	6.4	0.14	10.0	239	1.01	
Aug 10/94	33	63.0	6.4	0.12	10.0	248	1.01	
Aug 12/94	35	63.0	6.4	0.25	10.0	185	1.03	
Aug 15/94	38	63.0	16.2	0.24	4.1		1.06	
Aug 17/94	40	62.1	6.1	0.21	10.4	213	1.02	
Aug 19/94	42	63.0	6.2	0.23	10.3	231	1.02	
Aug 22/94	45	62.1	6.1	0.23	10.4	249	1.02	
Aug 24/94	47	61.2	6.0	0.21	10.4	246	1.02	
Aug 26/94	49	61.2	5.9	0.28	10.7	212	1.03	
Aug 29/94	52	61.2	5.9	0.28	10.7	195	1.03	
Aug 31/94	54	61.2	5.9	0.28	10.7	169	1.03	
Sep 2/94	56	61.2	5.9	0.29	10.7	161	1.03	
Sep 6/94	60	61.2	6.4	0.29	9.9	99	1.03	
Sep 9/94	63	61.2	6.2	0.29	10.1	89	1.03	
Sep 12/94	66	62.1	6.5	0.29	9.9	85	1.03	
Sep 14/94	68	60.3	6.3	0.30	9.9	55	1.03	
Sep 16/94	70	59.4	6.1	0.30	10.1	37	1.03	
Sep 19/94	73	60.3	6.0	0.30	10.3	112	1.03	
Sep 21/94	75	59.4	5.9	0.50	10.6	151	1.05	
Sep 23/94	77	59.4	6.1	0.59	10.4	222	1.06	
Sep 26/94	80	59.4	5.9	0.91	11.0	368	1.09	
Sep 28/94	82	59.4	6.3	0.92	10.3	425	1.10	
Sep 30/94	84	59.4	6.3	0.90	10.3	431	1.10	
Oct 3/94	87	59.4	6.3	0.99	10.4	457	1.11	
Oct 7/94	91	59.4	6.3	0.91	10.3	463	1.10	
Oct 11/94	95	59.4	6.3	1.07	10.5	484	1.11	
Oct 14/94	98	60.3	6.4	1.02	10.4	480	1.11	
Oct 17/94	101	60.3	6.4	1.06	10.5	415	1.11	
Oct 19/94	103	58.5	6.3	0.71	10.0	352	1.08	
Oct 21/94	105	58.5	6.3	0.31	9.6	132	1.03	
Oct 23/94	107							
Oct 25/94	109	57.6	6.3	0.31	9.4	26	1.03	
Oct 28/94	112	58.5	6.6	0.31	9.2	164	1.03	
Nov 1/94	116	58.5	6.4	0.52	9.6	195	1.06	
Nov 4/94	119	57.6	6.3	0.67	9.8	196	1.07	
Nov 8/94	123	57.6	6.2	0.74	10.1	259	1.08	
Nov 11/94	126	57.6	6.3	0.85	10.0	237	1.09	
Nov 15/94	130	56.7	6.1	0.95	10.3	216	1.10	

MLE System #1

Date	Day	Clarifier Recycle Flow (l/d)	Clarifier Recycle Ratio	Chemical Flow (l/d)	Total Flow (l/d)	Effluent NOx (mg/l)	Effluent Dilution Factor	Corrected Effluent NH4 (mg N/l)
Nov 18/94	133	56.7	6.1	0.94	10.3	179	1.10	
Nov 22/94	137	56.7	6.1	1.00	10.3	179	1.11	
Nov 25/94	140	56.7	6.1	0.96	10.3	115	1.10	14
Nov 29/94	144	63.0	6.8	0.96	10.3	122	1.10	18
Dec 2/94	147	62.1	6.7	0.98	10.3	138	1.11	20
Dec 6/94	151	62.1	6.8	1.01	10.1	125	1.11	20
Dec 9/94	154	62.1	6.7	1.02	10.3	131	1.11	14
Dec 12/94	157	62.1	6.7	1.11	10.4	124	1.12	11
Dec 16/94	161	65.7	7.0	1.00	10.3	145	1.11	8
Dec 20/94	165	64.8	7.0	1.02	10.3	153	1.11	10
Dec 23/94	168	64.8	6.9	1.05	10.5	131	1.11	10
Dec 27/94	172	64.8	7.0	1.04	10.4	138	1.11	3
Dec 30/94	175	64.8	7.0	1.06	10.4	136	1.11	8
Jan 3/95	179	64.8	6.9	1.03	10.4	124	1.11	19
Jan 6/95	182	64.8	7.0	1.09	10.4	98	1.12	28
Jan 10/95	186	64.8	6.9	1.03	10.4	98	1.11	40
Jan 13/95	189	64.8	7.0	0.93	10.2	89	1.10	120
Jan 17/95	193	64.8	6.9	0.91	10.2	116	1.10	69
Jan 20/95	196	64.8	6.9	1.16	10.5	293	1.12	19
Jan 24/95	200	64.8	6.9	1.13	10.5	214	1.12	17
Jan 27/95	203	65.7	7.0	1.06	10.5	149	1.11	32
Jan 31/95	207	65.7	7.0	1.00	10.4	137	1.11	64
Feb 3/95	210	65.7	7.0	1.01	10.4	150	1.11	66
Feb 7/95	214	65.7	7.2	1.02	10.1	142	1.11	67
Feb 10/95	217	65.7	7.3	1.06	10.1	138	1.12	59
Feb 14/95	221	64.8	7.2	1.06	10.1	164	1.12	78
Feb 17/95	224	65.7	7.2	0.92	10.0	130	1.10	32
Feb 21/95	228	65.7	7.2	0.93	10.1	166	1.10	8
Feb 24/95	231	65.7	7.2	0.99	10.1	309	1.11	28
Feb 28/95	235	64.8	7.1	1.11	10.2	89	1.12	19
Mar 3/95	238	64.8	7.1	0.89	10.0	100	1.10	34
Mar 7/95	242	64.8	7.1	0.93	10.0	102	1.10	23

MLE System #1

Date	Day	Corrected Effluent NOx (mg N/l)	Total Effluent Inorganic Nitrogen (mg N/l)	Total Inorganic Nitrogen Removal (%)
Jul 12/94	5			
Jul 14/94	7			
Jul 15/94	8			
Jul 18/94	11			
Jul 20/94	13			
Jul 22/94	15			
Jul 25/94	18	257		
Jul 27/94	20	258		
Aug 1/94	24	306		
Aug 3/94	26	304		
Aug 5/94	28	228		
Aug 8/94	31	242		
Aug 10/94	33	251		
Aug 12/94	35	190		
Aug 15/94	38			
Aug 17/94	40	217		
Aug 19/94	42	236		
Aug 22/94	45	255		
Aug 24/94	47	251		
Aug 26/94	49	218		
Aug 29/94	52	200		
Aug 31/94	54	174		
Sep 2/94	56	165		
Sep 6/94	60	102		
Sep 9/94	63	92		
Sep 12/94	66	88		
Sep 14/94	68	57		
Sep 16/94	70	38		
Sep 19/94	73	115		
Sep 21/94	75	158		
Sep 23/94	77	235		
Sep 26/94	80	401		
Sep 28/94	82	467		
Sep 30/94	84	473		
Oct 3/94	87	505		
Oct 7/94	91	508		
Oct 11/94	95	539		
Oct 14/94	98	532		
Oct 17/94	101	462		
Oct 19/94	103	379		
Oct 21/94	105	136		
Oct 23/94	107			
Oct 25/94	109	27		
Oct 28/94	112	170		
Nov 1/94	116	206		
Nov 4/94	119	211		
Nov 8/94	123	280		
Nov 11/94	126	259		
Nov 15/94	130	238		

MLE System #1

Date	Day	Corrected Effluent NOx (mg N/l)	Total Effluent Inorganic Nitrogen (mg N/l)	Total Inorganic Nitrogen Removal (%)
Nov 18/94	133	197		
Nov 22/94	137	198		
Nov 25/94	140	127	141	88
Nov 29/94	144	135	152	87
Dec 2/94	147	153	172	85
Dec 6/94	151	139	159	87
Dec 9/94	154	145	160	86
Dec 12/94	157	139	150	87
Dec 16/94	161	161	168	86
Dec 20/94	165	170	180	85
Dec 23/94	168	146	156	87
Dec 27/94	172	153	157	87
Dec 30/94	175	151	159	86
Jan 3/95	179	138	157	87
Jan 6/95	182	110	137	88
Jan 10/95	186	109	149	88
Jan 13/95	189	98	218	82
Jan 17/95	193	127	196	84
Jan 20/95	196	329	348	72
Jan 24/95	200	240	257	79
Jan 27/95	203	166	198	83
Jan 31/95	207	152	216	82
Feb 3/95	210	166	233	81
Feb 7/95	214	158	225	82
Feb 10/95	217	154	213	82
Feb 14/95	221	183	261	79
Feb 17/95	224	143	175	85
Feb 21/95	228	183	191	83
Feb 24/95	231	343	370	67
Feb 28/95	235	100	119	89
Mar 3/95	238	110	144	86
Mar 7/95	242	112	135	87

MLE System #2

Date	Day	PO4 Feed Flow (ml/hr)	CH3OH Feed Flow (ml/hr)	NH4Cl Feed Flow (ml/hr)	NaHCO3 Feed Flow (ml/hr)	Leachate (l/d)	Clarifier Recycle (l/d)	Anoxic Overflow (l/d)
Jul 12/94	5	11.3	0	0	0			
Jul 14/94	7	11.4	0	0	0			
Jul 15/94	8	11.4	0	0	0	10.1	60.3	
Jul 18/94	11	11.7	0	0	0	9.9	60.3	
Jul 20/94	13	11.4	0	0	0	10.4	60.3	
Jul 22/94	15	11.6	0	0	0	10.4	60.3	
Jul 25/94	18	11.4	0	0	0	5.5	59.4	
Jul 27/94	20	11.4	0	0	0	9.9	59.4	
Aug 1/94	24	11.7	0	0	0	9.8	59.4	
Aug 3/94	26	11.5	0	0	0	10.1	59.4	
Aug 5/94	28	11.5	0	0	0	10.0	59.4	
Aug 8/94	31	5.8	0	0	0	9.8	63.9	
Aug 10/94	33	5.2	0	0	0	9.9	63.0	73.0
Aug 12/94	35	5.6	6.2	0	0	9.9	61.2	71.2
Aug 15/94	38	5.7	5.4	0	0	10.2	62.1	72.4
Aug 17/94	40	4.6	5.8	0	0	10.1	63.0	73.2
Aug 19/94	42	5.2	5.6	0	0	9.9	62.1	72.1
Aug 22/94	45	5.4	5.4	0	0	9.6	62.1	71.8
Aug 24/94	47	5.0	4.9	0	0	9.5	63.0	72.6
Aug 26/94	49	4.6	9.1	0	0	9.8	62.1	72.0
Aug 29/94	52	4.9	8.8	0	0	9.6	62.1	71.8
Aug 31/94	54	4.8	8.8	0	0	9.5	62.1	71.7
Sep 2/94	56	5.0	8.9	0	0	9.5	62.1	71.7
Sep 6/94	60	5.1	8.9	0	0	9.5	62.1	71.7
Sep 9/94	63	5.1	9.1	0	0	9.6	62.1	71.8
Sep 12/94	66	5.1	9.0	0	0	9.5	62.1	71.7
Sep 14/94	68	5.0	9.2	0	0	10.1	62.1	72.3
Sep 16/94	70	5.2	9.2	0	0	9.8	62.1	72.0
Sep 19/94	73	4.9	9.5	8.9	0	9.6	62.1	72.2
Sep 21/94	75	4.8	8.9	8.5	10.7	9.8	62.1	72.4
Sep 23/94	77	5.2	9.1	8.5	13.0	9.6	62.1	72.2
Sep 26/94	80	5.2	9.3	8.8	29.2	9.6	59.4	69.5
Sep 28/94	82	5.5	9.2	8.8	30.3	9.4	58.5	68.5
Sep 30/94	84	4.8	9.4	9.0	33.0	9.5	58.5	68.5
Oct 3/94	87	4.7	9.0	8.8	35.0	9.1	57.6	67.2
Oct 7/94	91	4.4	9.1	8.8	23.6	9.4	60.3	70.2
Oct 11/94	95	4.7	9.2	9.1	15.9	9.4	59.4	69.3
Oct 14/94	98	5.5	9.5	9.5	27.3	9.2	58.5	68.3
Oct 17/94	101	4.9	9.2	9.3	25.2	9.5	59.4	69.5
Oct 19/94	103	4.7	9.1	9.5	1.3	9.5	60.3	70.4
Oct 21/94	105	4.9	9.4	9.6	0.0	9.5	56.7	66.8
Oct 23/94	107	4.9	9.4	9.6	0.0	9.5	56.7	66.8
Oct 25/94	109	4.9	9.4	0.0	0.0	9.5	56.7	66.3
Oct 28/94	112	4.9	9.4	0.0	0.0	9.6	56.7	66.4
Nov 1/94	116	5.1	9.3	9.6	9.2	9.9	56.7	67.2
Nov 4/94	119	4.8	9.2	8.7	20.0	9.8	57.6	67.9
Nov 8/94	123	4.9	9.4	9.9	19.7	9.4	58.5	68.5
Nov 11/94	126	5.2	9.9	9.8	21.4	9.2	57.6	67.4

MLE System #2

Date	Day	PO4 Feed Flow (ml/hr)	CH3OH Feed Flow (ml/hr)	NH4Cl Feed Flow (ml/hr)	NaHCO3 Feed Flow (ml/hr)	Leachate (l/d)	Clarifier Recycle (l/d)	Anoxic Overflow (l/d)
Nov 15/94	130	4.9	9.6	9.8	25.9	9.6	57.6	67.8
Nov 18/94	133	4.9	10.0	10.3	29.3	9.6	58.5	68.7
Nov 22/94	137	5.2	9.6	10.4	28.4	9.4	58.5	68.5
Nov 25/94	140	4.7	9.8	10.3	30.0	9.4	57.6	67.6
Nov 29/94	144	5.0	9.8	10.1	31.5	9.4	58.5	68.5
Dec 2/94	147	5.5	9.8	10.1	31.7	8.9	58.5	68.0
Dec 6/94	151	4.8	9.7	10.1	33.4	9.1	58.5	68.2
Dec 9/94	154	5.0	9.7	10.3	33.5	8.9	58.5	68.0
Dec 12/94	157	4.9	9.4	10.3	36.1	9.1	58.5	68.2
Dec 16/94	161	5.0	10.4	10.4	28.8	9.1	73.8	83.5
Dec 20/94	165	5.6	10.7	10.7	31.8	9.1	73.8	83.5
Dec 23/94	168	4.9	10.9	10.8	34.5	9.2	76.5	86.3
Dec 27/94	172	5.0	10.4	10.8	26.1	9.1	75.6	85.3
Dec 30/94	175	5.7	10.4	10.4	34.8	9.2	74.7	84.5
Jan 3/95	179	4.8	10.5	10.8	22.8	9.4	74.7	84.7
Jan 6/95	182	5.7	10.5	10.2	28.3	9.2	74.7	84.5
Jan 10/95	186	4.9	10.1	10.9	27.7	9.5	73.8	83.9
Jan 13/95	189	5.0	10.6	10.5	20.5	8.9	73.8	83.3
Jan 17/95	193	5.6	10.6	11.0	24.2	8.9	73.8	83.4
Jan 20/95	196	5.3	10.5	11.0	35.7	8.8	73.8	83.3
Jan 24/95	200	5.5	10.7	10.8	33.3	9.2	73.8	83.7
Jan 27/95	203	5.2	10.8	10.8	31.5	8.8	73.8	83.2
Jan 31/95	207	5.4	10.6	10.6	26.1	9.2	73.8	83.6
Feb 3/95	210	5.1	10.6	10.8	31.3	9.8	72.9	83.3
Feb 7/95	214	5.1	10.7	10.9	33.5	8.1	72.9	81.6
Feb 10/95	217	5.0	10.6	10.9	30.6	8.9	72.9	82.4
Feb 14/95	221	5.5	10.7	10.7	37.7	9.1	75.6	85.3
Feb 17/95	224	5.0	8.1	10.8	29.1	8.9	74.7	84.2
Feb 21/95	228	5.3	7.8	11.0	30.7	9.1	73.8	83.6
Feb 24/95	231	5.0	7.7	10.8	31.9	8.4	73.8	82.8
Feb 28/95	235	5.1	7.9	10.8	0	9.4	73.8	83.8
Mar 3/95	238	5.1	7.9	10.8	24.1	9.1	73.8	83.5
Mar 7/95	242	5	8.2	11.3	25.8	9.2	73.8	83.7

