EFFECTS OF TEMPERATURE AND MEAN CELL RESIDENCE TIME ON THE PERFORMANCE OF HIGH-RATE BIOLOGICAL NUTRIENT REMOVAL PROCESSES

by

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Dissertation submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Civil Engineering

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July, 1990

Blacksburg, Virginia

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(ABSTRACT)

The effects of temperature and mean cell residence time (MCRT) on processes involved in biological nitrogen and phosphorus removal were investigated by operating pilot-scale continuous-flow reactors over a range of temperatures and MCRTs. Two systems were operated as high-rate University of Cape Town (UCT) biological nutrient removal (BNR) processes. A third system was operated as a conventional, fully aerobic activated sludge system for comparison.

Less aerobic volume was needed to achieve complete nitrification in the BNR system than in the conventional system when temperature and MCRT conditions were suitable for complete nitrification. This occurred at 15 d MCRT and temperatures from 10 to 20 °C., and at 5 d MCRT and 20 °C. However, the BNR system was more susceptible to nitrifier washout at 5 d MCRT and temperatures of 10 and 15 °C. Although less volume was needed for complete nitrification in the BNR system, specific nitrification rates and the degree of nitrification were equal in

the two systems when compared on the basis of aerobic MCRT. This phenomenon occurred because the MLVSS concentrations were higher in the aerobic zone of the BNR system than in the conventional system for the same organic loading and total MCRT.

Nitrification and denitrification rates were a function of MCRT and temperature, with temperature having a greater effect at lower MCRTs. Batch experiments showed that anoxic uptake of phosphorus occurred, although at a much lower rate than aerobic uptake.

Biological phosphorus removal was adversely affected by colder temperatures. Operation of the BNR process at the lowest MCRT which provided complete nitrification prevented washout of phosphorus removal organisms, and provided the best combined nitrogen and phosphorus removal when phosphorus removal was COD-limited. Higher MCRTs were optimal under P-limiting conditions.

Anaerobic stabilization ranging from 8% to 27% was measured in the BNR system, and was a function of temperature at a 15 d MCRT. A mechanism for anaerobic stabilization was proposed.

Yield coefficients for the BNR and the conventional system were equal and were 0.41 mgVSS/mgCOD. The decay rate in the BNR system, 0.063 d^{-1}, was lower than the decay rate in the conventional system, 0.110 d^{-1}. This resulted in higher MLVSS concentrations in the BNR system.

Acknowledgements

The author would like to thank the following individuals for their assistance and support:

Special thanks to Dr. Clifford W. Randall for serving as my major adviser, and for his invaluable assistance (including countless hours behind closed doors discussing data), encouragement, and personal interest throughout my five years in the graduate program at Virginia Tech.

Drs. John T. Novak, William R. Knocke, Robert E. Benoit, and James P. Wightman for their participation in serving on my dissertation committee.

My wife, Victoria, and my children, Erica and Amy, for their understanding and support throughout my graduate career.

Vikram M. Pattarkine, my partner in this research project, for his contributions in the laboratory and in the preparation of this manuscript, and also for setting a good example in temperament and social conscience.

Andy Randall, for being a good friend.

Julie Petruska, for her valuable and mostly cheerful assistance in the laboratory, without which I, among others, would surely waste a lot of time. Marilyn Grender, for her assistance in the analytical laboratory. Pat Furey, for her help in office related tasks.

Special thanks also go to Gerald P. McCarthy, Executive Director, Virginia Environmental Endowment, for providing financial support for this project.

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I. Introduction

Eutrophication of the world's water resources is one of the major water pollution problems being faced today. High loadings of nutrients to receiving streams from wastewater effluents contribute significantly to high rates of eutrophication. Removal of phosphorus, P, and nitrogen, N, from wastewaters is important to protect lakes and rivers from eutrophication. Therefore, nutrient removal is being required of more wastewater treatment plants every day.

Nitrogen removal from wastewaters can be achieved by modifying the activated sludge process to include biological nitrification and denitrification. Many different flow schemes have been proposed for nitrogen removal, but the most economical alternative is to remove organic materials and nitrogen in a single-sludge system.

In the past, phosphorus has most often been removed through chemical precipitation, where alum,lime, or iron salts are added to the influent or directly into the activated sludge basin. Biological phosphorus removal (BPR), which is achieved by the uptake of phosphorus by the sludge in excess of normal metabolic requirements and removal through sludge wasting, is an alternative to chemical treatment. Recycling activated sludge microorganisms through anaerobic and aerobic conditions creates the necessary conditions for microorganisms to store excess phosphorus.

BPR and nitrogen removal can be achieved simultaneously by incorporating an anoxic (oxygen is absent and nitrate is used as electron acceptor) zone into the activated sludge process, along with an anaerobic (neither oxygen nor nitrate is present) zone and an aerobic (oxygen is present) zone. Processes which remove both nitrogen and phosphorus by biological means are referred to as biological nutrient removal (BNR) processes.

Nutrients can be removed economically in a BNR process because only one sludge and one clarifier are required, saving capital costs over previous multi-stage designs. Also, no chemical addition is required for phosphorus removal, and sludge production is less than with chemical precipitation. Recovery of part of the nitrogenous oxygen demand (NOD) is achieved through incorporating denitrification in the process, which serves to reduce aeration energy requirements. Evidence exists that aeration energy costs are further reduced because of anaerobic stabilization of organics occurring in the anaerobic zone (Randall *et al.*, 1987).

Implementation of BNR processes has advanced faster than an understanding of the mechanisms involved and the factors which affect them. For example, mechanisms of denitrification in a BNR process are little understood. Although nitrogen removal via nitrification and denitrification has been practiced for some time, little is known about how incoporation of nitrification and denitrification into a BNR process that includes an anaerobic zone for phosphorus removal affects biochemical mechanisms and rates of nitrogen removal.

Nitrification and denitrification are known to be sensitive to temperature, and design procedures are well established for separate stage and two-stage systems (USEPA, 1975). However, it is unclear whether nitrification in the complex microbial environment of a three-stage BNR system is accurately predicted by currently accepted temperature correction design procedures. Also, it is unknown if the same aerobic reactor volume is needed for nitrification in a BNR system as is needed in a conventional system. If less aerobic volume is needed for nitrification in a BNR system, then many conventional activated sludge plants could be converted to BNR operation with little or no additional reactor volume.

There are indications that biological phosphorus removal is also sensitive to temperature (Spatzierer *et al.*; 1985, Meganck *et al.*, 1985; Jones *et al.*, 1987). Yet, there is little information existing on the subject. The effects of many factors, including temperature, mean cell residence time (MCRT), and wastewater organic concentration, on biological phosphorus removal need to be investigated further. This is particularly true for high-rate BNR systems, *i. e.*, those operated at MCRTs of 15 days or less, and with total hydraulic retention times (HRTs) of less than 10 hours.

It is unclear whether yield and decay coefficients for conventional operation are applicable to BNR systems. Comparison of sludge yields between BNR and conventional systems would be particularly interesting so more reliable estimates of sludge production for BNR operation could be made.

Greater understanding of factors affecting high-rate BNR processes is needed for proper system designs and economic analysis of alternatives. As a result, the concept for this research project was developed.

Pilot-scale high-rate BNR activated sludge reactors were operated over a range of temperatures and MCRTs to observe their effects on the performance of BNR processes. A conventional activated sludge process was operated under the same conditions so comparisons could be made. The objectives of the research were to:

(1) Determine the effects of temperature and MCRT on nitrification and denitrification rates, and compare the aerobic volumes needed for nitrification of the BNR and the conventional systems.

(2) Determine the effects of temperature and MCRT on biological phosphorus removal in high-rate BNR systems,

(3) Quantify the amount, if any, of anaerobic stabilization which occurs in a BNR process, and observe the effects of temperature on anaerobic stabilization,

(4) Study the mechanisms of denitrification in the BNR system, and

(5) Evaluate and compare yield and decay kinetic coefficients.

II. Literature Review

In this chapter, the processes involved in biological nutrient removal (BNR) are reviewed. Each process is described separately in a manner that provides a framework for the evaluation of the research presented in this thesis.

Biokinetic Theory for Organics Removal

Mathematical models used to describe conventional activated sludge wastewater treatment can be found in numerous articles and textbooks (Lawrence and McCarty, 1970; Benefield and Randall, 1980; Grady and Lim, 1980). These models are based on the fact that microorganisms follow growth kinetics first proposed by Monod (1949). The main operational control parameter is mean cell residence time (MCRT), the average length of time a bacterial cell remains in the treatment system. MCRT can be calculated from the equation:

$$MCRT = (VX)/(Q_wX + Q_eX_e) \qquad (2.1)$$

where MCRT = mean cell residence time, time,

V = aeration basin volume, volume,

X = aeration basin biomass concentration, mass/volume,

Q_w = biomass wastage liquid flow rate, volume/time,

Q_e = effluent flow rate, volume/time, and

X_e = effluent biomass concentration, mass/volume.

Mixed liquor volatile suspended solids (MLVSS) concentration provides a good estimation of X for a soluble waste, and is normally used in determination of operational parameters (Lawrence and McCarty, 1970).

The observed yield represents the actual biomass produced per unit of substrate utilized and can be predicted by:

$$Y_{obs} = Y_{max}/(1 + (b)(MCRT)) \qquad (2.2)$$

where Y_{obs} = observed yield coefficient, mass/mass,

Y_{max} = maximum yield coefficient, mass/mass, and

b = biomass decay coefficient , $time^{-1}$.

The biomass concentration in the aeration basin can be determined from:

$$X = Y_{obs} (S_o - S) (MCRT/HRT) \qquad (2.3)$$

where S_o = influent substrate concentration, mass/volume,

S = effluent substrate concentration, mass/volume, and

HRT = hydraulic retention time, time.

The specific substrate utilization rate, q, is a measure of the unit of substrate removed per unit of biomass per unit time and can be calculated as follows:

$$q = (S_o - S)/((X)(HRT)) \qquad (2.4)$$

Substitution of this equation into the previous equation and rearranging yields the following equation:

$$1/MCRT = Y_{max}\, q - b \qquad (2.5)$$

Therefore, a plot of 1/MCRT versus q should give a straight line with a slope of Y_{max} and a y-intercept of b.

Nitrification

The removal of ammonia from wastewater is desirable for many reasons. Ammonia exerts a considerable oxygen demand on receiving waters, is toxic to fish, and exerts an extra chlorine demand (Stankewich, 1972). Biological nitrification is generally accepted as the most economical method of removing ammonia from wastewater.

Complete removal of nitrogen (N) from wastewater is receiving increased attention because of nitrogen's role in eutrophication. Some of the wastewater nitrogen is removed via wasting of excess sludge, which contains 10-12% nitrogen on a dry mass basis (McCarty, 1970). However, only about 20-30% nitrogen removal is achieved through sludge wasting in conventional treatment (Jones and Sabra, 1980). Higher degrees of nitrogen removal are most often achieved by combined nitrification and denitrification. Nitrate formed from nitrification can be denitrified to innocuous nitrogen gas and released to the atmosphere.

Nitrification and denitrification are integral parts of the natural nitrogen cycle. The principal nitrogen species and their conversion pathways as they occur in natural waters and wastewater treatment are presented in Figure 2-1 (Painter, 1977). Approximately 60% of the total nitrogen in domestic sewage is in the form of ammonium and 40% is organic nitrogen, which is deaminated to ammonium as bacterial hydrolysis of organics occurs in activated sludge treatment.

Nitrification is performed by two groups of bacteria: *Nitrosomonas*, which oxidize

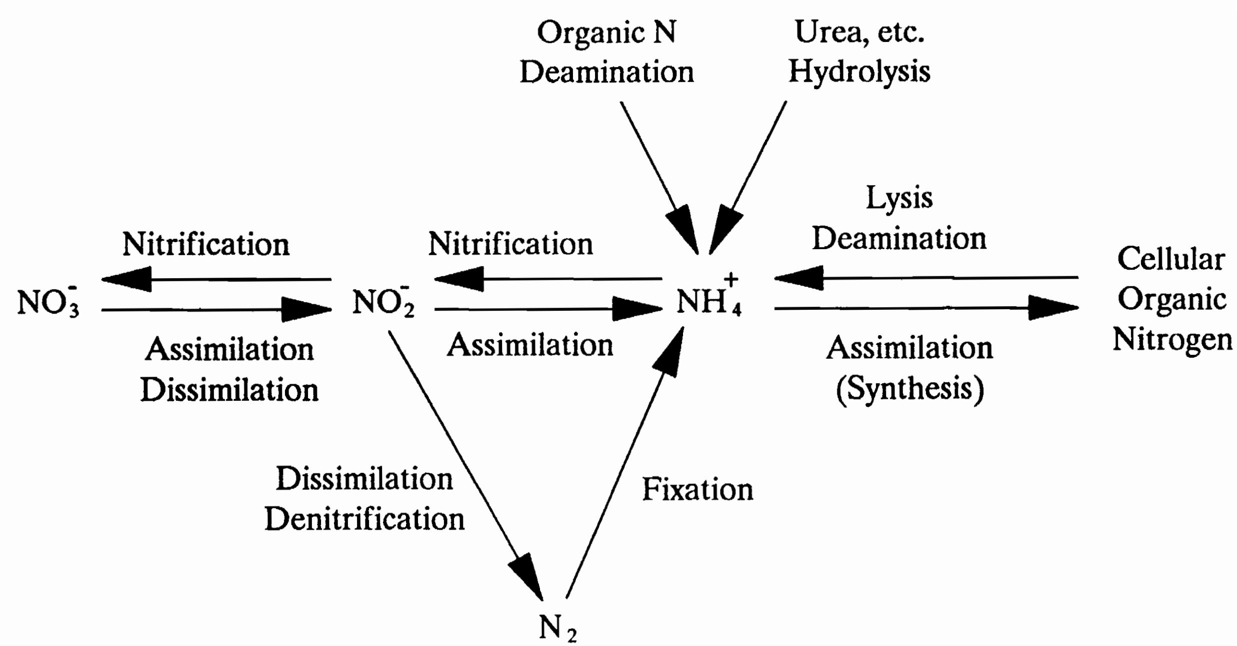

Figure 2-1. Biological Processes Involving Nitrogen (After Painter, 1977)

ammonia to nitrite, and *Nitrobacter*, which oxidize nitrite to nitrate. *Nitrosomonas* and *Nitrobacter* are aerobic autotrophic bacteria. Nitrification occurs if conditions are favorable for the growth of nitrifying bacteria, *i. e.*, high dissolved oxygen (DO), neutral pH and adequate alkalinity. The kinetic parameters are such that the growth rate of *Nitrobacter* easily exceeds that of *Nitrosomonas* (Grady and Lim, 1980). Therefore, the rate of nitrification is generally considered to be limited by the oxidation of ammonia to nitrite by *Nitrosomonas* (Stankewich, 1972; Poduska and Andrews, 1974).

In the presence of nitrifying bacteria and oxygen, nitrate (NO_3^-) is formed according to the following reactions (Benefield and Randall, 1980)

$$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2O \qquad (2.6)$$

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \qquad (2.7)$$

Total Reaction:

$$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2\ H^+ + H_2O \qquad (2.8)$$

Theoretically, 4.57 mg of oxygen are required to nitrify 1 mg of NH_4^+-N, and 7.14 mg of alkalinity as $CaCO_3$ are consumed.

The optimum pH for nitrification is about 7-8 (USEPA, 1975; Benefield and Randall, 1980; Antoniou *et al.*, 1990). Nitrification is sensitive to many environmental factors including temperature, pH, the activity of heterotrophs, toxicants, and even high concentrations of its own substrate (USEPA, 1975; WPCF, 1983; Antoniou *et al.*, 1990; Gee *et al.*, 1990b; Hanaki *et al.*, 1990).

Nitrification Rates

There are two general approaches for design for nitrification: the growth rate approach and the nitrification rate approach (USEPA, 1975). According to the model, the specific growth rate of *Nitrosomonas* is given by (USEPA, 1975):

$$\mu'_m = \mu_m e^{0.098(T-15)} (DO/K_o + DO)(1-0.833(7.2-pH)) \quad (2.9)$$

where μ'_m = maximum growth rate under most severe mixed liquor conditions of DO, temperature and pH,

μ_m = maximum specific growth rate of *Nitrosomonas*,

T = temperature °C,

DO = dissolved oxygen,

K_o = dissolved oxygen half-saturation constant, and

pH = operating pH.

Values of μ_m of 0.67 d^{-1} and 0.56 to 0.77 d^{-1} have been reported in recent studies (Antoniou *et al.*, 1990; Hanaki *et al.*, 1990). Typical values for the constants used in the model are μ_m = 0.3 d^{-1} and K_o = 0.5 mg/L (Barnard *et al.*, 1985). Values of μ_m for *Nitrosomonas* vary from 0.05 to 0.77 d^{-1} and cannot be accurately determined in a mixed culture, and an assumption in this range is often made for modeling purposes (Grady *et al.*, 1986).

Yield coefficients for *Nitrosomonas* and *Nitrobacter* were found to be equal to 0.28 mgVSS/mgNH_4^+-N and 0.08 mgVSS/mgNO_2^--N, respectively (Gee *et al.*, 1990), which is in good agreement with values found by McCarty (1964) through theoretical calculations from energy-release relationships. These researchers agree that nitrification follows Monod growth kinetics, and can therefore be modeled using the same equations presented in the previous section on biokinetic theory of organics removal.

There are many reports in the literature of values for specific nitrification rates ($mgNH_4^+$-N oxidized/mgMLVSS/d or mgN/gMLVSS/h) (USEPA, 1975; Gerber, 1986; Winter, 1989). These rates normalize nitrification rates to the total MLVSS concentration and can be quite misleading as MLVSS is more dependent on organic matter oxidized than ammonia-nitrogen oxidized.

A better way to describe rates of nitrification is through what is called the ammonia oxidation rate (USEPA, 1975). The ammonia oxidation rate is calculated by normalizing the nitrification rate to the *Nitrosomonas* VSS concentration and has the units of $mgNH_4^+$-N/mgVSS/d. Since the oxidation of ammonia to nitrite by *Nitrosomonas* is the limiting factor in nitrification, it follows that ammonia oxidation rate should be valid for use in nitrification design. Ammonia oxidation rates are used for nitrification design in many models (Marais *et al.*, 1984; Barnard *et al.*, 1985; Grady *et al.*, 1986). Ammonia oxidation rates can be calculated by dividing the specific nitrification rate by the fraction of *Nitrosomonas* in the MLVSS (USEPA, 1975).

Effects of Temperature on Nitrification

The rate of ammonia oxidation can be described from the relationship first proposed by Monod (1942):

$$dC/dt = -kMC/(K_s + C) \qquad (2.10)$$

where C = substrate concentration, mg/L,

t = time, days,

k = substrate utilization constant, mg/day per mg of organisms,

M = total bacterial mass, mg/L, and

K_s = half saturation constant, mg/L.

In a study of nitrification in streams, the half saturation constant, K_s, was found to increase with increasing temperature (Knowles *et. al.*, 1965). In another similar study, K_s did not increase with temperature, but increased as the initial nitrogen concentration increased (Stratton and McCarty, 1967). The substrate utilization constant, k, increased with temperature (Stratton and McCarty, 1967).

Temperature modifications have been applied in the following manner:

$$k_T = k_{20}\,\theta^{(T-20)} \tag{2.11}$$

where k_T = substrate utilization constant at temperature T,

k_{20} = substrate utilization constant at 20 °C, and

θ = temperature correction constant.

The temperature response of biological processes was found to depend on the substrate concentration in the system (Novak, 1974). The applicability of equation 2.11 is limited because θ is a substrate dependent variable. Temperature correction coefficients were found to be lower at lower substrate concentrations (Novak, 1974).