MLE System #2

Date	Day	Aerobic Overflow (l/d)	Aerobic Wasting (l/d)	Anoxic AHRT (hr)	Aerobic AHRT (hr)	Clarifier AHRT (hr)
Jul 12/94	5		0			
Jul 14/94	7		0			
Jul 15/94	8	70.7	0		3.40	1.36
Jul 18/94	11	70.5	0		3.41	1.36
Jul 20/94	13	71.0	0		3.38	1.35
Jul 22/94	15	71.0	0		3.38	1.35
Jul 25/94	18	65.2	0		3.68	1.47
Jul 27/94	20	69.6	0		3.45	1.38
Aug 1/94	24	69.5	1		3.45	1.38
Aug 3/94	26	69.8	1		3.44	1.38
Aug 5/94	28	69.7	1		3.44	1.38
Aug 8/94	31	73.8	1		3.25	1.30
Aug 10/94	33	73.0	1	1.64	3.29	1.31
Aug 12/94	35	71.2	0	1.68	3.37	1.35
Aug 15/94	38	72.4	0	1.66	3.31	1.33
Aug 17/94	40	73.2	0	1.64	3.28	1.31
Aug 19/94	42	72.1	0.5	1.66	3.33	1.33
Aug 22/94	45	71.8	0.5	1.67	3.34	1.34
Aug 24/94	47	72.6	0.5	1.65	3.30	1.32
Aug 26/94	49	72.0	0.5	1.67	3.33	1.33
Aug 29/94	52	71.8	0.5	1.67	3.34	1.34
Aug 31/94	54	71.7	0.5	1.67	3.35	1.34
Sep 2/94	56	71.7	0.5	1.67	3.35	1.34
Sep 6/94	60	71.7	0.5	1.67	3.35	1.34
Sep 9/94	63	71.8	0.5	1.67	3.34	1.34
Sep 12/94	66	71.7	0.5	1.67	3.35	1.34
Sep 14/94	68	72.3	0.75	1.66	3.32	1.33
Sep 16/94	70	72.0	0.75	1.67	3.33	1.33
Sep 19/94	73	72.2	0.75	1.66	3.32	1.33
Sep 21/94	75	72.7	0.75	1.66	3.30	1.32
Sep 23/94	77	72.5	0.75	1.66	3.31	1.32
Sep 26/94	80	70.2	0.75	1.73	3.42	1.37
Sep 28/94	82	69.2	0.75	1.75	3.47	1.39
Sep 30/94	84	69.3	0.75	1.75	3.46	1.38
Oct 3/94	87	68.1	0.75	1.78	3.53	1.41
Oct 7/94	91	70.8	0.75	1.71	3.39	1.36
Oct 11/94	95	69.7	0.75	1.73	3.44	1.38
Oct 14/94	98	68.9	0.75	1.76	3.48	1.39
Oct 17/94	101	70.1	0.75	1.73	3.43	1.37
Oct 19/94	103	70.4	0.75	1.71	3.41	1.36
Oct 21/94	105	66.8	0.75	1.80	3.59	1.44
Oct 23/94	107	66.8	0.75			
Oct 25/94	109	66.3	0.75	1.81	3.62	1.45
Oct 28/94	112	66.4	0.75	1.81	3.61	1.45
Nov 1/94	116	67.4	0.75	1.79	3.56	1.42
Nov 4/94	119	68.4	0.75	1.77	3.51	1.40
Nov 8/94	123	69.0	0.75	1.75	3.48	1.39
Nov 11/94	126	67.9	0.75	1.78	3.53	1.41

MLE System #2

Date	Day	Aerobic Overflow (l/d)	Aerobic Wasting (l/d)	Anoxic AHRT (hr)	Aerobic AHRT (hr)	Clarifier AHRT (hr)
Nov 15/94	130	68.4	0.75	1.77	3.51	1.40
Nov 18/94	133	69.4	0.75	1.75	3.46	1.38
Nov 22/94	137	69.2	0.75	1.75	3.47	1.39
Nov 25/94	140	68.3	0.75	1.77	3.51	1.41
Nov 29/94	144	69.3	1	1.75	3.47	1.39
Dec 2/94	147	68.8	1	1.76	3.49	1.40
Dec 6/94	151	69.0	1	1.76	3.48	1.39
Dec 9/94	154	68.8	1	1.76	3.49	1.39
Dec 12/94	157	69.1	1	1.76	3.47	1.39
Dec 16/94	161	84.2	1	1.44	2.85	1.14
Dec 20/94	165	84.3	1	1.44	2.85	1.14
Dec 23/94	168	87.2	1	1.39	2.75	1.10
Dec 27/94	172	86.0	1	1.41	2.79	1.12
Dec 30/94	175	85.4	1	1.42	2.81	1.12
Jan 3/95	179	85.3	1	1.42	2.81	1.13
Jan 6/95	182	85.2	1	1.42	2.82	1.13
Jan 10/95	186	84.6	1	1.43	2.84	1.13
Jan 13/95	189	83.8	0.67	1.44	2.86	1.15
Jan 17/95	193	83.9	0.67	1.44	2.86	1.14
Jan 20/95	196	84.1	0.67	1.44	2.85	1.14
Jan 24/95	200	84.4	0.67	1.43	2.84	1.14
Jan 27/95	203	84.0	0.5	1.44	2.86	1.14
Jan 31/95	207	84.3	0.5	1.43	2.85	1.14
Feb 3/95	210	84.1	0.5	1.44	2.85	1.14
Feb 7/95	214	82.4	0.5	1.47	2.91	1.16
Feb 10/95	217	83.2	0.5	1.46	2.89	1.15
Feb 14/95	221	86.3	0.5	1.41	2.78	1.11
Feb 17/95	224	84.9	0.5	1.42	2.83	1.13
Feb 21/95	228	84.3	0.5	1.44	2.85	1.14
Feb 24/95	231	83.6	0.5	1.45	2.87	1.15
Feb 28/95	235	83.8	0.5	1.43	2.86	1.15
Mar 3/95	238	84.1	0.5	1.44	2.85	1.14
Mar 7/95	242	84.3	0.5	1.43	2.85	1.14

MLE System #2

Date	Day	PO4 Feed Conc (g P/l)	CH3OH Feed Conc (ml/l)	NH4Cl Feed Conc (g NH4CL/l)	NaHCO3 Feed Conc (g/l)
Jul 12/94	5	0.692	0	0	0
Jul 14/94	7	0.692	0	0	0
Jul 15/94	8	0.692	0	0	0
Jul 18/94	11	0.675	0	0	0
Jul 20/94	13	0.675	0	0	0
Jul 22/94	15	0.675	0	0	0
Jul 25/94	18	0.672	0	0	0
Jul 27/94	20	0.672	0	0	0
Aug 1/94	24	0.656	0	0	0
Aug 3/94	26	0.656	0	0	0
Aug 5/94	28	0.656	0	0	0
Aug 8/94	31	0.644	0	0	0
Aug 10/94	33	0.644	0	0	0
Aug 12/94	35	0.644	15	0	0
Aug 15/94	38	0.644	5	0	0
Aug 17/94	40	0.644	5	0	0
Aug 19/94	42	0.644	10	0	0
Aug 22/94	45	0.536	10	0	0
Aug 24/94	47	0.536	20	0	0
Aug 26/94	49	0.536	20	0	0
Aug 29/94	52	0.536	20	0	0
Aug 31/94	54	0.536	30	0	0
Sep 2/94	56	0.536	40	0	0
Sep 6/94	60	0.539	50	0	0
Sep 9/94	63	0.539	50	0	0
Sep 12/94	66	0.875	50	0	0
Sep 14/94	68	0.875	50	0	0
Sep 16/94	70	0.875	50	0	0
Sep 19/94	73	0.875	50	24	80
Sep 21/94	75	0.865	50	62	80
Sep 23/94	77	0.865	50	62	80
Sep 26/94	80	0.865	50	110	80
Sep 28/94	82	0.865	50	110	80
Sep 30/94	84	0.865	50	138	80
Oct 3/94	87	0.865	50	138	80
Oct 7/94	91	0.865	50	138	80
Oct 11/94	95	0.902	50	138	80
Oct 14/94	98	0.902	60	111	80
Oct 17/94	101	0.902	60	111	80
Oct 19/94	103	0.902	60	111	80
Oct 21/94	105	0.902	70	111	80
Oct 23/94	107	0.902	70	111	0
Oct 25/94	109	0.911	50	0	0
Oct 28/94	112	0.911	25	0	0
Nov 1/94	116	0.911	36	44	80
Nov 4/94	119	0.911	47	93	80
Nov 8/94	123	0.911	69	95	80
Nov 11/94	126	0.842	88	122	80

MLE System #2

Date	Day	PO4 Feed Conc (g P/l)	CH3OH Feed Conc (ml/l)	NH4Cl Feed Conc (g NH4CL/l)	NaHCO3 Feed Conc (g/l)
Nov 15/94	130	0.842	105	143	80
Nov 18/94	133	0.842	110	150	80
Nov 22/94	137	0.842	110	159	80
Nov 25/94	140	0.842	110	159	80
Nov 29/94	144	1.000	110	159	80
Dec 2/94	147	1.000	110	159	80
Dec 6/94	151	1.000	110	159	80
Dec 9/94	154	1.000	110	159	80
Dec 12/94	157	1.000	110	159	80
Dec 16/94	161	1.032	110	151	80
Dec 20/94	165	1.032	130	151	80
Dec 23/94	168	1.032	120	151	80
Dec 27/94	172	1.032	120	151	80
Dec 30/94	175	0.989	120	151	80
Jan 3/95	179	0.989	120	151	80
Jan 6/95	182	0.989	90	151	80
Jan 10/95	186	0.989	80	151	80
Jan 13/95	189	0.989	80	151	80
Jan 17/95	193	0.989	80	151	80
Jan 20/95	196	0.989	80	151	80
Jan 24/95	200	0.951	100	151	80
Jan 27/95	203	0.951	100	151	80
Jan 31/95	207	0.951	100	151	80
Feb 3/95	210	0.951	90	151	80
Feb 7/95	214	0.955	90	151	80
Feb 10/95	217	0.955	90	151	80
Feb 14/95	221	0.951	90	151	80
Feb 17/95	224	0.951	130	135	80
Feb 21/95	228	0.951	120	129	80
Feb 24/95	231	0.951	120	129	80
Feb 28/95	235	0.951	135	123	80
Mar 3/95	238	0.974	135	123	80
Mar 7/95	242	0.974	135	123	80

MLE System #2

Date	Day	O-PO4 (g P/d)	Anoxic Methanol COD Load (g COD/d)	Simulated Ammonia Con'c (mg N/l)	Ammonia Load (g N/d)	NaHCO3 g CaCO3/d)	Anoxic ORF (mV)
Jul 12/94	5		0				
Jul 14/94	7		0				
Jul 15/94	8	0.196	0				
Jul 18/94	11	0.193	0	282	2.79		
Jul 20/94	13	0.189	0	276	2.87		
Jul 22/94	15	0.192	0	269	2.80		
Jul 25/94	18	0.186	0	322	1.77		
Jul 27/94	20	0.187	0	274	2.71		
Aug 1/94	24	0.190	0	273	2.68		
Aug 3/94	26	0.188	0	272	2.75		
Aug 5/94	28	0.185	0	260	2.60		
Aug 8/94	31	0.096	0	269	2.64		
Aug 10/94	33	0.088	0	253	2.50		
Aug 12/94	35	0.091	2.65	253	2.50		
Aug 15/94	38	0.092	0.77	260	2.65		
Aug 17/94	40	0.079	0.83	281	2.84		17
Aug 19/94	42	0.080	1.60	295	2.92		-2
Aug 22/94	45	0.077	1.54	392	3.76		-18
Aug 24/94	47	0.073	2.79	338	3.21		-23
Aug 26/94	49	0.066	5.19	300	2.94		-57
Aug 29/94	52	0.071	5.02	278	2.67		-41
Aug 31/94	54	0.070	7.52	280	2.66		-42
Sep 2/94	56	0.070	10.15	273	2.59		-38
Sep 6/94	60	0.074	12.68	280	2.66		-48
Sep 9/94	63	0.074	12.97	266	2.55		-163
Sep 12/94	66	0.116	12.83	315	2.99		-208
Sep 14/94	68	0.115	13.11	253	2.56		-222
Sep 16/94	70	0.118	13.11	230	2.25		-172
Sep 19/94	73	0.113	13.54	393	3.86		-113
Sep 21/94	75	0.109	12.68	555	5.55	32.62	-101
Sep 23/94	77	0.109	12.97	550	5.39	34.84	-100
Sep 26/94	80	0.116	13.25	821	8.06	53.37	-102
Sep 28/94	82	0.121	13.11	893	8.58	54.22	-67
Sep 30/94	84	0.107	13.40	1074	10.43	59.60	-82
Oct 3/94	87	0.101	12.83	1148	10.69	60.61	-73
Oct 7/94	91	0.099	12.97	1054	10.13	48.24	-77
Oct 11/94	95	0.108	13.11	1060	10.20	39.43	-74
Oct 14/94	98	0.127	16.25	940	8.86	52.02	-112
Oct 17/94	101	0.113	15.73	899	8.74	48.59	-85
Oct 19/94	103	0.110	15.56	941	9.16	21.25	-107
Oct 21/94	105	0.111	18.75	931	9.06		-148
Oct 23/94	107	0.106	18.75	931	9.06		
Oct 25/94	109	0.113	13.40	259	2.46		-153
Oct 28/94	112	0.113	6.70	233	2.24		-58
Nov 1/94	116	0.116	9.54	452	4.58	25.18	-61
Nov 4/94	119	0.109	12.32	671	6.72	37.38	-64
Nov 8/94	123	0.111	18.49	758	7.31	36.82	-87
Nov 11/94	126	0.108	24.83	933	8.81	38.47	-112