Denitrification

Denitrification is the metabolic process by which nitrate is reduced to nitrogen gas (Painter, 1977). It is similar to aerobic carbon oxidation except that nitrate (NO_3^-), rather than oxygen, is used as the electron acceptor by heterotrophic bacteria during the oxidation of organic carbon.

Many common activated sludge bacteria, including *Pseudomonas*, *Bacillus*, *Chromobacter*, and some species of *Acinetobacter*, are capable of denitrification (Painter, 1977; Lötter, 1985). Denitrification occurs in the absence of oxygen when the enzyme nitrate reductase is produced by denitrifying bacteria. Denitrifiers use oxygen when oxygen is present because higher energy yields are attained, but can easily and quickly switch to nitrate in anoxic conditions (WPCF, 1983).

On an electron transport basis, 1 mg NO_3^--N is equivalent to 2.86 mg O_2 (WPCF, 1983). Therefore, 100(2.86/4.57) or 62.5% of the nitrogenous oxygen requirement could conceivably be recovered when denitrification is employed. Recoveries of 20% of the total oxygen requirement are common (Randall, 1984). Denitrification is a net producer of alkalinity, theoretically producing 3.57 mg as $CaCO_3$ of alkalinity per mg of NO_3^--N denitrified. Production of alkalinity could be important in treatment because it partially offsets alkalinity destroyed during nitrification.

The optimum pH for denitrification is 7-8 (WPCF, 1983). Denitrification is inhibited by extremes of pH, temperature, low organic loadings, presence of dissolved oxygen and presence of toxic materials, but is not believed to be as sensitive to these environmental factors as is nitrification (USEPA, 1975; WPCF, 1983; Dawson and Murphy, 1972).

Denitrification Rates

Just as in the case of nitrification, environmental factors play a significant role in the kinetics of denitrifier growth and nitrate removal (USEPA, 1975). Factors which affect denitrification rates include temperature, pH, organic concentration, and nitrate concentration. A combined kinetic expression for the rate of denitrifier growth (and nitrate removal) is given by (USEPA, 1975):

$$\mu = \mu_m \, (S/K_s + S) \, (N/K_n + N) \qquad (2.12)$$

where μ = denitrifier growth rate, d^{-1},

μ_m = maximum denitrifier growth rate, d^{-1},

S = organics concentration, mg/L,

K_s = half saturation constant for organics, mg/L,

N = nitrate concentration, mgN/L, and

K_n = half saturation constant for nitrate, mgN/L.

Specific denitrification rate is related to temperature by the equation (Dawson and Murphy, 1972):

$$q_{DN} = q_{DN,20}(1.06)^{T-20} \qquad (2.13)$$

where q_{DN} = specific rate of denitrification, $mgNO_3$-N removed/mgMLVSS/h,

$q_{DN,20}$ = specific rate of denitrification at 20 °C

= 1.07 $mgNO_3$-N removed/mgMLVSS/h, and

T = operating temperature, °C.

Biological Phosphorus Removal (BPR)

Microorganisms in conventional activated sludge plants normally contain 2-3% phosphorus on a dry mass basis. The approximate amount may be calculated using the formula proposed by McCarty (1970) for sludge biomass, $C_{60}H_{87}O_{23}N_{12}P$. As with nitrogen, only about 20-30% of influent P is normally removed through sludge wasting in conventional treatment.

Phosphorus (P) removal from wastewater has received much attention because of its role in eutrophication. High degrees of P removal in past practice were achieved mainly through chemical precipitation. It is now well established that high degrees of P removal can be achieved without chemical addition (Barnard, 1974; Barnard, 1975).

A major breakthrough in the study of biological phosphorus removal (BPR) was made by Levin and Shapiro (1965). Accumulation of phosphorus in sludge under aerobic conditions and release of phosphorus back into solution under anaerobic conditions occurred, although the need for anaerobic-aerobic cycling of activated sludge to promote this activity was not understood until much later.

It was reported by Harold (1966) that accumulation of polyphosphate (polyP) was common for a large number of microorganisms. Limiting amounts of nutrients resulted in accumulation of polyP in certain bacteria. This phenomena was called "luxury" uptake. A rapid uptake of P was also seen in phosphate starved cells.

Higher accumulations of P in sludge permit greater than normal P removals through sludge wasting. The observation that sludge could accumulate higher percentages of P without chemical addition was first reported by Srinath *et al.* (1959). Since then, P accumulation in sludge greater than for normal metabolic requirements has been documented in several cases (Barnard *et al.*, 1975; Marais *et al.*, 1983). The common prerequisite for uptake of P beyond normal metabolic requirements was the inclusion of an anaerobic zone in the treatment process, and passing the sludge through anaerobic-aerobic sequences. Processes operated in this manner have become known as biological phosphorus removal (BPR) processes.

There have been many reports on the possible mechanisms of BPR. It was argued by Garber (1972) and Arvin and Kristensen (1985) that biologically mediated chemical precipitation played a major role in excess phosphorus uptake in the sludge. However, through x-ray diffraction analysis of sludge, it was shown by Buchan (1983) that phosphorus was accumulated intracellularly as polyphosphate (polyP), a biological mechanism. It is now generally accepted that BPR is achieved mainly through intracellular uptake of P, and that anaerobic release of P comes from polyP reserves (Marais *et al.*, 1983).

Effect of Influent Organic Matter on BPR

Greater phosphorus uptake, and better phosphorus removal, is achieved when the ratio of organics to phosphorus in the wastewater (COD:P) is high (Fukase *et al.*, 1985; Siebritz *et al.*, 1983), and the wastewater is fed into the anaerobic zone (Barnard, 1983; Barnard *et al.*, 1985; Marais and Ekama, 1984). This is because the release of P in the anaerobic zone is dependent on the concentration of readily biodegradable organic matter, and the amount of polyP that is stored under aerobic conditions is related to the amount of P release which occurred under anaerobic conditions.

It is well established that many short chain fatty acids, including acetate, propionate, butyrate, and lactate, stimulate P release under anaerobic conditions, and subsequent P uptake under aerobic conditions (Abu-Ghararah, 1988; Gerber *et al.*, 1986; Gerber *et al.*, 1987). The importance of providing fatty acids in the anaerobic zone for good performance of BPR was further demonstrated when addition of fermented primary sewage increased P release and subsequent P uptake (Barnard, 1983; Oldham, 1985). Addition of acetate to wastewater has been shown to induce an *enhanced* culture of microorganisms capable of high degrees of P uptake, with up to 0.38 mgP/mgVSS (Wentzel *et al.*, 1988). Addition of acetate to the anoxic zone was found to cause P release, indicating it may be the type and amount of substrate available that determines release, and not anaerobic conditions (Mostert *et al.*, 1987).

Microorganisms Involved in BPR

PolyP accumulation in sludge was first attributed to specific microorganisms by Fuhs and Chen (1975). Through a series of identification tests, the organism responsible for polyP accumulation was determined to belong to the *Acinetobacter* genus. These bacteria store phosphorus under aerobic conditions in high-energy polyP chains, presumably to use for energy under anaerobic conditions to sequester organic material for later oxidation. The function of the anaerobic zone was to promote the growth of facultative anaerobic bacteria, which would produce short chain volatile fatty acids such as acetate for storage by *Acinetobacter.*

Although *Acinetobacter* is believed to be the primary organism responsible for excess P uptake (Fuhs and Chen, 1975; Wentzel *et al.*, 1986), it is clear that other organisms are also involved. It was suggested by Brodisch and Joyner (1983) that *Aeromonas* and *Pseudomonas* spp. were the major bacteria involved in BPR as they constituted over 50% of the population of full-scale plants practicing BPR. The presence of *Aeromonas punctata*, facutative anaerobes capable of fermentation, enhanced P uptake of *Acinetobacter* by converting carbohydrates in sewage to short chain fatty acids (Brodisch, 1985). These results indicate the function of the anaerobic reactor is to provide for fermentation and not to impose stress conditions on the sludge, a condition previously believed necessary for enhanced P uptake (Nicholls and Osborn, 1979). Interestingly, *Aeromonas*, as well as *Pseudomonas*, was found to be capable of storing excess P (Lötter, 1985).

The numbers of *Acinetobacter* present did not significantly differ between a conventional and a BPR process, and the number of *Acinetobacter* was too small to account for the phosphate removal achieved in one treatment study, indicating that other bacteria must also be involved (Cloete *et al.*, 1985). Further, many bacteria common to activated sludge, *i. e.*, *Pseudomonas*, *Enterobacter*, *Bacillus*, *Aeromonas*, and *Aerobacter*, have been implicated in BPR (Lötter, 1985; Lötter and Murphy, 1985; Yeoman *et al.*, 1988). Many of these same bacteria are also capable of denitrification (Lötter, 1985).

Microorganisms capable of storing polyP are called polyP organisms (Wentzel *et al.*, 1986). In the anaerobic zone of a BPR process, polyP organisms can store all the available organic material, leaving no substrate for other heterotrophs in the aerobic zone (Gerber *et al.*, 1986). PolyP organisms thus gain a competitive advantage over other heterotrophs in processes including an anaerobic zone as the first biological reactor receiving substrate.

Mechanisms of BPR

Many models have been proposed to explain the mechanisms of BPR (Nicholls and Osborn, 1979; Marais *et al.*, 1983; Comeau *et al.*, 1986; Wentzel *et al.*, 1986; Tracy and Flammino, 1987; Wentzel *et al.*, 1989b). They all agree on certain basic fundamentals of the operation of BPR processes. In the anaerobic zone of a BPR activated sludge reactor, organic carbon in the form of short chain fatty acids is transported inside the cell membrane of the bacteria, where it is stored as the organic polymer poly-ß-hydroxybutyrate (PHB) (Fukase *et al.*, 1985). There is a correlation between storage of organics and release of polyP into solution in the anaerobic zone. Upon subsequent aeration, phosphorus is stored as polyP inside the cells as stored organics are oxidized. When high P content cells are recycled to the anaerobic zone, energy from phosphate bonds is used for cell maintenance and storage of organics under anaerobic conditions.

The models differ on the proposed metabolic pathways by which this complex chain of events occurs (Wentzel *et al.*, 1986; Tracy and Flammino, 1987). For illustrative purposes, one simplified pathway depicting a possible mechanism for polyP release and uptake is presented in Figure 2-2 (Tracy and Flammino, 1987). The circles in the figure represent bacterial cells. Under anaerobic conditions, the cells are initially high in polyP and low in stored organics. Phosphate (P_i) is moved from a polyP chain to ADP, thus forming ATP. Energy from breaking of a phosphate bond of ATP is used to transport and store organics (COD) inside the cell, while phosphate is released into solution. This occurs until either the stored polyP or the soluble organic material is depleted. At the end of the anaerobic stage, the cells are high in stored organics and low in polyP. As the cell enters aerobic conditions, stored organics are oxidized and phosphate is taken up and stored as polyP via transfer from ATP formed from the energy provided by oxidation of organics. The cell is then recycled through anaerobic conditions and the cycle continues.

It has been suggested that a higher food to microorganism (F:M) ratio in the anaerobic zone leads to increased rates of P release and uptake (Tracy and

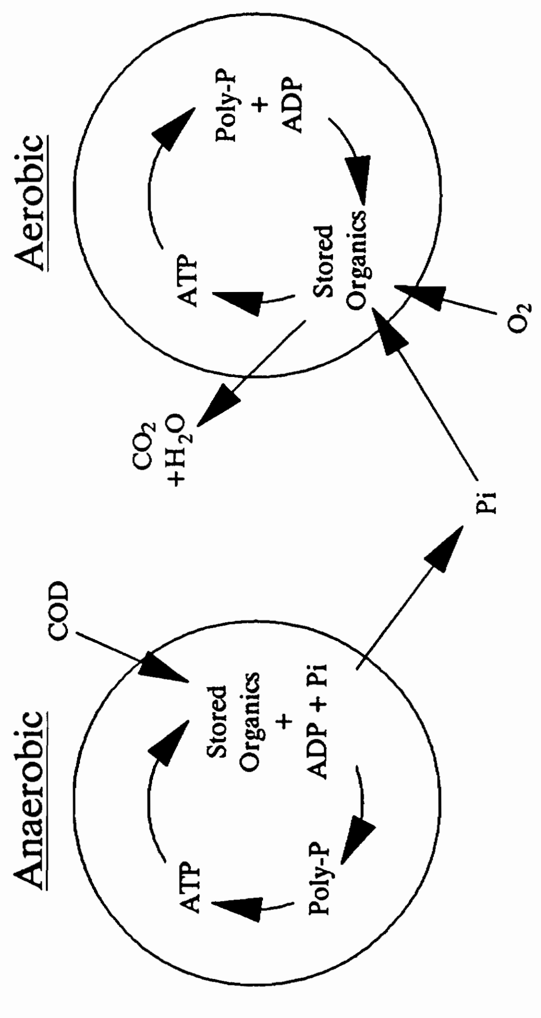

Figure 2-2. Biochemistry of Biological Phosphorus Removal (After Tracy and Flammino, 1987)

Flammino, 1987). This would mean that operation at a low MCRT would provide optimum conditions for BPR.

Effect of Temperature on BPR

Examination of the literature indicates that colder temperatures adversely affect P removal, even though many pilot-scale and full-scale plants have achieved adequate phosphorus removal under cold temperature conditions (Oldham and Dew, 1979; Barnard *et al.*, 1985; Oldham, 1985; Vassos *et al.*, 1987). At Kelowna, Canada, P removal dropped from 85% at temperatures above 15 °C to 68% at temperatures below 15 °C (Vassos *et al.*, 1987). In a lab-scale BPR process fed with domestic wastewater with added acetate, P release was 75% greater and the residual phosphorus was 33% lower at 29 °C than at 24 °C (Jones *et al.*, 1987). Only a 40% reduction in P and only 3.4% P in the sludge was attained in a pilot-scale BPR plant operated at 10 °C at a 23.5 d MCRT treating a semi-industrial wastewater (Meganck *et al.*, 1984). Other research indicates that anaerobic P release decreases with temperature (Yeoman *et al.*, 1988). Both release and uptake of P in BPR sludge from an Austrian full-scale facility decreased drastically when temperature decreased from 20 °C to 12 °C (Spatzierer *et al.*, 1985).

None of the models previously discussed includes a discussion of or corrections for temperature effects on phosphorus removal.

Combined Nitrogen and Phosphorus Removal

Processes designed to remove both nitrogen and phosphorus are known as biological nutrient removal (BNR) processes. BNR processes are characterized by the incorporation of three distinct zones within the reactor: anaerobic, anoxic and aerobic. In aerobic conditions, oxygen is present; in anoxic conditions, nitrate is present and oxygen is not; and in anaerobic conditions neither nitrate nor oxygen is present. The purpose of the anoxic zone in a BNR process is to provide for denitrification and nitrogen removal.

There have been many different flow schemes proposed for BNR (Barnard, 1975; Barnard, 1983; Siebritz *et al.* 1983; WPCF, 1983; Hong *et al.*, 1984; Murakami *et al.*, 1985; Brannan, 1986; Tetreault *et al.*, 1986). For purposes of this document, only the process used in this study (a UCT-type process as shown in Figure 3.1) will be discussed.

The UCT process has been demonstrated in pilot- and full-scale plants to perform reliable and consistent nitrogen and phosphorus removal under a variety of conditions (Marais and Ekama, 1984; Daigger *et al.*, 1987; Randall, 1988; Wable and Randall, 1988). The UCT process works best when each of the zones can be separated into smaller zones with baffles to simulate plug flow (Marais and Ekama, 1984; Wentzel *et al.*, 1986). The anaerobic zone is protected from addition of nitrates because only denitrified mixed liquor (anoxic recycle) is recycled there. The return activated sludge (RAS) and nitrified mixed liquor (nitrate) recycles feed the anoxic zone with nitrate, and are combined with mixed liquor from the last anaerobic section.

The Role of Nitrate in BPR

It is well established that nitrate introduced into the anaerobic zone of a BPR process reduces P release and subsequent P uptake (Siebritz *et al.*, 1983; Barnard *et al.*, 1985; Hascoet and Florentz, 1985). This is possibly due to polyP organisms using nitrate as an electron acceptor in the anaerobic zone, thus preventing organic uptake and P release (Hascoet and Florentz, 1985), or to prevention of the formation of fatty acids by the fermenters in the anaerobic zone (Marais and Ekama, 1984).

The role of nitrate in BNR processes needs further clarification. The anoxic reactors were found to have very small denitrification capacities in batch tests using an enhanced BPR sludge created by acetate addition (Wentzel *et al.*, 1989a). It was concluded that polyP organisms in the enhanced BPR sludge performed negligible denitrification. Further studies, however, yielded much different results. The denitrification achieved in the anoxic reactor of another BPR process with an enhanced culture was very high, the same as that in a non-BPR system with the same anoxic mass fraction (Wentzel *et al.*, 1990).

Most of the bacteria present in the sludges of the two previously mentioned studies were *Acinetobacter*. The researchers explain their differing results by the fact that there are three different groups of *Acinetobacter* spp. with different denitrification capabilities, and their combined behaviour gives rise to the overall behaviours

(Wentzel *et al.*, 1990). One group is incapable of denitrification, a second group can reduce nitrate to nitrite and the third group can reduce nitrate to nitrogen. Approximately 50% of *Acinetobacter* spp. isolated from one BPR sludge were capable of nitrate reduction (Lötter, 1985).

The anoxic zone in BNR processes is preferably situated directly following the anaerobic zone (Comeau *et al.* 1987). Most of the organic matter is stored in the cells as they enter the anoxic zone. Many studies show that there is at least a short period, *i. e.*, 10 minutes, in which denitrification occurs at a high rate apparently using stored organics as the carbon source (Gerber *et al.*, 1986; Gerber *et al.*, 1987; Marais *et al.*, 1983; Siebritz *et al.*, 1983).

If polyP organisms use nitrate to oxidize stored organics, this indicates P uptake may occur under anoxic conditions. In one set of experiments, P uptake occurred under anoxic conditions until nitrate was gone, and then P release occurred (Comeau *et al.*, 1986; Comeau *et al.*, 1987; Mostert *et al.*, 1987). The explanation is that phosphorus release and uptake occur simultaneously. This is possible if a fraction of the polyP organisms use nitrate as an electron acceptor and store phosphorus under anoxic conditions, while the other organisms continue to release phosphorus. It is also possible that when the polyP organisms exhaust the nitrate, anaerobic conditions exist and PHB storage begins, resulting in phosphorus release.

Nitrification Rates and Denitrification Rates in BNR Systems

Nitrification rates of 1.53 to 2.91 mgN/mgMLSS/h were observed by Gerber *et al.* (1986). Rates of 1.40 to 4.00 mgN/mgMLSS/h were reported for a sludge age of 20 days by Winter (1989), with the lower rates occurring when influent COD was highest. In general, it is assumed nitrification in BNR systems can be modeled in the same manner as it is modeled in other single-sludge nitrification-denitrification models (Grady *et al.*, 1986; Wentzel *et al.*, 1989). These models describe nitrification using a *Nitrosomonas* growth rate approach assuming a maximum specific growth rate for *Nitrosomonas* (Wentzel *et al.*, 1989).

Denitrification rates ranging from 0.61 to 2.51 mgN/gMLSS/h were reported by Gerber *et al.* (1986) and Gerber *et al.* (1987) using various organic substrates in batch experiments. Organic substrates were combined with BPR sludge and mixed anaerobically before nitrate addition. Acetate yielded the highest denitrification rate. Denitrification rates of approximately 1.7 mgN/gMLSS/h were reported by Comeau *et al.* (1986) and Comeau *et al.* (1987) using sewage with added acetate, and 0.6 to 1.9 mgN/gMLSS/h were reported for a sludge age of 20 days by Winter (1989) using acetate. Gerber *et al.* (1986) reported a relatively low rate of 0.64 mgN/gMLSS/h using settled sewage. Denitrification rates decreased from 1.2 to 0.4 mgN/gMLSS/h when the temperature decreased from 20 °C to 12 °C (Spatzierer *et al.* 1985).