MLE System #2

Date	Day	O-PO4 (g P/d)	Anoxic Methanol COD Load (g COD/d)	Simulated Ammonia Con'c (mg N/l)	Ammonia Load (g N/d)	NaHCO3 g CaCO3/d)	Anoxic ORF (mV)
Nov 15/94	130	0.101	28.73	1007	9.90	41.73	-134
Nov 18/94	133	0.101	31.35	1069	10.53	45.62	-165
Nov 22/94	137	0.106	30.10	1172	11.31	45.09	-172
Nov 25/94	140	0.096	30.72	1166	11.25	46.92	-170
Nov 29/94	144	0.121	30.72	1181	11.39	50.32	-174
Dec 2/94	147	0.134	30.72	1250	11.43	49.79	-181
Dec 6/94	151	0.116	30.41	1195	11.17	48.95	-176
Dec 9/94	154	0.121	30.41	1211	11.08	48.83	-180
Dec 12/94	157	0.119	29.47	1181	11.04	53.86	-164
Dec 16/94	161	0.125	32.60	1174	10.97	45.51	-168
Dec 20/94	165	0.139	39.64	1228	11.49	48.94	-173
Dec 23/94	168	0.122	37.28	1226	11.59	52.16	-165
Dec 27/94	172	0.124	35.57	1216	11.38	40.41	-175
Dec 30/94	175	0.136	35.57	1148	10.85	50.48	-173
Jan 3/95	179	0.114	35.91	1152	11.13	33.13	-308
Jan 6/95	182	0.137	26.93	1102	10.41	39.28	-322
Jan 10/95	186	0.116	23.03	1179	11.50	45.75	-331
Jan 13/95	189	0.119	24.17	1244	11.38	36.62	-315
Jan 17/95	193	0.135	24.17	1291	11.83	39.88	-225
Jan 20/95	196	0.128	23.94	1285	11.65	52.90	-151
Jan 24/95	200	0.128	30.50	1200	11.35	49.14	-188
Jan 27/95	203	0.121	30.78	1240	11.24	46.60	-205
Jan 31/95	207	0.125	30.21	1194	11.28	44.03	-185
Feb 3/95	210	0.118	27.19	1177	11.84	50.90	-187
Feb 7/95	214	0.119	27.45	1364	11.41	48.04	-207
Feb 10/95	217	0.118	27.19	1229	11.26	45.69	-197
Feb 14/95	221	0.127	27.45	1216	11.38	56.41	-168
Feb 17/95	224	0.117	30.01	1144	10.48	46.28	-174
Feb 21/95	228	0.123	26.68	1141	10.69	48.50	-180
Feb 24/95	231	0.116	26.33	1180	10.22	48.84	-145
Feb 28/95	235	0.117	30.40	996	9.62	12.13	-197
Mar 3/95	238	0.121	30.40	1010	9.45	39.31	-205
Mar 7/95	242	0.119	31.55	1050	9.94	43.68	-211

MLE System #2

Date	Day	Anoxic pH	Aerobic D.O. (mg/l)	Aerobic pH	Anoxic NH4 (mg N/l)	Anoxic Free Ammonia (mg N/l)	Aerobic NH4 (mg N/l)	Aerobic Free Ammonia (mg N/l)
Jul 12/94	5						8	
Jul 14/94	7		4.3					
Jul 15/94	8		3.6	7.5				
Jul 18/94	11		3.8	7.6		0.0	3	0.0
Jul 20/94	13		2.2	7.5		0.0	2	0.0
Jul 22/94	15		3.9	7.5		0.0	1	0.0
Jul 25/94	18		3.3			0.0	2	0.0
Jul 27/94	20		3.4	7.5		0.0	1	0.0
Aug 1/94	24		3.5	7.5		0.0	9	0.1
Aug 3/94	26		2.8	7.5		0.0	9	0.1
Aug 5/94	28		4.5	7.5		0.0	3	0.0
Aug 8/94	31		2.7	7.5		0.0	5	0.1
Aug 10/94	33		3.5	7.5		0.0	6	0.1
Aug 12/94	35		5.9	7.9	44	0.0	16	0.5
Aug 15/94	38	7.8	5.5	7.8	66	1.6	32	0.8
Aug 17/94	40	7.7	4.2	7.5	47	0.9	9	0.1
Aug 19/94	42	7.6	4.1	7.5	40	0.6	1	0.0
Aug 22/94	45	7.6	3.3	7.5	47	0.7	1	0.0
Aug 24/94	47	7.6	3.3	7.5	41	0.6	1	0.0
Aug 26/94	49	7.7	3.6	7.6	40	0.8	1	0.0
Aug 29/94	52	7.7	3.6	7.7	37	0.7	0	0.0
Aug 31/94	54	7.8	2.6	7.8	36	0.9	0	0.0
Sep 2/94	56	7.9	3.4	7.9	33	1.0	0	0.0
Sep 6/94	60	8.1	2.2	8.0	34	1.6	0	0.0
Sep 9/94	63	8.2	2.9	8.2	31	1.8	0	0.0
Sep 12/94	66	8.2	2.9	8.1	35	2.0	0	0.0
Sep 14/94	68	8.1	2.1	8.1	30	1.4	0	0.0
Sep 16/94	70	8.2	3.4	8.2	27	1.6	0	0.0
Sep 19/94	73	8.1	1.6	7.7	47	2.2	1	0.0
Sep 21/94	75	7.9	1.4	7.6	65	2.0	0	0.0
Sep 23/94	77	7.9	3.0	7.6	68	2.1	0	0.0
Sep 26/94	80	8.0	1.9	7.7	95	3.6	3	0.0
Sep 28/94	82	7.9	2.4	7.6	105	3.2	1	0.0
Sep 30/94	84	8.0	3.1	7.6	144	5.4	14	0.2
Oct 3/94	87	7.9	3.2	7.6	195	5.9	40	0.6
Oct 7/94	91	7.9	3.7	7.6	247	7.4	64	1.0
Oct 11/94	95	7.9	4.2	7.7	361	10.9	268	5.2
Oct 14/94	98	8.1	3.4	7.6	174	8.2	69	1.1
Oct 17/94	101	8.2	5.0	7.9	164	9.6	61	1.8
Oct 19/94	103	8.0	5.3	7.8	285	10.7	206	5.0
Oct 21/94	105	8.0	5.5	8.1	349	13.1	241	11.3
Oct 23/94	107	8.1		8.3	522	24.5	477	34.6
Oct 25/94	109	8.3	7.1	8.5	305	22.1	301	33.2
Oct 28/94	112	8.0	5.4	7.9	43	1.6	7	0.2
Nov 1/94	116	8.0	3.2	7.6	65	2.4	5	0.1
Nov 4/94	119	8.2	2.6	7.5	98	5.7	9	0.1
Nov 8/94	123	8.1	3.5	7.7	84	3.9	2	0.0
Nov 11/94	126	8.2	2.5	7.6	96	5.6	2	0.0

MLE System #2

Date	Day	Anoxic pH	Aerobic D.O. (mg/l)	Aerobic pH	Anoxic NH4 (mg N/l)	Anoxic Free Ammonia (mg N/l)	Aerobic NH4 (mg N/l)	Aerobic Free Ammonia (mg N/l)
Nov 15/94	130	8.2	3.1	7.6	107	6.3	1	0.0
Nov 18/94	133	8.4	3.1	7.6	127	11.4	4	0.1
Nov 22/94	137	8.3	2.9	7.5	129	9.3	12	0.1
Nov 25/94	140	8.2	2.7	7.5	119	7.0	5	0.1
Nov 29/94	144	8.4	3.2	7.6	165	14.8	8	0.1
Dec 2/94	147	8.4	3.3	7.6	165	14.8	10	0.2
Dec 6/94	151	8.5	3.3	7.7	166	18.3	12	0.2
Dec 9/94	154	8.4	3.6	7.6	165	14.8	15	0.2
Dec 12/94	157	8.3	3.0	7.6	151	10.9	20	0.3
Dec 16/94	161	8.4	3.0	7.7	115	10.3	12	0.2
Dec 20/94	165	8.3	1.9	7.8	152	11.0	18	0.4
Dec 23/94	168	8.4	3.0	7.9	143	12.8	13	0.4
Dec 27/94	172	8.3	2.7	7.8	134	9.7	18	0.4
Dec 30/94	175	8.4	3.4	8.0	155	13.9	22	0.8
Jan 3/95	179	8.1	2.6	7.6	199	9.3	90	1.4
Jan 6/95	182	8.2	3.7	7.6	251	14.7	172	2.6
Jan 10/95	186	8.2	2.5	7.9	237	13.8	144	4.3
Jan 13/95	189	8.1	2.7	7.6	341	16.0	216	3.3
Jan 17/95	193	8.2	2.1	7.6	246	14.4	134	2.1
Jan 20/95	196	8.4	2.8	7.7	138	12.4	38	0.7
Jan 24/95	200	8.4	2.4	7.6	139	12.4	43	0.7
Jan 27/95	203	8.3	2.1	7.6	151	10.9	37	0.6
Jan 31/95	207	8.4	2.8	7.3	171	15.3	71	0.6
Feb 3/95	210	8.5	2.0	7.6	164	18.1	44	0.7
Feb 7/95	214	8.4	2.1	7.4	170	15.2	53	0.5
Feb 10/95	217	8.4	2.1	7.5	138	12.4	28	0.3
Feb 14/95	221	8.4	2.1	7.7	143	12.8	25	0.5
Feb 17/95	224	8.5	2.6	7.9	102	11.2	3	0.1
Feb 21/95	228	8.4	2.4	7.5	130	11.6	13	0.2
Feb 24/95	231	8.5	3.1	7.7	109	12.0	5	0.1
Feb 28/95	235	8.4	3.7	7.6	102	9.1	6	0.1
Mar 3/95	238	8.4	3.0	7.6	103	9.2	7	0.1
Mar 7/95	242	8.3	2.7	7.4	114	8.3	5	0.0

MLE System #2

Date	Day	Effluent NH4 (mg N/l)	Anoxic NOx (mg N/l)	Aerobic NOx (mg N/l)	Effluent NOx (mg N/l)	Anoxic NO2 (mg N/l)	Aerobic NO2 (mg N/l)	Effluent NO2 (mg N/l)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8			213				
Jul 18/94	11			237				
Jul 20/94	13			236				
Jul 22/94	15			240				
Jul 25/94	18	0		251	245			
Jul 27/94	20	0		251	249		2.8	
Aug 1/94	24	5		316	322			
Aug 3/94	26	8		277	281		11.6	
Aug 5/94	28	2		231	234		15.5	17.3
Aug 8/94	31	5		233	233			
Aug 10/94	33	6		237	252		5.7	6.1
Aug 12/94	35	14	139	180	179	2.9	3.9	4.2
Aug 15/94	38	33	148	189	187	9.1	14.2	13.5
Aug 17/94	40	6	187	226	228			
Aug 19/94	42	0	205	243	245	4.8	5.3	5.3
Aug 22/94	45	0	210	250	249	1.0	1.6	1.4
Aug 24/94	47	0	203	246	246			
Aug 26/94	49	0	174	209	211	2.5	1.3	0.8
Aug 29/94	52	0	158	192	201	2.3	0.6	0.3
Aug 31/94	54	0	122	152	157			
Sep 2/94	56	0	95	128	130	5.5	0.3	0.2
Sep 6/94	60	0	19	47	49	5.4	0.4	0.2
Sep 9/94	63	0	0	35	37	0.3	0.8	0.3
Sep 12/94	66	0	0	34	35	0.1	0.7	0.3
Sep 14/94	68	0	1	31	33			
Sep 16/94	70	0	0	28	30	0.1	0.6	0.2
Sep 19/94	73	0	36	77	79	0.2	0.5	0.2
Sep 21/94	75	0	74	125	119	0.2	1.4	0.9
Sep 23/94	77	0	132	214	214	0.2	0.4	0.2
Sep 26/94	80	3	224	344	298	0.4	9.8	10.6
Sep 28/94	82	0	327	388	401	0.3	2.3	3.6
Sep 30/94	84	15	365	487	489	0.7	17.4	17.6
Oct 3/94	87	38	410	514	526	0.5	13.9	15.0
Oct 7/94	91	66	364	460	480	0.3	7.0	11.5
Oct 11/94	95	272	227	330	337	0.2	25.7	26.7
Oct 14/94	98	66	236	375	382	0.4	34.0	36.4
Oct 17/94	101	61	306	415	415	0.4	22.6	22.6
Oct 19/94	103	195	113	191	201	0.2	18.5	18.6
Oct 21/94	105	282	1	29	30	0.2	7.5	8.0
Oct 23/94	107	477						
Oct 25/94	109	291	0	17	18	0.1	7.5	8.3
Oct 28/94	112	4	63	103	112	0.3	8.5	10.6
Nov 1/94	116	4	85	145	144	0.5	11.8	13.0
Nov 4/94	119	9	85	180	176	1.8	36.3	35.4
Nov 8/94	123	1	119	202	205	0.9	10.0	9.9
Nov 11/94	126	2	57	179	172	2.7	31.8	31.5

MLE System #2

Date	Day	Effluent NH4 (mg N/l)	Anoxic NOx (mg N/l)	Aerobic NOx (mg N/l)	Effluent NOx (mg N/l)	Anoxic NO2 (mg N/l)	Aerobic NO2 (mg N/l)	Effluent NO2 (mg N/l)
Nov 15/94	130	1	1	123	127	1.1	28.9	29.4
Nov 18/94	133	5	1	117	118	0.1	43.0	43.0
Nov 22/94	137	10	1	100	90	0.2	48.0	40.0
Nov 25/94	140	4	1	93	89	0.1	44.0	42.0
Nov 29/94	144	7	0	123	128	0.1	69	72
Dec 2/94	147	9	0	117	126	0.0	74	78
Dec 6/94	151	12	0	124	127	0.0	80	84
Dec 9/94	154	16	0	123	130	0.0	73	77
Dec 12/94	157	23	1	108	105	0.3	66	64
Dec 16/94	161	12	0	90	95	0.0	57	60
Dec 20/94	165	20	0	86	86	0.0	68	73
Dec 23/94	168	11	0	106	114	0.0	61	64
Dec 27/94	172	18	1	97	99	0.4	66	70
Dec 30/94	175	23	1	101	106	0.1	37	38
Jan 3/95	179	89	0	60	60	0.0	37	37
Jan 6/95	182	167	1	81	75	0.3	54	50
Jan 10/95	186	150	0	81	69	0.0	55	47
Jan 13/95	189	217	0	69	60	0.0	48.0	42
Jan 17/95	193	129	0	104	96	0.0	72	66
Jan 20/95	196	39	115	283	268	64.0	167	160
Jan 24/95	200	42	1	152	140	0.3	86	80
Jan 27/95	203	37	0	131	122	0.0	78	71
Jan 31/95	207	67	1	141	142	0.8	85	85
Feb 3/95	210	41	1	155	149	0.7	96	92
Feb 7/95	214	53	1	136	129	0.3	85	80
Feb 10/95	217	26	0	143	137	0.0	88	84
Feb 14/95	221	25	1	165	147	0.7	98	86
Feb 17/95	224	3	1	146	143	0.2	83	84
Feb 21/95	228	13	2	158	148	0.8	80	75
Feb 24/95	231	4	54	229	219	29.0	117	113
Feb 28/95	235	6	0	95	94	0.0	78	77
Mar 3/95	238	8	0	102	97	0.0	63	61
Mar 7/95	242	5	1	105	99	0.2	64	59