It has been reported that denitrification occurs at two or more distinctive rates (Van Haandel *et al.*, 1981; Seibritz *et al.*, 1983; Marais and Ekama, 1984). The first rate is fast, lasting only from 1 to 10 minutes, and is used to describe denitrification using rapidly biodegradable COD as organic substrate. The second rate is slower and is used to describe denitrification using slowly biodegradable particulate COD. The third rate is slowest and describes endogenous denitrification.

The following equations are used to describe the three denitrification rates just described (Siebritz *et al.*, 1983):

$$K_1 = 0.03(1.20)^{(T-20)} \quad \text{for } T > 14\ °C \tag{2.14}$$

$$K_2 = 0.0042(1.08)^{(T-20)} \quad \text{for } T > 14\ °C \tag{2.15}$$

$$K_2 = K_3 \quad \text{for } T < 14\ °C$$

$$K_3 = 0.0032(1.03)^{(T-20)} \quad \text{for } 10\ °C < T < 14\ °C \tag{2.16}$$

where K_1, K_2, K_3 = denitrification rates (mgN/mgX_a/h),

T = temperature, and

X_a = active mass concentration (mgVASS/L).

Anaerobic Stabilization

Anaerobic stabilization is defined as organic removal under anaerobic conditions which causes a reduction in subsequent oxygen requirements. It is further defined as a net oxidation of organic compounds in a BNR process which cannot be attributed to oxygen or nitrate respiration. Models for BPR processes assume that no stabilization of organics occurs under anaerobic conditions (Marais *et al.*, 1983; Wentzel *et al.*, 1990). Investigation of anaerobic stabilization is warranted, because its existence means the utilization of biological nutrient removal processes can substantially reduce system oxygen requirements. Consequently, BNR processes may be the design of choice, based on economics, even when nutrient effluent standards do not have to be met (Randall, 1984; Randall *et al.*, 1985).

Measurement of anaerobic stabilization is possible through an oxygen balance of the system. This method has been used in previous studies which have shown that anaerobic stabilization occurs in BNR processes.

A substantial amount of the influent COD was stabilized in the anaerobic zone of a lab-scale BPR system, as indicated by a much lower than predicted oxygen consumption in the aerobic zone (Lan *et al.*, 1983). In discussions of anaerobic stabilization it was concluded that BPR systems have the potential for significantly reducing the oxygen demand when compared to conventional activated sludge systems performing nitrification (Randall, 1984; Randall *et al.*, 1984). Substantial stabilization of organic matter, *i. e.*, the reduction of subsequent oxygen requirements, occurred in the anaerobic stage of a pilot-scale BPR system (Randall *et al.*, 1985; Brannan *et al.*, 1986). Anaerobic stabilization of 0 to 50 percent of the influent COD was found in the operation of another pilot-scale UCT-type process (Randall *et al.*, 1987; Wable and Randall, 1988). In all cases, reported anaerobic stabilization was in addition to stabilization of organic material from denitrification.

One way to further prove the existence of anaerobic stabilization would be to operate a conventional, fully aerobic system to serve as a control to a BNR process. Oxygen requirements of the BNR process could be compared to oxygen requirements of the conventional process, and anaerobic stabilization could be determined through oxygen balances on the systems.

It was reported that the degree of anaerobic stabilization was a strong function of the influent COD (Randall *et al.*, 1987). Anaerobic COD stabilization averaged 27 and 23% of the total substrate stabilized in an experimental BNR system at MCRTs of 18 and 12 days, respectively, with 600 mg/L of dextrose as COD as the feed (Brannan, 1986; Brannan *et al.*, 1986). Anaerobic stabilization ceased when acetate was fed instead of dextrose.

Mechanisms of Anaerobic Stabilization

Energy utilization during the growth of fermenting bacteria is hypothesized as the primary mechanism of anaerobic stabilization (Brannan *et al.*, 1986; Randall *et al.*, 1987). Therefore, a readily fermentable organic substrate is necessary for anaerobic stabilization to occur.

It is known that many facultatively anaerobic bacteria are capable of fermenting glucose with hydrogen and carbon dioxide gas being produced (Stanier *et al.*, 1976; Daniels, 1984). This fermentation is characteristic of the genera *Escherichia, Enterobacter,* and *Proteus*, and it occurs in some *Aeromonas, Beneckea,* and *Photobacterium* species (*Bergey's Manual*, 1974; Stanier *et al.*, 1976).

This reaction can be explained in the following manner (Stanier *et al.*, 1976). One mole of glucose is metabolized via the Embden-Meyerhoff pathway to two moles of pyruvic acid. Then, each mole of pyruvic acid is split into one mole acetic acid and one mole formic acid. Formic acid rarely accumulates, however, since the previously mentioned bacteria possess the enzyme formic hydrogenlyase, which splits formic acid to CO_2 and H_2.

Hydrogen and carbon dioxide gases are also produced by many spore formers of the genera *Clostridium* and *Bacillus*. The biochemical mechanism is different, however, as the gases are formed as a *direct* product of pyruvic acid cleavage.

The fermentation reaction where acetic acid is produced from glucose can be written as follows:

$$\text{Glucose} \rightarrow 2\ \text{Pyruvic acid} \rightarrow 2\ \text{Acetic acid} + 2\ \text{Formic acid} \qquad (2.17)$$

Formic acid is then split into carbon dioxide and hydrogen gases by formic hydrogenlyase or direct cleavage, which results in a stabilization of organic matter:

$$HCOOH \rightarrow CO_2 + H_2 \qquad (2.18)$$

In Equation 2.16, protons (H^+ ions) act as the electron acceptor to oxidize the carbon in formic acid to carbon dioxide gas.

A balanced stoichiometric equation showing the complete pathway of glucose fermentation to acetic acid by these bacteria can be derived from Daniels (1984) as:

$$6.5\ C_6H_{12}O_6 + 13\ H_2O \rightarrow 26\ H_2 + 13\ CO_2 + 13\ CH_3COOH \qquad (2.19)$$

It is possible that anaerobic stabilization is achieved through this mechanism. Regardless of the pathway followed, one mole of glucose yields two moles of acetate, and hydrogen and carbon dioxide gas are produced. The oxygen requirements of the original glucose and the acetic acid products can be calculated from the following equations:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O \tag{2.20}$$

$$2\ CH_3COOH + 4\ O_2 \rightarrow 4\ CO_2 + 4\ H_2O \tag{2.21}$$

A comparison of the oxygen coefficients shows that 4 moles of oxygen are required to oxidize the acetic acid, where 6 moles of oxygen are required to oxidize glucose. This means that a total stabilization of 33% of the oxygen demand of glucose is realized through this fermentation, which is in the range of anaerobic stabilization reported in previous studies (Brannan ,1986; Brannan *et al.*, 1986; Lan *et al.*, 1986; Randall *et al.*, 1987).

It should be noted that there are many other possible fermentation pathways that can be followed in the anaerobic zone of a BNR process. Also, it has not been shown that facultative anaerobic bacteria in anaerobic zones of BNR systems ferment organics according to the previously described mechanisms. However, many facultative anaerobic bacteria common to activated sludge, including *Escherichia*, *Enterobacter*, *Bacillus*, and some species of *Aeromonas*, are known to be capable of stabilization of organics through fermentation of glucose to acetate with protons being the terminal electron acceptor (*Bergey's Manual*, 1974; Stanier *et al.*, 1976; Moore, 1990).

III. Experimental Methods

In this chapter, the overall experimental approach, including the operation of the experimental treatment systems, the methods of sampling and analysis, and the materials used, is described. The two major subsections in this chapter are: Operating Procedures, in which the methods and materials used in the operation of the experimental treatment systems are presented, and Analytical Procedures, in which the techniques for the analysis of samples are presented.

To accomplish the objectives of this research, three pilot-scale wastewater treatment systems were constructed and operated over a range of mean cell residence times (MCRTs) from 1.5 days to 15 days. Also, system performances were evaluated at temperatures of 10, 15 and 20 °C at MCRTs of 5 and 15 days, and at 20 °C at MCRTs of 2.7 and 1.5 days.

Operating Procedures

The materials and methods used for the construction and operation of the experimental treatment systems are presented in the first part of this section, and will be followed by the methods used for a separate denitrification batch test.

Experimental Treatment Systems

Three pilot-scale activated sludge wastewater treatment reactors were constructed of 3/8" plexiglass plastic. Each had a total volume of 50.4 liters and was subdivided into 12 equal sections by baffles. The baffles were placed in the reactors such that the fluid flowed over one baffle and under the next, thus simulating plug flow. The flow was under the first baffle in all three units. Each system was followed by a clarifier with a volume of approximately 12.6 L.

Two systems were operated as high rate UCT-type processes for nitrogen and phosphorus removal, much like the VIP-process originally investigated at the Lambert's Point wastewater treatment plants of Hampton Roads Sanitation District in Norfolk, Virginia, as reported by Randall *et. al.* (1987). One of the biological nutrient removal (BNR) systems was used primarily for the purposes of this study, while the other BNR system was used to study the role of metals in biological phosphorus removal as reported by Pattarkine (1990). The BNR systems were seeded with biological nutrient removal sludge obtained from the York River wastewater treatment plant of the Hampton Roads Sanitation District located in Seaford, Virginia.

The third reactor was operated as a fully aerobic, conventional system. This reactor was operated to serve as a control, and to compare data with the BNR systems. All sections of this reactor were aerated with compressed air and diffuser stones. This reactor was seeded with activated sludge from the Lower Strouble's Creek Treatment Plant of the Blacksburg-VPI Sanitation Authority.

Schematic diagrams of the experimental systems are shown in Figures 3-1 and 3-2. The first three sections of the BNR processes, as shown in Figure 3-1, were anaerobic, while the second three sections were anoxic. The final six sections were aerobic. The 3/3/6 scheme is typical for UCT processes. Aeration was provided by air compressors and diffuser stones. Return activated sludge (RAS) from the clarifier and mixed liquor from the last aerobic section were recycled to the first anoxic section. Mixed liquor from the last anoxic section was recycled to the first anaerobic section.

The conventional system, as shown in Figure 3-2, was operated with only one recycle, from the clarifier to the first section. This system was operated at all times under exactly the same conditions, *i. e.*, same feed, temperature, mean cell residence time (MCRT), flow rate, etc., as the experimental BNR system.

The experimental reactors were housed in an insulated utility building on the campus of Virginia Polytechnic Institute and State University (Virginia Tech). Temperature inside the building was controlled to ±1 °C by a thermostat controlled heating and cooling system.

Domestic wastewater was pumped from the sanitary sewer twice a day into 265 liter storage tanks. A concentrated potassium phosphate solution was added to each tank of wastewater to increase the wastewater phosphorus concentration by

Influent Feed = Municipal Wastewater
Influent Flow Rate (Q) = 151.2 L/d
All Recycles = 1Q = 151.2 L/d
Total Reactor Volume = 50.4 L
Total Nominal Hydraulic Retention Time (HRT) = 8 h

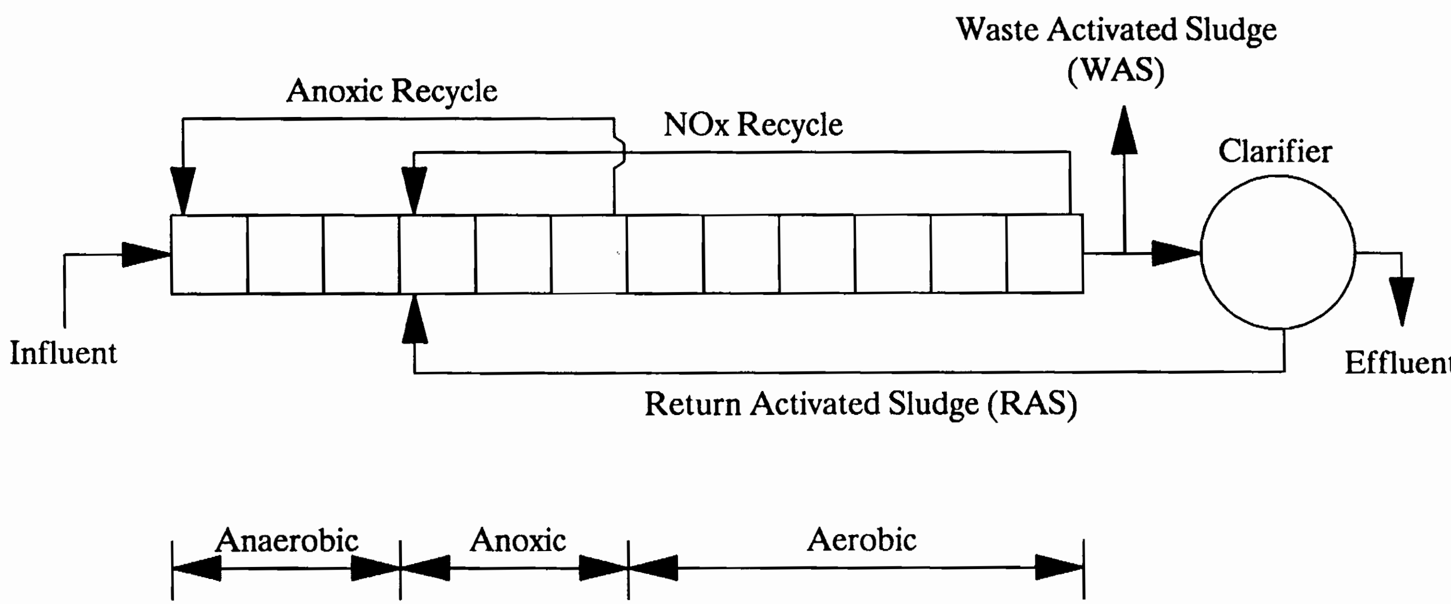

Figure 3-1. Schematic of the Experimental Biological Nutrient Removal System (University of Cape Town (UCT) -type Configuration)

Influent Feed = Municipal Wastewater
Influent Flow Rate (Q) = 151.2 L/d
Return Activated Sludge = 1Q = 151.2 L/d
Total Reactor Volume = 50.4 L
Total Nominal Hydraulic Retention Time (HRT) = 8 h

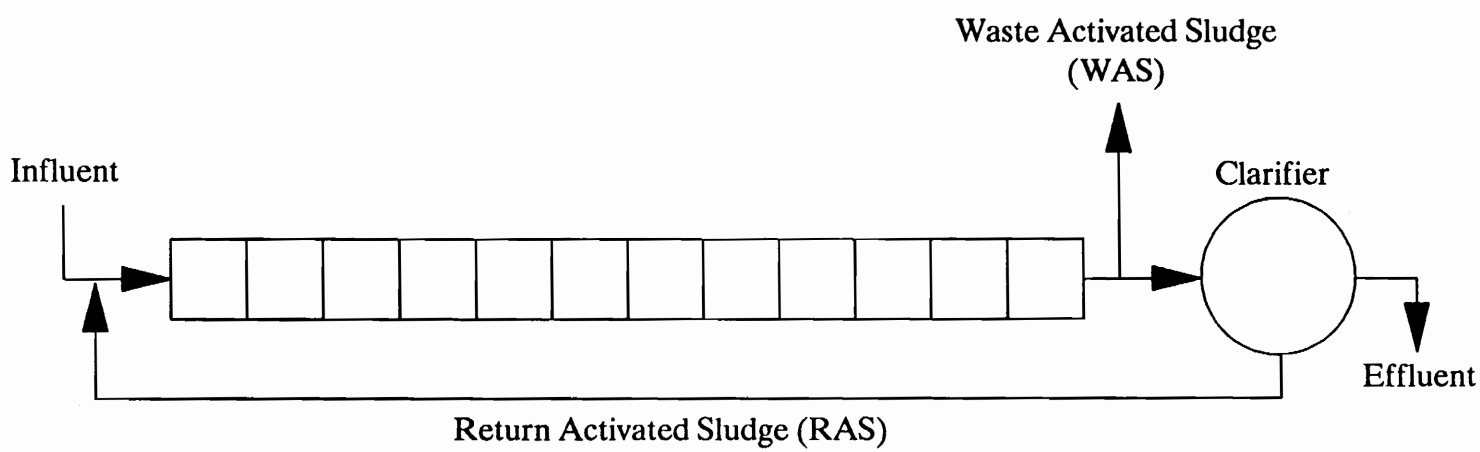

Figure 3-2. Schematic of the Conventional, Fully Aerobic System

approximately 13 mg/L to ensure P was never limiting. The sewage was held in the tank for 12 hours before feeding to the reactor to equilibrate with room temperature, to eliminate any dissolved oxygen, and to promote fermentation.

The experimental reactors were checked twice a day throughout the duration of the experiment. Routine maintenance tasks performed on the reactors are presented in Appendix D.

Wastewater and recycles were pumped by Cole-Parmer (Chicago,IL) peristaltic pumps with Masterflex™ pump heads. Influent was pumped at a rate of 151.2 L/d to each reactor, giving a nominal hydraulic retention time (HRT) of 8 hours for each system. All recycle flow rates were on a 1:1 ratio to influent flow (151.2 L/d).

Mean cell residence time (MCRT) served as the primary control parameter. Constant values of MCRT were maintained by daily wasting of an amount of mixed liquor which, when added with the solids lost in the effluent, would remove the reciprocal of the MCRT times the total amount of solids present in the system (Lawrence and McCarty, 1970). Calculation of the waste sludge was performed after each sampling period (every 3 to 5 days) to ensure MCRT was maintained at a constant and precise value. Wasting was performed at the end of each 24 hour operating period, allowing the reactors to stabilize before sampling the next day. At lower MCRTs, because of the large volumes of mixed liquor to be wasted, wasting was performed by pumping mixed liquor continuously from the reactor.

Conditions were assumed to be at an approximate steady state when operational parameters remained fairly constant over a period of time. Steady state data were never taken any sooner than at least three MCRTs after MCRT was changed. At least 30 days were allowed for steady state to be reached after a temperature change at 15 days MCRT, and at least 3 MCRTs were allowed to pass after a temperature change at other values of MCRT. The reactors were never at a true steady state because of daily variations in the wastewater characteristics. However, after sufficient time had passed, and parameters such as observed yield, degree of nitrification, and the percent phosphorus in the sludge had stabilized, data were collected which, for purposes of this document, will be referred to as steady state data.

Steady state data consisted of analyses of samples from all 12 sections, influents from the previous 24 hours, return activated sludge recycles, and effluents. Because of the extensive amount of sampling and analyses, steady state sampling could only be performed on one reactor per day. Parameters were measured in selected sections, *i. e.*, sections 3, 6, and 12, of each reactor about every 4 or 5 days after a change in temperature or MCRT was made. Collected samples were transported to the Virginia Tech Environmental Engineering laboratory, which took about 20 minutes, where they were immediately filtered and analyzed.

Four influent samples were collected and analyzed for each sampling day throughout most of the study. The samples were designated as Inf''', Inf'', Inf', and

Inf. The Inf''' sample was from the influent tank fed from 24 to 12 hours prior to effluent sampling, and was taken when the sewage was first pumped into the tank (24 hours prior to effluent sampling). Inf'' was taken from the same tank right before it emptied (12 hours prior to effluent sampling). Inf' was taken from the next tank when wastewater was initially pumped to the experimental systems (12 hours prior to effluent sampling), while the Inf sample was taken from this same tank before it emptied, which was at the same time as effluent samples were taken.

Denitrification Batch Experiment

Mixed liquor from the anoxic zone of the BNR system operating at 15 d MCRT and 20 °C was mixed with an equal volume of filtered domestic wastewater with 100 mg/L of acetate as COD added. The mixture was stirred anaerobically for 60 minutes, and then separated into two batches. To one batch, potassium nitrate was added to provide an initial NO_3^--N concentration of 30 mg/L, and it was stirred anoxically for 80 minutes. Throughout the anaerobic and anoxic phases, the mixture was kept under a nitrogen gas atmosphere. The second batch was aerated with compressed air and a diffuser stone for 80 minutes. The pH and the concentrations of soluble phosphorus, soluble COD, and soluble nitrate-nitrogen were measured at 10 minute intervals throughout the experiment by withdrawing samples from the mixed liquor and filtering through a 0.45 μ membrane filter.