MLE System #2

Date	Day	Anoxic O-PO4 (mg P/l)	Aerobic O-PO4 (mg P/l)	Anoxic TSS (mg/l)	Aerobic TSS (mg/l)	Effluent TSS (mg/l)	Anoxic VSS (mg/l)	Aerobic VSS (mg/l)
Jul 12/94	5				2504			1900
Jul 14/94	7							
Jul 15/94	8				2992			2216
Jul 18/94	11				2688			2016
Jul 20/94	13				2372			1704
Jul 22/94	15				2676			1912
Jul 25/94	18				2860	31		1948
Jul 27/94	20		14.3		2944	62		1944
Aug 1/94	24		12.6		2776	78		1724
Aug 3/94	26		11.6					
Aug 5/94	28		11.6		2484	67		1512
Aug 8/94	31		6.9		2048	46		1316
Aug 10/94	33		6.7					
Aug 12/94	35	1.4	3.9	2692	1884	15	1884	1316
Aug 15/94	38	7.2	6.4	3368	1852	12	1788	1320
Aug 17/94	40	7.0	6.5	2400	1660	7	1660	1160
Aug 19/94	42	6.6	6.2	2308	1584	5	1612	1124
Aug 22/94	45	6.3	5.9	2400	1696	7	1652	1188
Aug 24/94	47	5.6	5.4	2404	1684	8	1644	1168
Aug 26/94	49	4.7	4.6	2564	1652	14	1768	1172
Aug 29/94	52	4.3	4.0	2680	1876	5	1868	1324
Aug 31/94	54	3.8	3.4	2820	2024	6	1980	1424
Sep 2/94	56	3.2	3.1	2776	2156	6	1948	1520
Sep 6/94	60	2.3	2.2	3040	2440	6	2220	1808
Sep 9/94	63	1.8	1.7	3512	2536	8	2596	1892
Sep 12/94	66	2.2	2.0	3640	2696	6	2728	2056
Sep 14/94	68	2.2	2.0	3668	2692	10	2760	2032
Sep 16/94	70	2.5	2.3	3376	2560	5	2568	1928
Sep 19/94	73	3.6	3.3	3428	2532	4	2644	1960
Sep 21/94	75	4.3	3.9	3296	2528	5	2564	1976
Sep 23/94	77	4.7	4.4	3568	2628	2	2776	2064
Sep 26/94	80	5.5	5.2	3504	2776	22	2788	2200
Sep 28/94	82	5.5	5.0	3772	2928	10	3016	2352
Sep 30/94	84	5.4	4.8	4048	2860	11	3244	2308
Oct 3/94	87	5.4	4.7	4004	2940	38	3270	2384
Oct 7/94	91	4.7	3.9	4132	3032	34	3360	2456
Oct 11/94	95	5.1	4.3	4428	2948	28	3616	2424
Oct 14/94	98	4.2	3.3	4664	2960	72	3844	2436
Oct 17/94	101	6.6	5.4	4436	2988	51	3660	2432
Oct 19/94	103	5.1	4.1	4632	3152	131	3824	2616
Oct 21/94	105	4.8	4.0	4684	3004	71	3844	2480
Oct 23/94	107							
Oct 25/94	109	4.1	3.1	4020	2324	34	3252	1892
Oct 28/94	112			3428	2452	21	2672	1908
Nov 1/94	116	6.1	5.7	3368	2392	6	2640	1876
Nov 4/94	119	5.8	5.5	3508	2844	12	2784	2252
Nov 8/94	123	5.4	5.1	3536	3200	24	2840	2592
Nov 11/94	126	3.2	3.0	4456	3440	57	3684	2852

MLE System #2

Date	Day	Anoxic O-PO4 (mg P/l)	Aerobic O-PO4 (mg P/l)	Anoxic TSS (mg/l)	Aerobic TSS (mg/l)	Effluent TSS (mg/l)	Anoxic VSS (mg/l)	Aerobic VSS (mg/l)
Nov 15/94	130	2.7	2.5	5184	4120	35	4376	3488
Nov 18/94	133	2.5	2.2	5568	4356	19	4760	3696
Nov 22/94	137	2.8	2.3	5688	4220	33	4804	3572
Nov 25/94	140	2.8	2.1	5572	4748	112	4776	4064
Nov 29/94	144	2.7	2.3	5748	5136	29	4948	4412
Dec 2/94	147	2.7	2.5	5508	4884	39	4788	4256
Dec 6/94	151	2.8	2.5	5736	4964	29	5028	4248
Dec 9/94	154	3.3	2.7	5900	4716	20	5208	4164
Dec 12/94	157	3.7	3.0	5700	5136	25	5052	4544
Dec 16/94	161	3.9	3.1	5804	4424	18	5148	3928
Dec 20/94	165	3.5	2.8	5928	4988	25	5304	4456
Dec 23/94	168	2.9	2.5	6248	4940	33	5600	4428
Dec 27/94	172	3.9	3.2	6328	5392	45	5688	4832
Dec 30/94	175	3.5	2.8	6548	5412	32	5904	4868
Jan 3/95	179	3.0	2.4	6276	5436	52	5684	4920
Jan 6/95	182	5.3	4.4	6360	5248	30	5748	4712
Jan 10/95	186	5.9	5.0	6304	5032	56	5712	4560
Jan 13/95	189	5.5	4.4	5788	4772	110	5216	4284
Jan 17/95	193	4.9	4.4	6192	5048	18	5560	4544
Jan 20/95	196	2.8	3.6	6360	5524	84	5656	4852
Jan 24/95	200	3.7	3.6	6700	5584	52	5960	4960
Jan 27/95	203	3.8	3.4	7160	5908	18	6404	5258
Jan 31/95	207	4.1	4.2	6948	6220	39	6228	5584
Feb 3/95	210	3.9	3.9	7560	6216	14	6796	5588
Feb 7/95	214	4.9	4.8	8120	6556	38	7284	5872
Feb 10/95	217	4.6	4.5	7860	6508	132	7048	5824
Feb 14/95	221	3.3	3.5	8220	6880	15	7320	6128
Feb 17/95	224	3.6	3.3	8088	7240	33	7212	6448
Feb 21/95	228	4.1	4.3	8428	7276	19	7516	6476
Feb 24/95	231	3.8	4.0	8416	7080	15	7524	6320
Feb 28/95	235	3.9	3.9	8736	7504	19	7816	6684
Mar 3/95	238	3.8	3.5	8572	7452	26	7672	6660
Mar 7/95	242	3.9	3.5	8904	7656	22	7948	6820

MLE System #2

Date	Day	Effluent VSS (mg/l)	Anoxic BOD5 (mg/l)	Aerobic BOD5 (mg/l)	Effluent BOD5 (mg/l)	Anoxic COD (mg/l)	Aerobic COD (mg/l)	Effluent COD (mg/l)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8							
Jul 18/94	11							
Jul 20/94	13							
Jul 22/94	15							
Jul 25/94	18	25						
Jul 27/94	20	40					417	376
Aug 1/94	24	48						
Aug 3/94	26							390
Aug 5/94	28	38						
Aug 8/94	31	29						
Aug 10/94	33							
Aug 12/94	35	12						
Aug 15/94	38	8				318	335	335
Aug 17/94	40	6						
Aug 19/94	42	5		31		368	351	335
Aug 22/94	45	6				368	351	351
Aug 24/94	47	6						
Aug 26/94	49	9				479	446	429
Aug 29/94	52	4				446	412	429
Aug 31/94	54	5						
Sep 2/94	56	5				420	386	403
Sep 6/94	60	5				472	403	420
Sep 9/94	63	6	22	5	5	429	394	412
Sep 12/94	66	6				429	394	394
Sep 14/94	68	9						
Sep 16/94	70	4				333	300	300
Sep 19/94	73	4				300	283	300
Sep 21/94	75	4						
Sep 23/94	77	2				302	318	350
Sep 26/94	80	16				366	318	318
Sep 28/94	82	9						
Sep 30/94	84	8						
Oct 3/94	87	26				430	445	445
Oct 7/94	91	30				455	438	438
Oct 11/94	95	24				473	473	473
Oct 14/94	98	50				438	456	419
Oct 17/94	101	43						
Oct 19/94	103	97						
Oct 21/94	105	56				582	492	492
Oct 23/94	107							
Oct 25/94	109	28				620	515	526
Oct 28/94	112	17				397	368	385
Nov 1/94	116	6				336	323	321
Nov 4/94	119	11				309	235	270
Nov 8/94	123	21				326	281	281
Nov 11/94	126	49				341	306	270

MLE System #2

Date	Day	Effluent VSS (mg/l)	Anoxic BOD5 (mg/l)	Aerobic BOD5 (mg/l)	Effluent BOD5 (mg/l)	Anoxic COD (mg/l)	Aerobic COD (mg/l)	Effluent COD (mg/l)
Nov 15/94	130	32				341	274	291
Nov 18/94	133	14						
Nov 22/94	137	29						
Nov 25/94	140	97				378	167	234
Nov 29/94	144	25				281	205	234
Dec 2/94	147	34	79	9	11	353	207	202
Dec 6/94	151	27				320	200	196
Dec 9/94	154	20	74	7	12	300	120	115
Dec 12/94	157	21				333	94	97
Dec 16/94	161	16						
Dec 20/94	165	22				476	194	292
Dec 23/94	168	30				407	202	233
Dec 27/94	172	39	88	17	20	441	196	226
Dec 30/94	175	28				406	248	286
Jan 3/95	179	47				504	367	367
Jan 6/95	182	26	115	19	17	303	146	199
Jan 10/95	186	53	90			302	145	153
Jan 13/95	189	100				433	250	300
Jan 17/95	193	18				346	180	187
Jan 20/95	196	75						
Jan 24/95	200	46	113	14	15			
Jan 27/95	203	16				333	206	214
Jan 31/95	207	33	113	10	13	333	199	240
Feb 3/95	210	14						
Feb 7/95	214	28						
Feb 10/95	217	118	53	7	9			
Feb 14/95	221	9	15	10	11			
Feb 17/95	224	27				356	167	206
Feb 21/95	228	17	34	14	13	356	248	216
Feb 24/95	231	13				296		137
Feb 28/95	235	16				348	186	
Mar 3/95	238	19	61	13	15	328	184	205
Mar 7/95	242	19				306	160	

MLE System #2

Date	Day	Anoxic VSS/TSS	Aerobic VSS/TSS	Effluent VSS/TSS	Anoxic NO2/NOx	Aerobic NO2/NOx	Effluent NO2/NOx
Jul 12/94	5		0.76				
Jul 14/94	7						
Jul 15/94	8		0.74				
Jul 18/94	11		0.75				
Jul 20/94	13		0.72				
Jul 22/94	15		0.71				
Jul 25/94	18		0.68	0.81			
Jul 27/94	20		0.66	0.65		0.01	
Aug 1/94	24		0.62	0.62			
Aug 3/94	26						
Aug 5/94	28		0.61	0.57		0.07	0.07
Aug 8/94	31		0.64	0.63			
Aug 10/94	33					0.02	0.02
Aug 12/94	35	0.70	0.70	0.80	0.02	0.02	0.02
Aug 15/94	38	0.53	0.71	0.67	0.06	0.08	
Aug 17/94	40	0.69	0.70	0.86			
Aug 19/94	42	0.70	0.71	1.00	0.02	0.02	0.02
Aug 22/94	45	0.69	0.70	0.86	0.00	0.01	0.01
Aug 24/94	47	0.68	0.69	0.75			
Aug 26/94	49	0.69	0.71	0.64	0.01	0.01	0.00
Aug 29/94	52	0.70	0.71	0.80	0.01	0.00	0.00
Aug 31/94	54	0.70	0.70	0.83			
Sep 2/94	56	0.70	0.71	0.83	0.06	0.00	0.00
Sep 6/94	60	0.73	0.74	0.83	0.28	0.01	0.00
Sep 9/94	63	0.74	0.75	0.75	0.75	0.02	0.01
Sep 12/94	66	0.75	0.76	1.00	0.50	0.02	0.01
Sep 14/94	68	0.75	0.75	0.90			
Sep 16/94	70	0.76	0.75	0.80	0.33	0.02	0.01
Sep 19/94	73	0.77	0.77	1.00	0.01	0.01	0.00
Sep 21/94	75	0.78	0.78	0.80	0.00	0.01	0.01
Sep 23/94	77	0.78	0.79	1.00			
Sep 26/94	80	0.80	0.79	0.73	0.00	0.03	0.04
Sep 28/94	82	0.80	0.80	0.90	0.00	0.01	0.01
Sep 30/94	84	0.80	0.81	0.73			
Oct 3/94	87	0.82	0.81	0.68	0.00	0.03	0.03
Oct 7/94	91	0.81	0.81	0.88	0.00	0.02	0.02
Oct 11/94	95	0.82	0.82	0.86	0.00	0.08	0.08
Oct 14/94	98	0.82	0.82	0.69	0.00	0.09	0.10
Oct 17/94	101	0.83	0.81	0.84	0.00	0.05	0.05
Oct 19/94	103	0.83	0.83	0.74	0.00	0.10	0.09
Oct 21/94	105	0.82	0.83	0.79	0.20	0.26	0.27
Oct 23/94	107						
Oct 25/94	109	0.81	0.81	0.82	0.00	0.44	0.46
Oct 28/94	112	0.78	0.78	0.81	0.00	0.08	0.09
Nov 1/94	116	0.78	0.78	1.00	0.01	0.08	0.09
Nov 4/94	119	0.79	0.79	0.92	0.02	0.20	0.20
Nov 8/94	123	0.80	0.81	0.88	0.01	0.05	0.05
Nov 11/94	126	0.83	0.83	0.86	0.05	0.18	0.18

MLE System #2

Date	Day	Anoxic VSS/TSS	Aerobic VSS/TSS	Effluent VSS/TSS	Anoxic NO2/NOx	Aerobic NO2/NOx	Effluent NO2/NOx
Nov 15/94	130	0.84	0.85	0.91	1.10	0.23	0.23
Nov 18/94	133	0.85	0.85	0.74	0.10	0.37	0.36
Nov 22/94	137	0.84	0.85	0.88	0.20	0.48	0.44
Nov 25/94	140	0.86	0.86	0.87	0.10	0.47	0.47
Nov 29/94	144	0.86	0.86	0.86	0.00	0.56	0.56
Dec 2/94	147	0.87	0.87	0.87	0.00	0.63	0.62
Dec 6/94	151	0.88	0.86	0.93	0.00	0.65	0.66
Dec 9/94	154	0.88	0.88	1.00	0.00	0.59	0.59
Dec 12/94	157	0.89	0.88	0.84	0.30	0.61	0.61
Dec 16/94	161	0.89	0.89	0.89	0.00	0.63	0.63
Dec 20/94	165	0.89	0.89	0.88	0.00	0.79	0.85
Dec 23/94	168	0.90	0.90	0.91	0.00	0.58	0.56
Dec 27/94	172	0.90	0.90	0.87	0.40	0.68	0.71
Dec 30/94	175	0.90	0.90	0.88	0.10	0.37	0.36
Jan 3/95	179	0.91	0.91	0.90	0.00	0.62	0.62
Jan 6/95	182	0.90	0.90	0.87	0.30	0.67	0.67
Jan 10/95	186	0.91	0.91	0.95	0.00	0.68	0.68
Jan 13/95	189	0.90	0.90	0.91	0.00	0.70	0.70
Jan 17/95	193	0.90	0.90	1.00	0.00	0.69	0.69
Jan 20/95	196	0.89	0.88	0.89	0.56	0.59	0.60
Jan 24/95	200	0.89	0.89	0.88	0.30	0.57	0.57
Jan 27/95	203	0.89	0.89	0.89	0.00	0.60	0.58
Jan 31/95	207	0.90	0.90	0.85	0.80	0.60	0.60
Feb 3/95	210	0.90	0.90	1.00	0.70	0.62	0.62
Feb 7/95	214	0.90	0.90	0.74	0.30	0.63	0.62
Feb 10/95	217	0.90	0.89	0.89	0.00	0.62	0.61
Feb 14/95	221	0.89	0.89	0.60	0.70	0.59	0.59
Feb 17/95	224	0.89	0.89	0.82	0.20	0.57	0.59
Feb 21/95	228	0.89	0.89	0.89	0.40	0.51	0.51
Feb 24/95	231	0.89	0.89	0.87	0.54	0.51	0.52
Feb 28/95	235	0.89	0.89	0.84	0.00	0.82	0.82
Mar 3/95	238	0.90	0.89	0.73	0.00	0.62	0.63
Mar 7/95	242	0.89	0.89	0.86	0.20	0.61	0.60

MLE System #2

Date	Day	Anoxic NH4 Removal Rate (mg N/d)	Aerobic NH4 Removal Rate (mg N/d)	% Anoxic NH4 Removal	% Aerobic NH4 Removal	% System NH4 Removal	Anoxic NOx Load (mg N/d)
Jul 12/94	5						
Jul 14/94	7						
Jul 15/94	8						
Jul 18/94	11						
Jul 20/94	13						
Jul 22/94	15						
Jul 25/94	18					100	
Jul 27/94	20					100	
Aug 1/94	24					98	
Aug 3/94	26					97	
Aug 5/94	28					99	
Aug 8/94	31					98	
Aug 10/94	33					98	
Aug 12/94	35	325	2023	9.4	64.5	95	11020
Aug 15/94	38	-117	2434	-2.5	50.9	87	11740
Aug 17/94	40	-48	2797	-1.4	81.3	98	14240
Aug 19/94	42	85	2827	2.9	98.0	100	15098
Aug 22/94	45	456	3297	11.9	97.7	100	15527
Aug 24/94	47	278	2927	8.5	98.3	100	15499
Aug 26/94	49	91	2844	3.1	98.8	100	12992
Aug 29/94	52	36	2629	1.4	98.9	100	11925
Aug 31/94	54	97	2560	3.6	99.2	100	9441
Sep 2/94	56	233	2360	9.0	99.7	100	7955
Sep 6/94	60	246	2410	9.2	98.8	100	2934
Sep 9/94	63	340	2212	13.2	99.4	100	2178
Sep 12/94	66	501	2489	16.6	99.1	100	2113
Sep 14/94	68	398	2155	15.5	99.3	100	1927
Sep 16/94	70	322	1930	14.2	99.3	100	1742
Sep 19/94	73	492	3359	12.7	98.9	100	4784
Sep 21/94	75	865	4686	15.5	99.5	100	7763
Sep 23/94	77	487	4905	9.0	99.9	100	13302
Sep 26/94	80	1598	6431	19.5	97.3	100	20438
Sep 28/94	82	1444	7125	16.7	99.1	100	22708
Sep 30/94	84	1368	8914	12.2	90.3	99	28501
Oct 3/94	87	-114	10388	-0.9	79.2	97	29613
Oct 7/94	91	-3390	12851	-24.3	74.1	94	27746
Oct 11/94	95	1083	6347	4.1	25.4	74	19608
Oct 14/94	98	1012	7125	7.9	60.0	93	21942
Oct 17/94	101	975	7118	7.9	62.5	93	24660
Oct 19/94	103	1525	5553	7.1	27.7	79	11533
Oct 21/94	105	-583	7212	-2.6	30.9	70	1647
Oct 23/94	107	1234	3006	3.4	8.6	49	
Oct 25/94	109	-700	265	-3.6	1.3	-12	969
Oct 28/94	112	-222	2391	-8.4	83.7	98	5843
Nov 1/94	116	500	4030	10.3	92.3	99	8224
Nov 4/94	119	579	6042	8.0	90.8	99	10371
Nov 8/94	123	1671	5615	22.5	97.6	100	11820
Nov 11/94	126	2451	6334	27.5	97.9	100	10314

MLE System #2

Date	Day	Anoxic NH4 Removal Rate (mg N/d)	Aerobic NH4 Removal Rate (mg N/d)	% Anoxic NH4 Removal	% Aerobic NH4 Removal	% System NH4 Removal	Anoxic NOx Load (mg N/d)
Nov 15/94	130	2709	7185	27.2	99.1	100	7088
Nov 18/94	133	2036	8449	18.9	96.8	100	6855
Nov 22/94	137	3168	8009	26.4	90.6	99	5853
Nov 25/94	140	3496	7704	30.3	95.8	100	5362
Nov 29/94	144	556	10749	4.7	95.1	99	7197
Dec 2/94	147	791	10535	6.6	93.9	99	6847
Dec 6/94	151	549	10493	4.6	92.7	99	7256
Dec 9/94	154	732	10190	6.1	90.8	99	7197
Dec 12/94	157	1910	8918	15.6	86.6	98	6320
Dec 16/94	161	2253	8594	19.0	89.5	99	6644
Dec 20/94	165	123	11182	1.0	88.0	98	6350
Dec 23/94	168	242	11213	1.9	90.8	99	8112
Dec 27/94	172	1304	9888	10.2	86.5	99	7335
Dec 30/94	175	-613	11225	-4.9	85.7	98	7547
Jan 3/95	179	986	9187	5.5	54.5	92	4487
Jan 6/95	182	2041	6561	8.8	30.9	85	6057
Jan 10/95	186	2238	7711	10.1	38.8	87	5980
Jan 13/95	189	-1092	10309	-4.0	36.3	83	5095
Jan 17/95	193	1210	9259	5.6	45.1	90	7677
Jan 20/95	196	2961	8293	20.5	72.2	97	20888
Jan 24/95	200	2901	7996	20.0	68.8	97	11220
Jan 27/95	203	1397	9462	10.0	75.3	97	9670
Jan 31/95	207	2222	8319	13.4	58.2	94	10408
Feb 3/95	210	1379	9968	9.2	72.9	97	11304
Feb 7/95	214	1389	9510	9.1	68.5	96	9916
Feb 10/95	217	1926	9048	14.5	79.5	98	10426
Feb 14/95	221	1061	10048	8.0	82.3	98	12477
Feb 17/95	224	2114	8338	19.7	97.0	100	10909
Feb 21/95	228	783	9766	6.7	89.9	99	11664
Feb 24/95	231	1559	8611	14.7	95.4	100	16902
Feb 28/95	235	1512	8049	15.0	94.1	99	7014
Mar 3/95	238	1364	8016	13.7	93.2	99	7530
Mar 7/95	242	774	9116	7.5	95.6	100	7751

MLE System #2

Date	Day	Anoxic Denitr Rate (mg N/d)	Anoxic Specific Denitr Rate (mg N/d/ mg VSS)	% Anoxic Denitr	Aerobic Nitr Rate (mg N/d)	Aerobic Specific Nitr Rate (mg N/d/ mg VSS)	% Aerobic Nitr	Anoxic COD:NOx Entering (mg COD/ mg N)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8							
Jul 18/94	11							
Jul 20/94	13							
Jul 22/94	15							
Jul 25/94	18							
Jul 27/94	20							
Aug 1/94	24							
Aug 3/94	26							
Aug 5/94	28							
Aug 8/94	31							
Aug 10/94	33							
Aug 12/94	35	1118	0.119	10.1	2921	0.222	93.2	0.24
Aug 15/94	38	1019	0.114	8.7	2970	0.225	62.1	0.07
Aug 17/94	40	550	0.066	3.9	2855	0.246	83.0	0.06
Aug 19/94	42	313	0.039	2.1	2741	0.244	95.0	0.11
Aug 22/94	45	443	0.054	2.9	2873	0.242	85.1	0.10
Aug 24/94	47	757	0.092	4.9	3123	0.267	104.9	0.18
Aug 26/94	49	462	0.052	3.6	2520	0.215	87.5	0.40
Aug 29/94	52	578	0.062	4.8	2442	0.184	91.9	0.42
Aug 31/94	54	692	0.070	7.3	2151	0.151	83.3	0.80
Sep 2/94	56	1141	0.117	14.3	2367	0.156	100.0	1.28
Sep 6/94	60	1571	0.142	53.6	2008	0.111	82.4	4.32
Sep 9/94	63	2150	0.166	98.7	2485	0.131	111.6	5.95
Sep 12/94	66	2099	0.154	99.3	2424	0.118	96.6	6.07
Sep 14/94	68	1884	0.137	97.7	2199	0.108	101.3	6.80
Sep 16/94	70	1720	0.134	98.8	1995	0.103	102.6	7.53
Sep 19/94	73	2183	0.165	45.6	2962	0.151	87.2	2.83
Sep 21/94	75	2404	0.188	31.0	3726	0.189	79.1	1.63
Sep 23/94	77	3767	0.271	28.3	5990	0.290	121.9	0.97
Sep 26/94	80	4860	0.349	23.8	8587	0.390	130.0	0.65
Sep 28/94	82	324	0.021	1.4	4458	0.190	62.0	0.58
Sep 30/94	84	3481	0.215	12.2	8748	0.379	88.6	0.47
Oct 3/94	87	2046	0.125	6.9	7424	0.311	56.6	0.43
Oct 7/94	91	2183	0.130	7.9	7002	0.285	40.4	0.47
Oct 11/94	95	3865	0.214	19.7	7269	0.300	29.0	0.67
Oct 14/94	98	5826	0.303	26.6	9738	0.400	82.0	0.74
Oct 17/94	101	3404	0.186	13.8	7823	0.322	68.7	0.64
Oct 19/94	103	3581	0.187	31.0	5495	0.210	27.4	1.35
Oct 21/94	105	1580	0.082	95.9	1870	0.075	8.0	11.39
Oct 23/94	107							
Oct 25/94	109	969	0.060	100.0	1127	0.060	5.6	13.83
Oct 28/94	112	1659	0.124	28.4	2657	0.139	93.0	1.15
Nov 1/94	116	2514	0.190	30.6	4063	0.217	93.0	1.16
Nov 4/94	119	4597	0.330	44.3	6540	0.290	98.2	1.19
Nov 8/94	123	3669	0.258	31.0	5780	0.223	100.5	1.56
Nov 11/94	126	6473	0.351	62.8	8314	0.292	128.5	2.41

MLE System #2

Date	Day	Anoxic Denitr Rate (mg N/d)	Anoxic Specific Denitr Rate (mg N/d/ mg VSS)	% Anoxic Denitr	Aerobic Nitr Rate (mg N/d)	Aerobic Specific Nitr Rate (mg N/d/ mg VSS)	% Aerobic Nitr	Anoxic COD:NOx Entering (mg COD/ mg N)
Nov 15/94	130	7020	0.321	99.0	8347	0.239	115.1	4.05
Nov 18/94	133	6786	0.285	99.0	8053	0.218	92.3	4.57
Nov 22/94	137	5784	0.241	98.8	6852	0.192	77.5	5.14
Nov 25/94	140	5295	0.222	98.7	6287	0.155	78.1	5.73
Nov 29/94	144	7197	0.291	100.0	8519	0.193	75.4	4.27
Dec 2/94	147	6847	0.286	100.0	8047	0.189	71.7	4.49
Dec 6/94	151	7256	0.289	100.0	8556	0.201	75.6	4.19
Dec 9/94	154	7197	0.276	100.0	8465	0.203	75.4	4.23
Dec 12/94	157	6252	0.247	98.9	7392	0.163	71.8	4.66
Dec 16/94	161	6644	0.258	100.0	7579	0.193	78.9	4.91
Dec 20/94	165	6350	0.239	100.0	7251	0.163	57.1	6.24
Dec 23/94	168	8112	0.290	100.0	9239	0.209	74.8	4.60
Dec 27/94	172	7250	0.255	98.8	8253	0.171	72.2	4.85
Dec 30/94	175	7462	0.253	98.9	8538	0.175	65.2	4.71
Jan 3/95	179	4487	0.158	100.0	5117	0.104	30.3	8.00
Jan 6/95	182	5973	0.208	98.6	6817	0.145	32.1	4.45
Jan 10/95	186	5980	0.209	100.0	6853	0.150	34.4	3.85
Jan 13/95	189	5095	0.195	100.0	5783	0.135	20.4	4.74
Jan 17/95	193	7677	0.276	100.0	8730	0.192	42.6	3.15
Jan 20/95	196	11314	0.400	54.2	14229	0.293	123.8	1.15
Jan 24/95	200	11137	0.374	99.3	12753	0.257	109.7	2.72
Jan 27/95	203	9670	0.302	100.0	11004	0.209	87.5	3.18
Jan 31/95	207	10324	0.332	99.2	11798	0.211	82.5	2.90
Feb 3/95	210	11221	0.330	99.3	12951	0.232	94.8	2.41
Feb 7/95	214	9834	0.270	99.2	11132	0.190	80.2	2.77
Feb 10/95	217	10426	0.296	100.0	11894	0.204	104.5	2.61
Feb 14/95	221	12391	0.339	99.3	14146	0.231	115.9	2.20
Feb 17/95	224	10825	0.300	99.2	12317	0.191	143.3	2.75
Feb 21/95	228	11497	0.306	98.6	13151	0.203	121.1	2.29
Feb 24/95	231	12429	0.330	73.5	14672	0.232	162.5	1.56
Feb 28/95	235	7014	0.179	100.0	7965	0.119	93.1	4.33
Mar 3/95	238	7530	0.196	100.0	8580	0.129	99.7	4.04
Mar 7/95	242	7667	0.193	98.9	8766	0.129	91.9	4.07

MLE System #2

Date	Day	Anoxic COD:NOx Removed (mg COD/ mg N)	Aerobic Alk:NH4 Added (g CaCO3/ g N)	Aerobic Alk:NH4 Nitrified (g CaCO3/ g N)	Aerobic SRT (days)	System SRT (days)	Simulated Leachate Flow (l/d)
Jul 12/94	5						
Jul 14/94	7						
Jul 15/94	8						10.1
Jul 18/94	11						9.9
Jul 20/94	13						10.4
Jul 22/94	15						10.4
Jul 25/94	18						5.5
Jul 27/94	20						9.9
Aug 1/94	24				10		9.8
Aug 3/94	26				10		10.1
Aug 5/94	28				10		10.0
Aug 8/94	31				10		9.8
Aug 10/94	33				10		9.9
Aug 12/94	35	2.37					9.9
Aug 15/94	38	0.75					10.2
Aug 17/94	40	1.50					10.1
Aug 19/94	42	5.10			20	40.7	9.9
Aug 22/94	45	3.48			20	40.0	9.6
Aug 24/94	47	3.69			20	40.1	9.5
Aug 26/94	49	11.23			20	39.1	9.8
Aug 29/94	52	8.68			20	41.7	9.6
Aug 31/94	54	10.88			20	41.1	9.5
Sep 2/94	56	8.89			20	40.3	9.5
Sep 6/94	60	8.07			20	40.1	9.5
Sep 9/94	63	6.03			20	41.2	9.6
Sep 12/94	66	6.11			20	41.0	9.5
Sep 14/94	68	6.96			13	27.4	10.1
Sep 16/94	70	7.62			13	28.1	9.8
Sep 19/94	73	6.20			13	28.2	9.8
Sep 21/94	75	5.28	5.87	8.76	13	27.9	10.0
Sep 23/94	77	3.44	6.46	5.82	13	28.6	9.8
Sep 26/94	80	2.73	6.62	6.22	13	25.7	9.8
Sep 28/94	82	40.49	6.32	12.16	13	27.1	9.6
Sep 30/94	84	3.85	5.71	6.81	13	28.0	9.7
Oct 3/94	87	6.27	5.67	8.16	13	25.3	9.3
Oct 7/94	91	5.94	4.76	6.89	13	24.9	9.6
Oct 11/94	95	3.39	3.87	5.42	13	26.4	9.6
Oct 14/94	98	2.79	5.87	5.34	13	23.7	9.4
Oct 17/94	101	4.62	5.56	6.21	13	24.0	9.7
Oct 19/94	103	4.35	2.32	3.87	13	19.8	9.7
Oct 21/94	105	11.87			13	23.3	9.7
Oct 23/94	107						
Oct 25/94	109	13.83			13	26.4	9.5
Oct 28/94	112	4.04			13	26.3	9.6
Nov 1/94	116	3.80	5.49	6.20	13	28.1	10.1
Nov 4/94	119	2.68	5.56	5.72	13	26.4	10.0
Nov 8/94	123	5.04	5.04	6.37	13	24.5	9.6
Nov 11/94	126	3.84	4.37	4.63	13	23.1	9.4