Analytical Procedures

The regularly monitored parameters and the methods used for analysis are presented in Table 3-1. Chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N or NH_4^+-N), and total phosphorus (TP) were measured on unfiltered influent samples, and occasionally on unfiltered mixed liquor samples. Nitrate (NO_3^--N) and nitrite (NO_2^--N) were measured by ion chromatography after filtration through 934AH Whatman glass fiber filters. Soluble orthophosphorus (OP) and COD samples were analyzed on samples filtered through 0.45 μ pore size membrane filters. Dissolved oxygen (DO), temperature and pH were monitored periodically.

During steady state sampling, COD, NO_2^--N, NO_3^--N, OP mixed liquor suspended solids (MLSS), and mixed liquor volatile suspended solids (MLVSS) were measured on influents, effluents, the return activated sludge (RAS), and each section of each reactor. Other parameters such as TP, TKN, NH_3-N, pH, and alkalinity were measured on influents, effluents, and selected sections. Sludge volume index (SVI) and oxidation/reduction potential (ORP) were measured during steady state periods. SVI was measured as the 30 minute settled volume (ml) in a 1 L graduated cylinder of mixed liquor from the last aerobic section divided by the MLSS (g). ORP was measured with an Ag/AgCl reference electrode.

Table 3-1. Parameters Monitored

Parameter	Method (Number)[1]
COD	Closed Reflux, Titrimetric Method (508 B)
MLSS	Total Suspended Solids Dried at 103-105 °C (209 C)
MLVSS	Fixed and Volatile Solids Ignited at 550 °C (209 D)
SP	Ascorbic Acid Method (424 F)
TP	Persulfate Digestion (424 C - III) followed by Ascorbic Acid Method (424 F)
TKN	Semi-micro-Kjeldahl Method (420 B) followed by Distillation (417 A) and Titration (417 D)
NH_3-N	Preliminary Distillation Step (417 A) followed by Titrimetric Method (417 D)
NO_2-N NO_3-N	Determination of Anions by Ion Chromatography with Conductivity Measurement (429)
Alkalinity	Alkalinity (269)
pH	Direct measurement with a Fisher Model 610A pH meter (423)
Dissolved Oxygen	Direct measurement with YSI Model 54 A Membrane Electrode Oxygen Meter (421 F)
Temperature	Direct measurement *in situ* using mercury-filled Celcius thermometer (212)

[1]Reference: *Standard Methods* (1985).

Oxygen utilization rates (OURs) were measured for aerobic sections at steady state at MCRTs of 5 and 15 days for use in performing oxygen balances on the systems. OURs were measured according to *Standard Methods* (1985) except for the differences described here. At 15 d MCRT, the rates were measured *in situ*. The dissolved oxygen probe was placed at the midpoint of a reactor section and allowed to equilibrate. All pumps and air compressors of the reactor were turned off and the dissolved oxygen consumption was measured for 5 minutes. The settled sludge interface after 5 minutes was always less than 0.75 inches from the surface out of 16 inches total reactor height (slow settling), which made *in situ* measurement possible without mixing. At 5 d MCRT, settling was much faster and *in situ* measurement of OURs was not possible. Therefore, mixed liquor was transferred to a BOD bottle for OUR testing. Mixing was provided by a mechanical stirrer on the DO probe.

Statistical Methods Used in Data Analysis

Linear regression was used to statistically fit straight lines to dissolved oxygen raw data to determine oxygen uptake rates. Linear regression was also used to fit straight lines to data in plots used to determine the microbial growth coefficients Y_{max} and b.

In cases where ranges of values are analyzed, means and standard deviations are reported to provide some indication of error on the analyzed data.

IV. Results

The objectives of this research were accomplished by operating three continuous-flow activated sludge reactors for approximately 15 months. Two of the reactors (Reactor 1 and Reactor 2) were operated as UCT-type biological nutrient removal (BNR) processes for nitrogen (N) and phosphorus (P) removal (Figure 3-1). Reactor 1 served to provide data for nitrification rates, denitrification rates, nitrogen removal, and phosphorus removal. Reactor 2 was operated primarily to provide data on metals release and uptake with phosphorus, which is discussed elsewhere (Pattarkine, 1990), but also provided some data on phosphorus removal which is presented here. The third reactor (Reactor 3) was operated as a conventional activated sludge process, for comparison, and was completely aerobic (Figure 3-2). The reactors were operated and data were collected as described in the *Experimental Methods* chapter. The remainder of this chapter is devoted to the presentation of the results of this study.

The experimental treatment systems were evaluated over a range of mean cell residence times (MCRTs) and temperatures. Temperatures of 10, 15, and 20 °C were studied at MCRTs of 15 and 5 days. MCRTs of 2.7 days and 1.5 days were evaluated at 20 °C.

Because excess phosphorus was being added to the feed, biological phosphorus removal was limited by influent COD concentration unless otherwise noted. The experimental reactors were operated in this manner to determine the maximum phosphorus removal or percent P in the sludge that could be attained under the given conditions.

Shown in Appendix A is a summary of activities for the duration of the study. The experimental treatment systems were operated and monitored from February 13, 1989 to April 19, 1990. Many different operating conditions were studied, and they are distinguished from one another by separating them into different phases.

A summary of the steady state data obtained for the BNR and conventional systems is presented in Table B-1 in Appendix B. The data presented for one given steady state condition are the results of a rigorous day of sampling and testing. Appendix C contains all raw data collected during the experiment. The daily routine and maintenance schedule followed during the study is located in Appendix D.

Examination of the data presented in Appendices B and C allows evaluation and comparison of many aspects of the performance of the experimental treatment systems under the given operating conditions. Removals of nitrogen, phosphorus, and COD can be calculated from the difference between influent and effluent totals. Nitrification performance can be determined by looking at effluent NH_3-N concentrations.

It is difficult to compare nitrogen and phosphorus removal results from different operating conditions, *i. e.*, different temperatures and MCRTs, of the BNR system because the influent wastewater COD concentrations varied so much, and had definite effects on the results. The feed was not augmented for COD buffering because it was desired to use domestic wastewater only. Care should be taken to consider the effects of COD when comparing nitrogen and phosphorus removal results between different operating conditions. Higher influent COD concentrations generally meant higher nitrogen and phosphorus removals, and higher percent phosphorus in the sludge.

Shown in Figure 4-1 are the percentages of phosphorus in the sludges (%P/VSS) from all three systems from the beginning of the study (Day 1) to the end. Descriptions of the different phases of the study are detailed in Appendix A. From this figure it can be seen that a large number of samples were analyzed over a long period of time. Also, some idea of the variability of the experimental data on %P/VSS can be observed. Some of the data presented in this figure will be discussed further later in this chapter.

Many different experiments were performed throughout the study, and the conditions under which the systems were being operated should be known before interpreting the data presented in Figure 4-1. In general, %P/VSS fluctuated less than day-to-day phosphorus removal results. Therefore, the parameter %P/VSS is used to evaluate the capacity for phosphorus removal throughout this study.

Summary of Steady State Data

The most important influent and effluent data, *i. e.*, P, N, and COD, from the steady state periods are shown in Table 4-1. Also presented in Table 4-1 are the

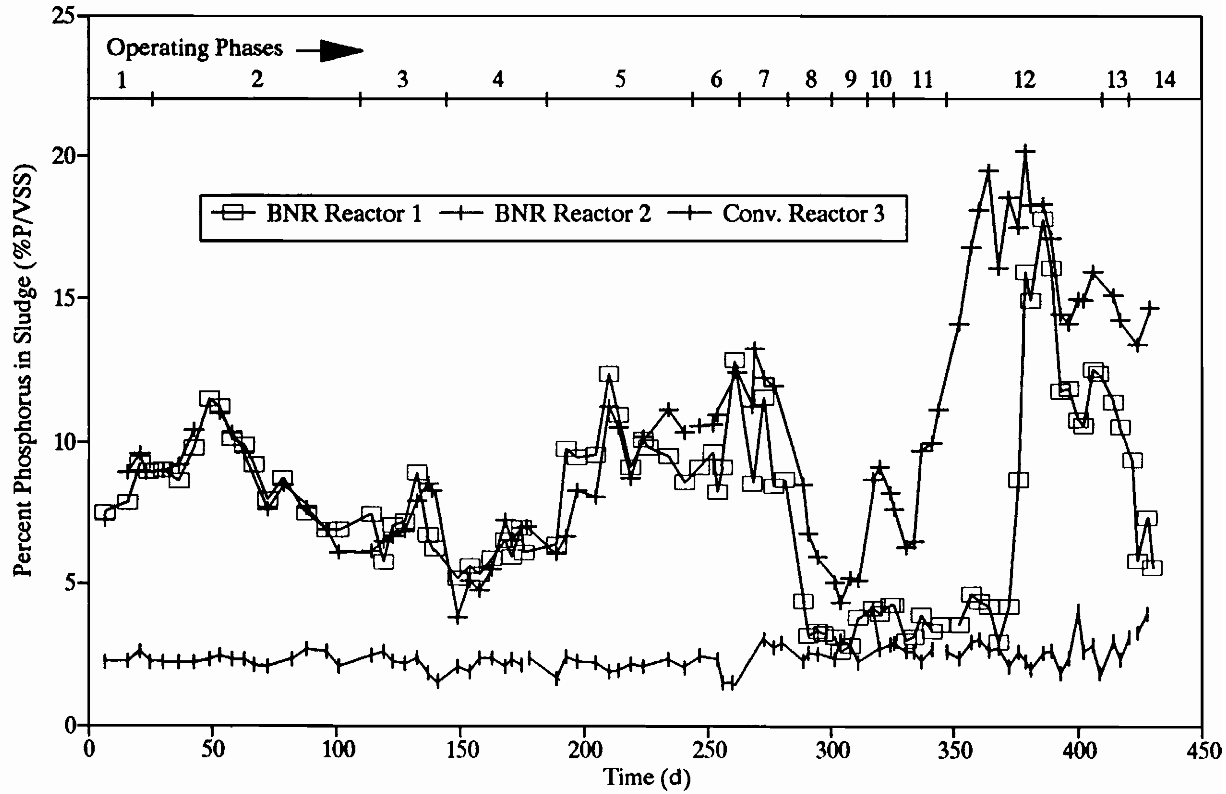

Figure 4-1. Percent Phosphorus in Sludge during Project Period
(For description of operating phases see Appendix A)