MLE System #2

Date	Day	Anoxic COD:NOx Removed (mg COD/ mg N)	Aerobic Alk:NH4 Added (g CaCO3/ g N)	Aerobic Alk:NH4 Nitrified (g CaCO3/ g N)	Aerobic SRT (days)	System SRT (days)	Simulated Leachate Flow (l/d)
Nov 15/94	130	4.09	4.21	5.00	13	25.1	9.8
Nov 18/94	133	4.62	4.33	5.66	13	27.1	9.8
Nov 22/94	137	5.20	3.99	6.58	13	26.0	9.6
Nov 25/94	140	5.80	4.17	7.46	13	20.8	9.6
Nov 29/94	144	4.27	4.42	5.91	10	19.4	9.6
Dec 2/94	147	4.49	4.36	6.19	10	19.1	9.1
Dec 6/94	151	4.19	4.38	5.72	10	19.6	9.3
Dec 9/94	154	4.23	4.41	5.77	10	20.3	9.1
Dec 12/94	157	4.71	4.88	7.29	10	19.6	9.3
Dec 16/94	161	4.91	4.15	6.00	10	20.7	9.3
Dec 20/94	165	6.24	4.26	6.75	10	19.9	9.4
Dec 23/94	168	4.60	4.50	5.65	10	19.9	9.5
Dec 27/94	172	4.91	3.55	4.90	10	19.3	9.4
Dec 30/94	175	4.77	4.65	5.91	10	19.8	9.4
Jan 3/95	179	8.00	2.98	6.48	10	18.9	9.7
Jan 6/95	182	4.51	3.77	5.76	10	19.9	9.4
Jan 10/95	186	3.85	3.98	6.68	10	18.9	9.8
Jan 13/95	189	4.74	3.22	6.33	15	23.3	9.2
Jan 17/95	193	3.15	3.37	4.57	15	29.7	9.2
Jan 20/95	196	2.12	4.54	3.72	15	25.1	9.1
Jan 24/95	200	2.74	4.33	3.85	15	27.3	9.5
Jan 27/95	203	3.18	4.15	4.23	20	39.7	9.1
Jan 31/95	207	2.93	3.90	3.73	20	36.6	9.5
Feb 3/95	210	2.42	4.30	3.93	20	39.9	10.1
Feb 7/95	214	2.79	4.21	4.32	20	38.9	8.4
Feb 10/95	217	2.61	4.06	3.84	20	29.7	9.2
Feb 14/95	221	2.21	4.96	3.99	20	40.7	9.4
Feb 17/95	224	2.77	4.42	3.76	20	37.9	9.2
Feb 21/95	228	2.32	4.54	3.69	20	39.4	9.4
Feb 24/95	231	2.12	4.78	3.33	20	40.3	8.7
Feb 28/95	235	4.33	1.26	1.52	20	39.8	9.7
Mar 3/95	238	4.04	4.16	4.58	20	39.2	9.4
Mar 7/95	242	4.11	4.39	4.98	20	39.4	9.5

MLE System #2

Date	Day	Clarifier Recycle Flow (l/d)	Clarifier Recycle Ratio	Chemical Flow (l/d)	Total Flow (l/d)	Effluent NOx (mg/l)	Effluent Dilution Factor	Corrected Effluent NH4 (mg N/l)
Jul 12/94	5							
Jul 14/94	7							
Jul 15/94	8	60.3	6.0	0.27	10.4		1.03	
Jul 18/94	11	60.3	6.1	0.28	10.2		1.03	
Jul 20/94	13	60.3	5.8	0.27	10.7		1.03	
Jul 22/94	15	60.3	5.8	0.28	10.7		1.03	
Jul 25/94	18	59.4	10.8	0.27	5.8	245	1.05	
Jul 27/94	20	59.4	6.0	0.27	10.2	249	1.03	
Aug 1/94	24	59.4	6.1	0.28	10.1	322	1.03	
Aug 3/94	26	59.4	5.9	0.28	10.4	281	1.03	
Aug 5/94	28	59.4	5.9	0.28	10.3	234	1.03	
Aug 8/94	31	63.9	6.5	0.14	9.9	233	1.01	
Aug 10/94	33	63.0	6.4	0.12	10.0	252	1.01	
Aug 12/94	35	61.2	6.2	0.28	10.2	179	1.03	
Aug 15/94	38	62.1	6.1	0.27	10.5	187	1.03	
Aug 17/94	40	63.0	6.2	0.25	10.3	228	1.02	
Aug 19/94	42	62.1	6.3	0.26	10.2	245	1.03	
Aug 22/94	45	62.1	6.5	0.26	9.9	249	1.03	
Aug 24/94	47	63.0	6.6	0.24	9.7	246	1.03	
Aug 26/94	49	62.1	6.3	0.33	10.1	211	1.03	
Aug 29/94	52	62.1	6.5	0.33	9.9	201	1.03	
Aug 31/94	54	62.1	6.5	0.33	9.8	157	1.03	
Sep 2/94	56	62.1	6.5	0.33	9.8	130	1.04	
Sep 6/94	60	62.1	6.5	0.34	9.8	49	1.04	
Sep 9/94	63	62.1	6.5	0.34	9.9	37	1.04	
Sep 12/94	66	62.1	6.5	0.34	9.8	35	1.04	
Sep 14/94	68	62.1	6.1	0.34	10.4	33	1.03	
Sep 16/94	70	62.1	6.3	0.35	10.1	30	1.04	
Sep 19/94	73	62.1	6.3	0.35	10.2	79	1.04	
Sep 21/94	75	62.1	6.2	0.59	10.6	119	1.06	
Sep 23/94	77	62.1	6.3	0.66	10.5	214	1.07	
Sep 26/94	80	59.4	6.1	1.05	10.9	298	1.11	
Sep 28/94	82	58.5	6.1	1.08	10.7	401	1.11	
Sep 30/94	84	58.5	6.0	1.13	10.8	489	1.12	
Oct 3/94	87	57.6	6.2	1.17	10.5	526	1.13	
Oct 7/94	91	60.3	6.3	0.89	10.5	480	1.09	
Oct 11/94	95	59.4	6.2	0.72	10.3	337	1.07	
Oct 14/94	98	58.5	6.2	1.02	10.4	382	1.11	
Oct 17/94	101	59.4	6.1	0.94	10.7	415	1.10	
Oct 19/94	103	60.3	6.2	0.36	10.1	201	1.04	
Oct 21/94	105	56.7	5.8	0.34	10.1	30	1.04	
Oct 23/94	107							
Oct 25/94	109	56.7	6.0	0.34	9.8	18	1.04	
Oct 28/94	112	56.7	5.9	0.34	9.9	112	1.04	
Nov 1/94	116	56.7	5.6	0.57	10.7	144	1.06	
Nov 4/94	119	57.6	5.8	0.82	10.8	176	1.08	
Nov 8/94	123	58.5	6.1	0.82	10.5	205	1.08	
Nov 11/94	126	57.6	6.1	0.88	10.3	172	1.09	

MLE System #2

Date	Day	Clarifier Recycle Flow (l/d)	Clarifier Recycle Ratio	Chemical Flow (l/d)	Total Flow (l/d)	Effluent NOx (mg/l)	Effluent Dilution Factor	Corrected Effluent NH4 (mg N/l)
Nov 15/94	130	57.6	5.9	0.97	10.8	127	1.10	1
Nov 18/94	133	58.5	5.9	1.06	10.9	118	1.11	6
Nov 22/94	137	58.5	6.1	1.04	10.7	90	1.11	11
Nov 25/94	140	57.6	6.0	1.07	10.7	89	1.11	4
Nov 29/94	144	58.5	6.1	1.11	10.8	128	1.12	8
Dec 2/94	147	58.5	6.4	1.13	10.3	126	1.12	10
Dec 6/94	151	58.5	6.3	1.15	10.5	127	1.12	13
Dec 9/94	154	58.5	6.4	1.16	10.3	130	1.13	18
Dec 12/94	157	58.5	6.3	1.21	10.6	105	1.13	26
Dec 16/94	161	73.8	7.9	1.06	10.4	95	1.11	13
Dec 20/94	165	73.8	7.9	1.15	10.5	86	1.12	22
Dec 23/94	168	76.5	8.1	1.21	10.7	114	1.13	12
Dec 27/94	172	75.6	8.1	1.00	10.4	99	1.11	20
Dec 30/94	175	74.7	7.9	1.22	10.7	106	1.13	26
Jan 3/95	179	74.7	7.7	0.91	10.6	60	1.09	97
Jan 6/95	182	74.7	7.9	1.07	10.5	75	1.11	186
Jan 10/95	186	73.8	7.6	1.02	10.8	69	1.10	166
Jan 13/95	189	73.8	8.1	0.87	10.0	60	1.09	238
Jan 17/95	193	73.8	8.1	0.97	10.1	96	1.11	143
Jan 20/95	196	73.8	8.1	1.24	10.3	268	1.14	44
Jan 24/95	200	73.8	7.8	1.19	10.6	140	1.13	47
Jan 27/95	203	73.8	8.1	1.14	10.2	122	1.13	42
Jan 31/95	207	73.8	7.8	1.01	10.5	142	1.11	74
Feb 3/95	210	72.9	7.2	1.13	11.2	149	1.11	46
Feb 7/95	214	72.9	8.7	1.18	9.5	129	1.14	60
Feb 10/95	217	72.9	8.0	1.11	10.3	137	1.12	29
Feb 14/95	221	75.6	8.1	1.29	10.7	147	1.14	28
Feb 17/95	224	74.7	8.2	1.01	10.2	143	1.11	3
Feb 21/95	228	73.8	7.9	1.05	10.4	148	1.11	14
Feb 24/95	231	73.8	8.5	1.07	9.7	219	1.12	4
Feb 28/95	235	73.8	7.6	0.31	10.0	94	1.03	6
Mar 3/95	238	73.8	7.9	0.89	10.2	97	1.10	9
Mar 7/95	242	73.8	7.8	0.94	10.4	99	1.10	5

MLE System #2

Date	Day	Corrected Effluent NOx (mg N/l)	Total Effluent Inorganic Nitrogen (mg N/l)	Total Inorganic Nitrogen Removal (%)
Jul 12/94	5			
Jul 14/94	7			
Jul 15/94	8			
Jul 18/94	11			
Jul 20/94	13			
Jul 22/94	15			
Jul 25/94	18	257		
Jul 27/94	20	256		
Aug 1/94	24	331		
Aug 3/94	26	289		
Aug 5/94	28	240		
Aug 8/94	31	236		
Aug 10/94	33	255		
Aug 12/94	35	184		
Aug 15/94	38	192		
Aug 17/94	40	234		
Aug 19/94	42	251		
Aug 22/94	45	256		
Aug 24/94	47	252		
Aug 26/94	49	218		
Aug 29/94	52	208		
Aug 31/94	54	162		
Sep 2/94	56	135		
Sep 6/94	60	51		
Sep 9/94	63	38		
Sep 12/94	66	36		
Sep 14/94	68	34		
Sep 16/94	70	31		
Sep 19/94	73	82		
Sep 21/94	75	126		
Sep 23/94	77	228		
Sep 26/94	80	330		
Sep 28/94	82	446		
Sep 30/94	84	546		
Oct 3/94	87	592		
Oct 7/94	91	524		
Oct 11/94	95	362		
Oct 14/94	98	423		
Oct 17/94	101	455		
Oct 19/94	103	208		
Oct 21/94	105	31		
Oct 23/94	107			
Oct 25/94	109	19		
Oct 28/94	112	116		
Nov 1/94	116	152		
Nov 4/94	119	190		
Nov 8/94	123	222		
Nov 11/94	126	188		

MLE System #2

Date	Day	Corrected Effluent NOx (mg N/l)	Total Effluent Inorganic Nitrogen (mg N/l)	Total Inorganic Nitrogen Removal (%)
Nov 15/94	130	140	141	
Nov 18/94	133	131	136	
Nov 22/94	137	100	111	
Nov 25/94	140	99	103	91
Nov 29/94	144	143	151	87
Dec 2/94	147	142	152	88
Dec 6/94	151	143	156	87
Dec 9/94	154	146	164	86
Dec 12/94	157	119	145	88
Dec 16/94	161	106	119	90
Dec 20/94	165	97	119	90
Dec 23/94	168	129	141	88
Dec 27/94	172	110	129	89
Dec 30/94	175	120	146	87
Jan 3/95	179	66	163	86
Jan 6/95	182	83	269	76
Jan 10/95	186	76	242	79
Jan 13/95	189	66	303	76
Jan 17/95	193	106	249	81
Jan 20/95	196	305	349	73
Jan 24/95	200	158	205	83
Jan 27/95	203	137	179	86
Jan 31/95	207	157	231	81
Feb 3/95	210	166	211	82
Feb 7/95	214	147	208	85
Feb 10/95	217	154	183	85
Feb 14/95	221	167	196	84
Feb 17/95	224	159	162	86
Feb 21/95	228	165	179	84
Feb 24/95	231	246	251	79
Feb 28/95	235	97	103	90
Mar 3/95	238	106	115	89
Mar 7/95	242	109	114	89

Bardenpho System

Leachate (Influent) Data

Date	Day	NH4 (mg N/l)	NOx (mg N/l)	NO2 (mg N/l)	O-PO4 (mp P/l)	pH
Mar 10/95	3	181	0.3	0.0	0.23	7.4
Mar 13/95	6	172	0.3	0.0	0.17	7.4
Mar 15/95	8	171	0.7	0.0	0.32	7.5
Mar 17/95	10	168	0.3	0.1	0.26	7.5
Mar 20/95	13	149	0.2	0.1	0.21	7.5
Mar 22/95	15	123	0.5	0.2	0.33	7.6
Mar 24/95	17	135	0.6	0.2	0.21	7.5
Mar 27/95	20	103	0.9	0.1	0.15	7.4
Mar 30/95	23	124	0.4	0.1	0.17	7.4
Apr 3/95	27	154	0.2	0.1	0.39	7.5
Apr 5/95	29	156	0.2	0.1	0.36	7.7
Apr 7/95	31	159	0.3	0.1	0.27	7.6

Bardenpho System

Leachate (Influent) Data

Date	Day	Alkalinity (mg CaCO ₃ /l)	TSS (mg/l)	VSS (mg/l)	BOD ₅ (mg/l)	COD (mg/l)
Mar 10/95	3	1540				306
Mar 13/95	6		32	17		321
Mar 15/95	8	1460			11	311
Mar 17/95	10					261
Mar 20/95	13		34	15		244
Mar 22/95	15	960				207
Mar 24/95	17					188
Mar 27/95	20	1160	16	8		188
Mar 30/95	23					234
Apr 3/95	27		21	10		234
Apr 5/95	29				18	253
Apr 7/95	31					256

Bardenpho System

Date	Day	PO4	PO4	CH3OH	CH3OH	NH4Cl	NaHCO3	NaHCO3
		#1 Feed Flow (ml/hr)	#2 Feed Flow (ml/hr)	#1 Feed Flow (ml/hr)	#2 Feed Flow (ml/hr)	#1 Feed Flow (ml/hr)	#1 Feed Flow (ml/hr)	#2 Feed Flow (ml/hr)
Mar 10/95	3	5.3	5.3	7.7	7.3	9.1	32.7	0
Mar 13/95	6	4.9	4.9	8.0	8.0	9.3	27.2	0
Mar 15/95	8	5.8	5.8	7.9	7.9	9.4	29.7	0
Mar 17/95	10	5.0	5.0	7.9	7.9	9.4	27.3	0
Mar 20/95	13	5.3	5.3	8.3	8.3	9.4	25.1	0
Mar 22/95	15	5.1	5.1	8.0	8.0	9.8	27.8	0
Mar 24/95	17	5.1	5.1	8.5	8.5	9.4	27.8	0
Mar 27/95	20	5.2	5.2	7.9	7.9	9.6	29.0	0
Mar 30/95	23	5.0	5.0	8.0	8.0	9.6	29.0	0
Apr 3/95	27	4.9	4.9	7.9	7.9	9.4	27.8	0
Apr 5/95	29	5.4	5.4	8.3	8.3	9.6	26.8	0
Apr 7/95	31	4.9	4.9	8.0	8.0	9.7	27.2	0

Bardenpho System

Date	Day	Leachate (l/d)	Aerobic #1 Recycle (l/d)	Clarifier Recycle (l/d)	Post Flow (l/d)	Anoxic #1 Overflow (l/d)	Anoxic #2 Overflow (l/d)
Mar 10/95	3	8.9	36.9	18.4	27.0	64.7	27.3
Mar 13/95	6	9.1	36.9	18.4	24.8	64.9	25.1
Mar 15/95	8	9.1	36.9	18.4	25.0	65.0	25.3
Mar 17/95	10	9.1	36.9	18.4	27.7	64.9	28.0
Mar 20/95	13	8.9	36.0	27.0	36.6	72.5	36.9
Mar 22/95	15	9.1	36.9	27.0	37.2	73.5	37.5
Mar 24/95	17	9.1	36.9	27.0	36.6	73.6	36.9
Mar 27/95	20	9.1	36.9	27.0	36.6	73.5	36.9
Mar 30/95	23	9.1	36.9	27.0	36.0	73.5	36.3
Apr 3/95	27	8.9	36.0	27.4	38.4	72.8	38.7
Apr 5/95	29	9.0	36.0	27.4	39.6	73.0	39.9
Apr 7/95	31	8.9	36.0	27.4	39.6	72.8	39.9

Bardenpho System

Date	Day	Aerobic #1 Overflow (l/d)	Aerobic #2 Overflow (l/d)	Aerobic #1 Wasting (l/d)	Anoxic #1 AHRT (hr)	Anoxic #2 AHRT (hr)	Aerobic #1 AHRT (hr)
Mar 10/95	3	65.5	27.3	0.5	1.85	4.40	3.66
Mar 13/95	6	65.6	25.1	0.5	1.85	4.78	3.66
Mar 15/95	8	65.7	25.3	0.5	1.85	4.74	3.65
Mar 17/95	10	65.6	28.0	0.5	1.85	4.28	3.66
Mar 20/95	13	73.1	36.9	0.5	1.66	3.25	3.29
Mar 22/95	15	74.2	37.5	0.5	1.63	3.20	3.23
Mar 24/95	17	74.2	36.9	0.5	1.63	3.25	3.23
Mar 27/95	20	74.2	36.9	0.5	1.63	3.25	3.23
Mar 30/95	23	74.2	36.3	0.5	1.63	3.30	3.23
Apr 3/95	27	73.5	38.7	0.5	1.65	3.10	3.27
Apr 5/95	29	73.6	39.9	0.5	1.64	3.01	3.26
Apr 7/95	31	73.5	39.9	0.5	1.65	3.01	3.27

Bardenpho System

Date	Day	Aerobic #2 AHRT (hr)	Clarifier AHRT (hr)	PO4 #1, #2 Feed Conc (g P/l)	CH3OH #1 Feed Conc (ml/l)	CH3OH #2 Feed Conc (ml/l)
Mar 10/95	3	8.79	3.52	0.974	65	50
Mar 13/95	6	9.56	3.82	0.974	100	80
Mar 15/95	8	9.48	3.79	0.974	100	80
Mar 17/95	10	8.57	3.43	0.974	90	70
Mar 20/95	13	6.50	2.60	0.840	90	90
Mar 22/95	15	6.40	2.56	0.840	90	90
Mar 24/95	17	6.50	2.60	0.840	80	80
Mar 27/95	20	6.50	2.60	0.840	80	80
Mar 30/95	23	6.61	2.64	0.840	80	80
Apr 3/95	27	6.20	2.48	0.840	85	85
Apr 5/95	29	6.01	2.40	0.872	85	85
Apr 7/95	31	6.01	2.41	0.872	85	85

Bardenpho System

Date	Day	NH ₄ Cl	NaHCO ₃	O-PO ₄	Anoxic #1	Anoxic #2	Simulated
		Feed Conc (g NH ₄ Cl/l)	#1 Feed Conc (g/l)		Methanol COD Load (g COD/d)	Methanol COD Load (g COD/d)	Leachate Ammonia Con'c (mg N/l)
Mar 10/95	3	150	80	0.126	14.26	10.40	1117
Mar 13/95	6	150	80	0.116	22.80	18.24	1108
Mar 15/95	8	150	80	0.138	22.52	18.01	1116
Mar 17/95	10	150	80	0.119	20.26	15.76	1113
Mar 20/95	13	150	80	0.109	21.29	21.29	1116
Mar 22/95	15	150	80	0.106	20.52	20.52	1109
Mar 24/95	17	150	80	0.105	19.38	19.38	1081
Mar 27/95	20	150	80	0.106	18.01	18.01	1070
Mar 30/95	23	150	80	0.102	18.24	18.24	1090
Apr 3/95	27	150	80	0.102	19.14	19.14	1121
Apr 5/95	29	150	80	0.116	20.11	20.11	1132
Apr 7/95	31	150	80	0.105	19.38	19.38	1155

Bardenpho System

Date	Day	Ammonia Load (g N/d)	NaHCO3 g CaCO3/d)	Anoxic #1 ORP (mV)	Anoxic #2 ORP (mV)	Anoxic #1 pH	Anoxic #2 pH
Mar 10/95	3	10.18	51.11	-188	-150	8.2	8.8
Mar 13/95	6	10.33	45.13	-261	-267	8.3	8.9
Mar 15/95	8	10.41	47.26	-222	-218	8.4	8.9
Mar 17/95	10	10.38	44.52	-252	-236	8.3	9.0
Mar 20/95	13	10.18	41.71	-255	-273	8.2	8.8
Mar 22/95	15	10.35	40.72	-212	-228	8.3	8.9
Mar 24/95	17	10.08	40.72	-276	-239	8.2	8.8
Mar 27/95	20	9.98	43.73	-227	-221	8.2	9.0
Mar 30/95	23	10.17	43.73	-240	-244	8.1	8.9
Apr 3/95	27	10.23	42.13	-230	-219	8.1	8.8
Apr 5/95	29	10.45	41.10	-268	-226	8.3	8.9
Apr 7/95	31	10.55	41.44	-209	-236	8.2	8.9

Bardenpho System

Date	Day	Aerobic #1	Aerobic #2	Aerobic #1	Aerobic #2	Anoxic #1	Anoxic #2	Aerobic #1
		D.O. (mg/l)	D.O. (mg/l)	pH	pH	NH4 (mg N/l)	NH4 (mg N/l)	NH4 (mg N/l)
Mar 10/95	3	3.9	4.6	7.6	8.1	142	15	11
Mar 13/95	6	3.0	2.1	7.4	7.9	165	24	29
Mar 15/95	8	3.8	4.2	7.5	8.2	147	7	11
Mar 17/95	10	3.6	4.2	7.5	8.0	153	10	13
Mar 20/95	13	3.5	2.2	7.4	7.8	156	19	29
Mar 22/95	15	4.0	3.2	7.5	7.9	141	17	23
Mar 24/95	17	3.9	2.9	7.4	7.8	146	16	20
Mar 27/95	20	3.8	3.8	7.5	8.1	118	10	14
Mar 30/95	23	4.1	4.4	7.3	7.9	125	9	13
Apr 3/95	27	4.3	2.8	7.3	7.8	145	17	20
Apr 5/95	29	4.3	2.7	7.5	8.0	144	17	23
Apr 7/95	31	3.8	3.7	7.4	8.0	137	14	18

Bardenpho System

Date	Day	Aerobic #2 NH4 (mg N/l)	Effluent NH4 (mg N/l)	Anoxic #1 NOx (mg N/l)	Anoxic #2 NOx (mg N/l)	Aerobic #1 NOx (mg N/l)	Aerobic #2 NOx (mg N/l)	Effluent NOx (mg N/l)
Mar 10/95	3	3	3	89	92	250	82	66
Mar 13/95	6	0	1	0	0	129	20	15
Mar 15/95	8	0	0	12	2	164	14	11
Mar 17/95	10	0	0	0	0	147	16	11
Mar 20/95	13	0	0	0	0	106	11	10
Mar 22/95	15	0	0	1	1	115	15	13
Mar 24/95	17	0	0	0	1	131	14	11
Mar 27/95	20	0	0	4	2	155	17	15
Mar 30/95	23	0	0	5	3	148	17	16
Apr 3/95	27	0	0	3	3	148	17	15
Apr 5/95	29	0	0	0	1	150	15	12
Apr 7/95	31	0	0	4	2	118	18	15

Bardenpho System

Date	Day	Anoxic #1 NO2 (mg N/l)	Anoxic #2 NO2 (mg N/l)	Aerobic #1 NO2 (mg N/l)	Aerobic #2 NO2 (mg N/l)	Effluent NO2 (mg N/l)	Anoxic #1 O-PO4 (mg P/l)	Anoxic #2 O-PO4 (mg P/l)
Mar 10/95	3	52	60	159	26	18	5.1	3.5
Mar 13/95	6	0	0	93	1	1	5.6	3.6
Mar 15/95	8	9	1	119	0	0	4.9	3.1
Mar 17/95	10	0	0	100	0	0	5.5	3.5
Mar 20/95	13	0	0	71	1	0	6.2	4.3
Mar 22/95	15	1	0	77	1	1	6.6	4.5
Mar 24/95	17	0	0	78	1	0	6.8	4.7
Mar 27/95	20	2	1	91	1	1	6.6	4.0
Mar 30/95	23	3	1	90	1	0	6.7	4.0
Apr 3/95	27	1	2	86	1	0	4.2	3.9
Apr 5/95	29	0	0	80	1	0	7.6	4.0
Apr 7/95	31	3	2	88	1	0	6.7	3.8

Bardenpho System

Date	Day	Aerobic #1 O-PO4 (mg P/l)	Aerobic #2 O-PO4 (mg P/l)	Anoxic #1 TSS (mg/l)	Anoxic #2 TSS (mg/l)	Aerobic #1 TSS (mg/l)	Aerobic #2 TSS (mg/l)	Effluent TSS (mg/l)
Mar 10/95	3	5.1	4.9	9004	8380	6420	6708	26
Mar 13/95	6	5.4	6.3	7664	7444	5640	5648	27
Mar 15/95	8	5.4	4.9	8268	7372	5460	6456	61
Mar 17/95	10	5.5	5.5	9200	8276	6092	6464	27
Mar 20/95	13	5.7	6.0	9036	7756	6096	6340	92
Mar 22/95	15	6.4	6.7	12040	7400	6112	5820	14
Mar 24/95	17	6.2	6.5	10396	7620	6232	6260	25
Mar 27/95	20	6.5	6.6	12456	8368	7428	6428	11
Mar 30/95	23	7.1	7.2	11548	8780	7972	7380	13
Apr 3/95	27	6.7	7.0	11284	8876	7500	7188	14
Apr 5/95	29	6.9	7.1	11392	7768	6936	6612	19
Apr 7/95	31	6.6	6.8	11572	9488	8440	7192	18

Bardenpho System

Date	Day	Anoxic #1 VSS (mg/l)	Anoxic #2 VSS (mg/l)	Aerobic #1 VSS (mg/l)	Aerobic #2 VSS (mg/l)	Effluent VSS (mg/l)	Anoxic #1 BOD5 (mg/l)	Anoxic #2 BOD5 (mg/l)
Mar 10/95	3	7896	7276	5608	5852	24		
Mar 13/95	6	6672	6432	4900	4904	25		
Mar 15/95	8	7148	6248	4676	5528	51		
Mar 17/95	10	7956	7084	5252	5560	24	37	108
Mar 20/95	13	7808	6636	5228	5472	83		
Mar 22/95	15	10448	6352	5284	5008	13		
Mar 24/95	17	8992	6520	5368	5404	23		
Mar 27/95	20	10748	7184	6380	5536	11		
Mar 30/95	23	9932	7496	6816	6300	12		
Apr 3/95	27	9748	7564	6440	6176	12		
Apr 5/95	29	9836	6664	5944	5656	18	19	80
Apr 7/95	31	9972	8080	7264	6152	17		

Bardenpho System

Date	Day	Aerobic #1 BOD5 (mg/l)	Aerobic #2 BOD5 (mg/l)	Effluent BOD5 (mg/l)	Anoxic #1 COD (mg/l)	Anoxic #2 COD (mg/l)	Aerobic #1 COD (mg/l)	Aerobic #2 COD (mg/l)
Mar 10/95	3				203	149	70	292
Mar 13/95	6				351	548	370	306
Mar 15/95	8				284	327	147	278
Mar 17/95	10	25	7	8	327	360	151	228
Mar 20/95	13				311	377	216	244
Mar 22/95	15				284	361	199	284
Mar 24/95	17				303	380	217	246
Mar 27/95	20				246	284	146	246
Mar 30/95	23				289	291	174	253
Apr 3/95	27				291	329	142	234
Apr 5/95	29	12	10	5	292	370	185	234
Apr 7/95	31				288	325	159	273

Bardenpho System

Date	Day	Effluent COD (mg/l)	Anoxic #1 VSS/TSS	Anoxic #2 VSS/TSS	Aerobic #1 VSS/TSS	Aerobic #2 VSS/TSS	Effluent VSS/TSS
Mar 10/95	3	255	0.88	0.87	0.87	0.87	0.92
Mar 13/95	6	366	0.87	0.86	0.87	0.87	0.93
Mar 15/95	8	244	0.86	0.85	0.86	0.86	0.84
Mar 17/95	10	261	0.86	0.86	0.86	0.86	0.89
Mar 20/95	13	261	0.86	0.86	0.86	0.86	0.90
Mar 22/95	15	284	0.87	0.86	0.86	0.86	0.93
Mar 24/95	17	246	0.86	0.86	0.86	0.86	0.92
Mar 27/95	20	246	0.86	0.86	0.86	0.86	1.00
Mar 30/95	23	234	0.86	0.85	0.85	0.85	0.92
Apr 3/95	27	253	0.86	0.85	0.86	0.86	0.86
Apr 5/95	29	253	0.86	0.86	0.86	0.86	0.95
Apr 7/95	31	238	0.86	0.85	0.86	0.86	0.94

Bardenpho System

							Anoxic #1 NH4 Removal Rate (mg N/d)
Date	Day	Anoxic #1 NO2/NOx	Anoxic #2 NO2/NOx	Aerobic #1 NO2/NOx	Aerobic #2 NO2/NOx	Effluent NO2/NOx	
Mar 10/95	3	0.58	0.65	0.64	0.32	0.27	1452
Mar 13/95	6	0.00	0.00	0.72	0.05	0.07	682
Mar 15/95	8	0.75	0.50	0.73	0.00	0.00	1269
Mar 17/95	10	0.00	0.00	0.68	0.00	0.00	928
Mar 20/95	13	0.00	0.00	0.67	0.09	0.00	-78
Mar 22/95	15	1.00	0.00	0.67	0.07	0.08	829
Mar 24/95	17	0.00	0.00	0.60	0.07	0.00	83
Mar 27/95	20	0.50	0.50	0.59	0.06	0.07	1819
Mar 30/95	23	0.60	0.33	0.61	0.06	0.00	1459
Apr 3/95	27	0.33	0.67	0.58	0.06	0.00	385
Apr 5/95	29	0.00	0.00	0.53	0.07	0.00	769
Apr 7/95	31	0.75	1.00	0.75	0.06	0.00	1221

Bardenpho System

Date	Day	Anoxic #2 NH4 Removal Rate (mg N/d)	Aerobic #1 NH4 Removal Rate (mg N/d)	Aerobic #2 NH4 Removal Rate (mg N/d)	% Anoxic #1 NH4 Removal	% Anoxic #2 NH4 Removal	% Aerobic #1 NH4 Removal	% Aerobic #2 NH4 Removal
Mar 10/95	3	-113	8471	328	13.6	-37.9	92.2	80.0
Mar 13/95	6	117	8812	603	6.0	16.2	82.2	100.0
Mar 15/95	8	98	8826	177	11.7	35.5	92.4	100.0
Mar 17/95	10	80	9082	280	8.5	22.2	91.4	100.0
Mar 20/95	13	360	9184	702	-0.7	33.9	81.3	100.0
Mar 22/95	15	218	8664	638	7.4	25.5	83.5	100.0
Mar 24/95	17	141	9254	591	0.8	19.3	86.2	100.0
Mar 27/95	20	143	7639	369	17.3	28.0	88.0	100.0
Mar 30/95	23	141	8228	327	13.7	30.2	89.5	100.0
Apr 3/95	27	110	9091	658	3.5	14.3	86.1	100.0
Apr 5/95	29	232	8813	679	6.8	25.5	83.9	100.0
Apr 7/95	31	154	8656	559	10.9	21.6	86.7	100.0

Bardenpho System

Date	Day	% System NH4 Removal	Anoxic #1 NOx Load (mg N/d)	Anoxic #2 NOx Load (mg N/d)	Anoxic #1 Denitr Rate (mg N/d)	Anoxic #2 Denitr Rate (mg N/d)	Anoxic #1	Anoxic #2
							Specific Denitr Rate (mg N/d/ mg VSS)	Specific Denitr Rate (mg N/d/ mg VSS)
Mar 10/95	3	100	10442	6750	4681	4238	0.119	0.116
Mar 13/95	6	100	5039	3199	5039	3199	0.151	0.099
Mar 15/95	8	100	6260	4100	5481	4049	0.153	0.130
Mar 17/95	10	100	5629	4072	5629	4072	0.142	0.115
Mar 20/95	13	100	4088	3880	4088	3880	0.105	0.117
Mar 22/95	15	100	4599	4278	4526	4240	0.087	0.134
Mar 24/95	17	100	5136	4795	5136	4758	0.114	0.146
Mar 27/95	20	100	6133	5673	5839	5599	0.109	0.156
Mar 30/95	23	100	5897	5328	5529	5219	0.111	0.139
Apr 3/95	27	100	5741	5683	5522	5567	0.113	0.147
Apr 5/95	29	100	5731	5940	5731	5900	0.117	0.177
Apr 7/95	31	100	4662	4673	4370	4593	0.088	0.114

Bardenpho System

Date	Day			Aerobic #1		Aerobic #1	Aerobic #2	% Aerobic #1 Nitr
		% Anoxic #1 Denitr	% Anoxic #2 Denitr	Nitr Rate (mg N/d)	Nitr Rate (mg N/d)	Specific Nitr Rate (mg N/d/ mg VSS)	Specific Nitr Rate (mg N/d/ mg VSS)	
Mar 10/95	3	44.8	62.8	10618	-273	0.189	-0.005	115.5
Mar 13/95	6	100.0	100.0	8461	502	0.173	0.010	79.0
Mar 15/95	8	87.5	98.8	9990	304	0.214	0.005	104.6
Mar 17/95	10	100.0	100.0	9642	448	0.184	0.008	97.0
Mar 20/95	13	100.0	100.0	7744	406	0.148	0.007	68.5
Mar 22/95	15	98.4	99.1	8461	525	0.160	0.010	81.6
Mar 24/95	17	100.0	99.2	9723	480	0.181	0.009	90.5
Mar 27/95	20	95.2	98.7	11213	554	0.176	0.010	129.2
Mar 30/95	23	93.8	98.0	10620	508	0.156	0.008	115.5
Apr 3/95	27	96.2	98.0	10660	542	0.166	0.009	100.9
Apr 5/95	29	100.0	99.3	11040	559	0.186	0.010	105.1
Apr 7/95	31	93.7	98.3	8381	639	0.115	0.010	84.0

Bardenpho System

Date	Day	% Aerobic #2 Nitr	Anoxic #1	Anoxic #2	Anoxic #1	Anoxic #2	Aerobic #1	Aerobic #1
			COD:NOx Entering (mg COD/ mg N)	COD:NOx Entering (mg COD/ mg N)	COD:NOx Removed (mg COD/ mg N)	COD:NOx Removed (mg COD/ mg N)	Alk:NH4 Added (g CaCO3/ g N)	Alk:NH4 Nitrified (g CaCO3/ g N)
Mar 10/95	3	-66.7	1.37	1.54	3.05	2.45	5.02	4.81
Mar 13/95	6	83.3	4.52	5.70	4.52	5.70	4.37	5.33
Mar 15/95	8	171.4	3.60	4.39	4.11	4.45	4.54	4.73
Mar 17/95	10	160.0	3.60	3.87	3.60	3.87	4.29	4.62
Mar 20/95	13	57.9	5.21	5.49	5.21	5.49	4.10	5.39
Mar 22/95	15	82.4	4.46	4.80	4.53	4.84	3.93	4.81
Mar 24/95	17	81.3	3.77	4.04	3.77	4.07	4.04	4.19
Mar 27/95	20	150.0	2.94	3.18	3.09	3.22	4.38	3.90
Mar 30/95	23	155.6	3.09	3.42	3.30	3.49	4.30	4.12
Apr 3/95	27	82.4	3.33	3.37	3.47	3.44	4.12	3.95
Apr 5/95	29	82.4	3.51	3.38	3.51	3.41	3.93	3.72
Apr 7/95	31	114.3	4.16	4.15	4.43	4.22	3.93	4.94

Bardenpho System

Date	Day	Aerobic #1 SRT (days)	System SRT (days)	Simulated Leachate Flow (l/d)	Aerobic #1 Recycle Flow (l/d)	Aerobic #1 Recycle Ratio	Clarifier Recycle Flow (l/d)
Mar 10/95	3	20	72.8	9.1	36.9	4.0	18.4
Mar 13/95	6	20	71.8	9.3	36.9	4.0	18.4
Mar 15/95	8	20	73.1	9.3	36.9	4.0	18.4
Mar 17/95	10	20	73.9	9.3	36.9	4.0	18.4
Mar 20/95	13	20	60.1	9.1	36.0	3.9	27.0
Mar 22/95	15	20	76.3	9.3	36.9	4.0	27.0
Mar 24/95	17	20	72.9	9.3	36.9	4.0	27.0
Mar 27/95	20	20	71.7	9.3	36.9	4.0	27.0
Mar 30/95	23	20	71.0	9.3	36.9	4.0	27.0
Apr 3/95	27	20	72.6	9.1	36.0	3.9	27.4
Apr 5/95	29	20	70.9	9.2	36.0	3.9	27.4
Apr 7/95	31	20	66.4	9.1	36.0	3.9	27.4

Bardenpho System

Date	Day	Clarifier Recycle Ratio	Chemical Flow (l/d)	Total Flow (l/d)	Effluent NOx (mg/l)	Effluent Dilution Factor	Corrected Effluent NOx (mg/l)	Total Inorganic Nitrogen Removal (%)
Mar 10/95	3	2.0	1.62	10.7	66	1.18	78	93
Mar 13/95	6	2.0	1.50	10.8	15	1.16	17	98
Mar 15/95	8	2.0	1.60	10.9	11	1.17	13	99
Mar 17/95	10	2.0	1.50	10.8	11	1.16	13	99
Mar 20/95	13	3.0	1.48	10.6	10	1.16	12	99
Mar 22/95	15	2.9	1.53	10.9	13	1.16	15	99
Mar 24/95	17	2.9	1.55	10.9	11	1.17	13	99
Mar 27/95	20	2.9	1.56	10.9	15	1.17	18	98
Mar 30/95	23	2.9	1.55	10.9	16	1.17	19	98
Apr 3/95	27	3.0	1.51	10.6	15	1.17	17	98
Apr 5/95	29	3.0	1.53	10.8	12	1.17	14	99
Apr 7/95	31	3.0	1.50	10.6	15	1.16	17	98

APPENDIX C
STATISTICAL ANALYSES

MLE Systems

Day	Anoxic 1 AHRT (hr)	Anoxic 2 AHRT (hr)	Aerobic 1 AHRT (hr)	Aerobic 2 AHRT (hr)	Clarifier 1 AHRT (hr)	Clarifier 2 AHRT (hr)
161	1.59	1.44	3.16	2.85	1.26	1.14
165	1.61	1.44	3.19	2.85	1.28	1.14
168	1.61	1.39	3.19	2.75	1.28	1.10
172	1.61	1.41	3.19	2.79	1.28	1.12
175	1.61	1.42	3.19	2.81	1.28	1.12
179	1.61	1.42	3.19	2.81	1.28	1.13
182	1.61	1.42	3.19	2.82	1.28	1.13
186	1.61	1.43	3.19	2.84	1.28	1.13
189	1.61	1.44	3.20	2.86	1.28	1.15
193	1.61	1.44	3.20	2.86	1.28	1.14
196	1.61	1.44	3.19	2.85	1.27	1.14
200	1.61	1.43	3.19	2.84	1.28	1.14
203	1.59	1.44	3.15	2.86	1.26	1.14
207	1.59	1.43	3.15	2.85	1.26	1.14
210	1.59	1.44	3.15	2.85	1.26	1.14
214	1.60	1.47	3.16	2.91	1.27	1.16
217	1.60	1.46	3.17	2.89	1.27	1.15
221	1.62	1.41	3.20	2.78	1.28	1.11
224	1.60	1.42	3.17	2.83	1.27	1.13
228	1.60	1.44	3.17	2.85	1.27	1.14
231	1.60	1.45	3.16	2.87	1.27	1.15
235	1.62	1.43	3.20	2.86	1.28	1.15
238	1.62	1.44	3.21	2.85	1.28	1.14
242	1.62	1.43	3.21	2.85	1.28	1.14

MLE Systems

t-Test: Paired Two Sample for Means Anoxic AHRT's

	<i>Variable 1</i>	<i>Variable 2</i>
Mean	1.60625	1.4325
Variance	9.4E-05	0.00028
Observatio	24	24
Pearson Co	-0.36817	
Hypothesiz	0	
df	23	
t Stat	38.29635	
P(T<=t) on	1.22E-22	
t Critical or	1.71387	
P(T<=t) tw	2.45E-22	
t Critical tw	2.068655	

t-Test: Paired Two Sample for Means Aerobic AHRT's

	<i>Variable 1</i>	<i>Variable 2</i>
Mean	3.182083	2.840833
Variance	0.000365	0.001182
Observatio	24	24
Pearson Co	-0.35358	
Hypothesiz	0	
df	23	
t Stat	37.27586	
P(T<=t) on	2.26E-22	
t Critical or	1.71387	
P(T<=t) tw	4.52E-22	
t Critical tw	2.068655	

t-Test: Paired Two Sample for Means Clarifier AHRT's

	<i>Variable 1</i>	<i>Variable 2</i>
Mean	1.274167	1.13625
Variance	6.01E-05	0.000181
Observatio	24	24
Pearson Co	-0.34381	
Hypothesiz	0	
df	23	
t Stat	38.19845	
P(T<=t) on	1.3E-22	
t Critical or	1.71387	
P(T<=t) tw	2.6E-22	
t Critical tw	2.068655	

MLE Systems

Day	System 1 Ammonia Load (g N/d)	System 2 Ammonia Load (g N/d)
161	11.16	10.97
165	11.40	11.49
168	11.62	11.59
172	11.19	11.38
175	10.92	10.85
179	11.35	11.13
182	10.56	10.41
186	11.72	11.50
189	11.29	11.38
193	11.70	11.83
196	11.64	11.65
200	11.37	11.35
203	11.31	11.24
207	11.18	11.28
210	11.44	11.84
214	11.66	11.41
217	10.86	11.26
221	11.35	11.38
224	10.77	10.48
228	10.47	10.69
231	10.11	10.22
235	9.59	9.62
238	9.46	9.45
242	9.55	9.94

t-Test: Paired Two Sample for Means
Ammonia Loads

	Variable 1	Variable 2
Mean	10.98625	11.01417
Variance	0.480477	0.450938
Observatio	24	24
Pearson Co	0.958088	
Hypothesiz	0	
df	23	
t Stat	-0.68825	
P(T<=t) on	0.249091	
t Critical or	1.71387	
P(T<=t) tw	0.498182	
t Critical tw	2.068655	

MLE Systems

Day	System 1	System 2
	Aerobic	Aerobic
	Nitr	Nitr
	Rate (mg N/d)	Rate (mg N/d)
207	11342	11798
210	12031	12951
214	13959	11132
217	10912	11894
221	13184	14146
224	10306	12317
228	13643	13151
231	13682	14672
235	7055	7965
238	7859	8580
242	8012	8766

t-Test: Paired Two Sample for Means
MLE Aerobic Nitrification Rates

	Variable 1	Variable 2
Mean	11089.55	11579.27
Variance	6364226	5136931
Observatio	11	11
Pearson Co	0.870369	
Hypothesiz	0	
df	10	
t Stat	-1.30544	
P(T<=t) on	0.110489	
t Critical on	1.812462	
P(T<=t) tw	0.220979	
t Critical tw	2.228139	

MLE Systems

Day	MLE Systems		System 1	System 2		
	System 1	System 2	Total	Total	System 1	System 2
	Ammonia	Ammonia	Effluent	Effluent	Anoxic	Anoxic
	Load	Load	Inorganic	Inorganic	NOx	NOx
	(g N/d)	(g N/d)	Nitrogen	Nitrogen	Load	Load
			(mg N/l)	(mg N/l)	(g N/d)	(g N/d)
203	11.31	11.24	198	179	10252	9670
207	11.18	11.28	216	231	9791	10408
210	11.44	11.84	233	211	10517	11304
214	11.66	11.41	225	208	12156	9916
217	10.86	11.26	213	183	9463	10426
221	11.35	11.38	261	196	11731	12477
224	10.77	10.48	175	162	9004	10909
228	10.47	10.69	191	179	11830	11664
235	9.59	9.62	119	103	6094	7014
238	9.46	9.45	144	115	6871	7530
242	9.55	9.94	135	114	7000	7751

t-Test: Paired Two Sample for Means
Ammonia Loadings

	Variable 1	Variable 2
Mean	10.69455	10.78091
Variance	0.666947	0.649069
Observatio	11	11
Pearson Co	0.954355	
Hypothesiz	0	
df	10	
t Stat	-1.16757	
P(T<=t) on	0.135033	
t Critical or	1.812462	
P(T<=t) tw	0.270067	
t Critical tw	2.228139	

t-Test: Paired Two Sample for Means
Total Effluent Inorganic Nitrogen

	Variable 1	Variable 2
Mean	191.8182	171
Variance	1975.564	1855.6
Observatio	11	11
Pearson Co	0.907323	
Hypothesiz	0	
df	10	
t Stat	3.655517	
P(T<=t) on	0.002211	
t Critical or	1.812462	
P(T<=t) tw	0.004422	
t Critical tw	2.228139	

t-Test: Paired Two Sample for Means
Anoxic NOx Loads

	Variable 1	Variable 2
Mean	9519	9915.364
Variance	4415096	3189132
Observatio	11	11
Pearson Co	0.858508	
Hypothesiz	0	
df	10	
t Stat	-1.21986	
P(T<=t) on	0.125253	
t Critical or	1.812462	
P(T<=t) tw	0.250505	
t Critical tw	2.228139	

Bardenpho System

	Anoxic #1 NOx Load (mg N/d)	Anoxic #2 NOx Load (mg N/d)	Anoxic #1 Denit Rate (mg N/d)	Anoxic #2 Denit Rate (mg N/d)
Day				
13	4088	3880	4088	3880
15	4599	4278	4526	4240
17	5136	4795	5136	4758
20	6133	5673	5839	5599
23	5987	5328	5529	5219
27	5741	5683	5522	5567
29	5731	5940	5731	5900
31	4662	4673	4370	4593

t-Test: Paired Two Sample for Means
Bardenpho Anoxic NOx Loads

	Variable 1	Variable 2
Mean	5259.625	5031.25
Variance	561049.1	546775.4
Observatio	8	8
Pearson Co	0.93065	
Hypothesiz	0	
df	7	
t Stat	2.329128	
P(T<=t) on	0.026341	
t Critical or	1.894578	
P(T<=t) tw	0.052682	
t Critical tw	2.364623	

t-Test: Paired Two Sample for Means
Bardenpho Anoxic Denit Rates

	Variable 1	Variable 2
Mean	5092.625	4969.5
Variance	456255.4	512431.7
Observatio	8	8
Pearson Co	0.94545	
Hypothesiz	0	
df	7	
t Stat	1.493344	
P(T<=t) on	0.089493	
t Critical or	1.894578	
P(T<=t) tw	0.178987	
t Critical tw	2.364623	