Table 4-1. Summary of Selected Influent and Effluent Steady State Data

System	MCRT (d)	Temp (C)	Date	Influent TKN (mg/L)	Influent NH3-N (mg/L)	Influent NOx-N (mg/L)	Influent TN (mg/L)	Influent TP (mg/L)	Influent Avg COD (mg/L)	Effluent TKN (mg/L)	Effluent NH3-N (mg/L)	Effluent NOx-N (mg/L)	Effluent Total SP (mg/L)	Effluent OP (mg/L)	Effluent COD (mg/L)	%P/VSS
BNR	15	20	03JUL89	22.4	15.9	0.0	22.4	16.4	176	0.1		7.3		11.7	12	6.3
	15	15	02MAY89	30.4	22.0	0.3	30.7	17.7	235	0.1		9.7		13.5	19	8.8
	15	10	08AUG89	24.5	17.8	0.0	24.5	14.3	166	0.2		9.6		12.6	17	6.1
	5	20	28MAR90	30.0	27.5	0.1	30.1	20.3	244	0.0	0.0	11.4	13.4	12.8	29	12.4
	5	15	21NOV89	34.3	27.2	0.1	34.4	19.0	201	6.2	5.9	8.8	18.6	18.5	27	8.7
	5	10	07DEC89	38.0	28.4	0.0	38.0	17.6	283	21.1	19.4	1.6	15.8	15.9	24	3.2
	2.7	20	11APR90	31.5	23.8	0.0	31.5	18.7	263	1.6	1.6	6.1	12.0	11.6	*26	9.4
	1.5	20	19APR90	36.6	29.8	0.0	36.6	19.5	247	16.2	15.4	2.3	15.3	14.9	33	5.6
Conven-tional	15	20	04JUL89	25.6	17.4	0.0	25.6	15.3	281	0.6		13.8	13.6	13.0	35	1.5
	15	15	06MAY89	29.3	-	0.0	29.3	16.8	176	0.0	0.0	24.1		15.3	15	2.3
	15	10	10AUG89	25.4	17.6	0.1	25.5	15.8	173	0.0	0.0	18.8	13.3	14.1	23	2.4
	5	20	29MAR90	35.0	28.9	0.3	35.3	20.3	344	0.0	0.0	21.5	19.2	18.5	*24	1.9
	5	15	20NOV89	28.9	24.1	0.1	29.0	18.3	110	0.0	0.0	27.4	17.8	17.6	4	2.9
	5	10	08DEC89	31.8	23.2	0.0	31.8	18.6	266	9.9	8.1	12.6	17.4	17.8	36	2.6
	2.7	20	10APR90	34.3	26.0	0.2	34.5	19.1	257	0.0	0.0	21.7	17.4	16.8	*27	3.1
	1.5	20	17APR90	36.6	30.0	0.0	36.6	19.2	263	6.4	5.6	15.5	17.8	17.2	31	3.9

* Section 12 COD value substituted for suspected erroneous effluent value.

steady state percentages of phosphorus in the sludge (%P/VSS) from the last aerobic section from which sludge was wasted. Complete summaries of all data taken during steady state periods, including reactor profiles of solids and phosphorus concentrations, are presented in Appendix B. It is clear that at a 15 d MCRT, the BNR system performed well in all aspects at temperatures between 10 and 20 °C, which was the range of temperatures studied. Complete nitrification was achieved at all temperatures studied, and total nitrogen (TN = TKN + NO_x-N) removals of 60% to 70% were attained.

Phosphorus removals of 4.7 to 2.3 mg/L were obtained in the BNR system at the 15 d MCRT. This degree of P removal was high considering the relatively low influent COD concentrations during the 15 d MCRT runs, except for the removal of only 2.3 mg/L at 10 °C, which was lower than expected.

The BNR system performed well at a 5 d MCRT at a temperature of 20 °C. Phosphorus was decreased by 6.9 mg/L from the influent total phosphorus (TP) concentration. The steady state P and COD profiles through the reactors for the 5 d MCRT and 20 °C are shown as examples of conditions providing good P removal. Figure 4-2, the P profile, shows a release of P occurred in the anaerobic zone, followed by a subsequent uptake of P in the aerobic zone, resulting in a net removal of 7.4 mgP/L. It appears that some uptake of P occurred in the second and third anaerobic zones. However, the decrease in P can be attributed to backmixing from the first anoxic zone (section 4). An increase in solids concentrations from the first to the third sections occurred, providing further evidence of backmixing. It should

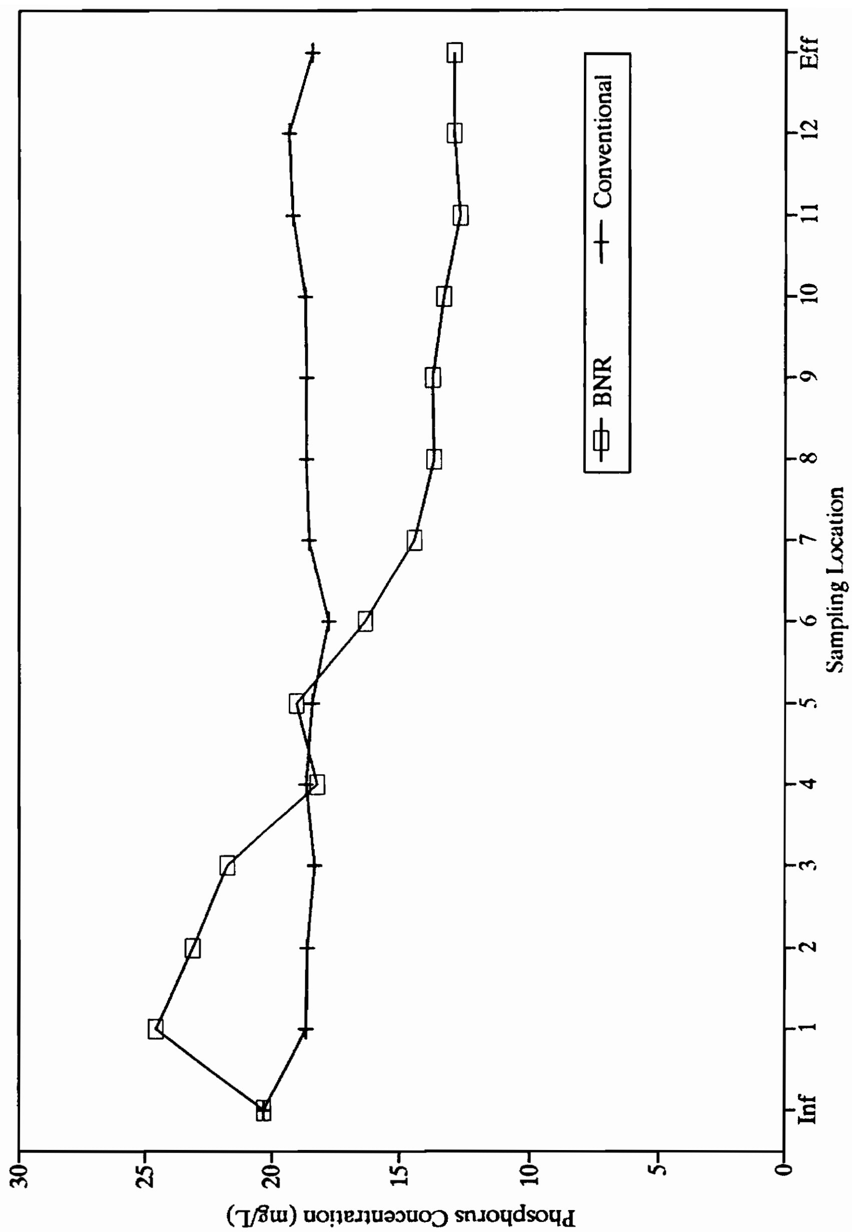

Figure 4-2. Steady State Phosphorus Profiles - 5 d MCRT, 20 C

also be noted that the decrease in P concentration from section 3 to section 4 is not necessarily P uptake, because two recycles with lower P concentrations are introduced at this point causing dilution of the P concentration.

The P profile of the conventional system under the same conditions, *i. e.*, 5 d MCRT and 20 °C, is also pictured in Figure 4-2. This figure shows a net removal of only 2 mg/L.

Figure 4-3, the COD profiles under the same conditions, show that all COD removal took place in the first (anaerobic in the case of the BNR system) zone in both systems.

At 5 d MCRT and 15 °C, both N and P removal decreased. Nitrogen removal was affected primarily by incomplete nitrification, as evidenced by 5 mg/L NH_3-N in the effluent. The effluent TP and OP for this data point are not representative of the average effluent P concentrations for this condition. P removal as indicated by the influent and effluent values for this day indicate that < 1 mg/L of P was removed. Average removals of P at a 5 d MCRT and 15 °C were about 6 mgP/L. The propensity for P removal is best indicated by %P/VSS, which fluctuated little, rather than actual P removal, which varied widely from day to day and which was highly dependent on influent COD concentrations. The %P/VSS decreased fron 12.4 at 20 °C to 8.7 at 15 °C.

At 5 d MCRT and 10 °C, conditions proved to be unfavorable for nitrogen and phosphorus removal. Nitrification was inhibited as evidenced by 19.4 mg/L NH_3-N in the effluent, while the %P/VSS decreased dramatically to 3.2%.

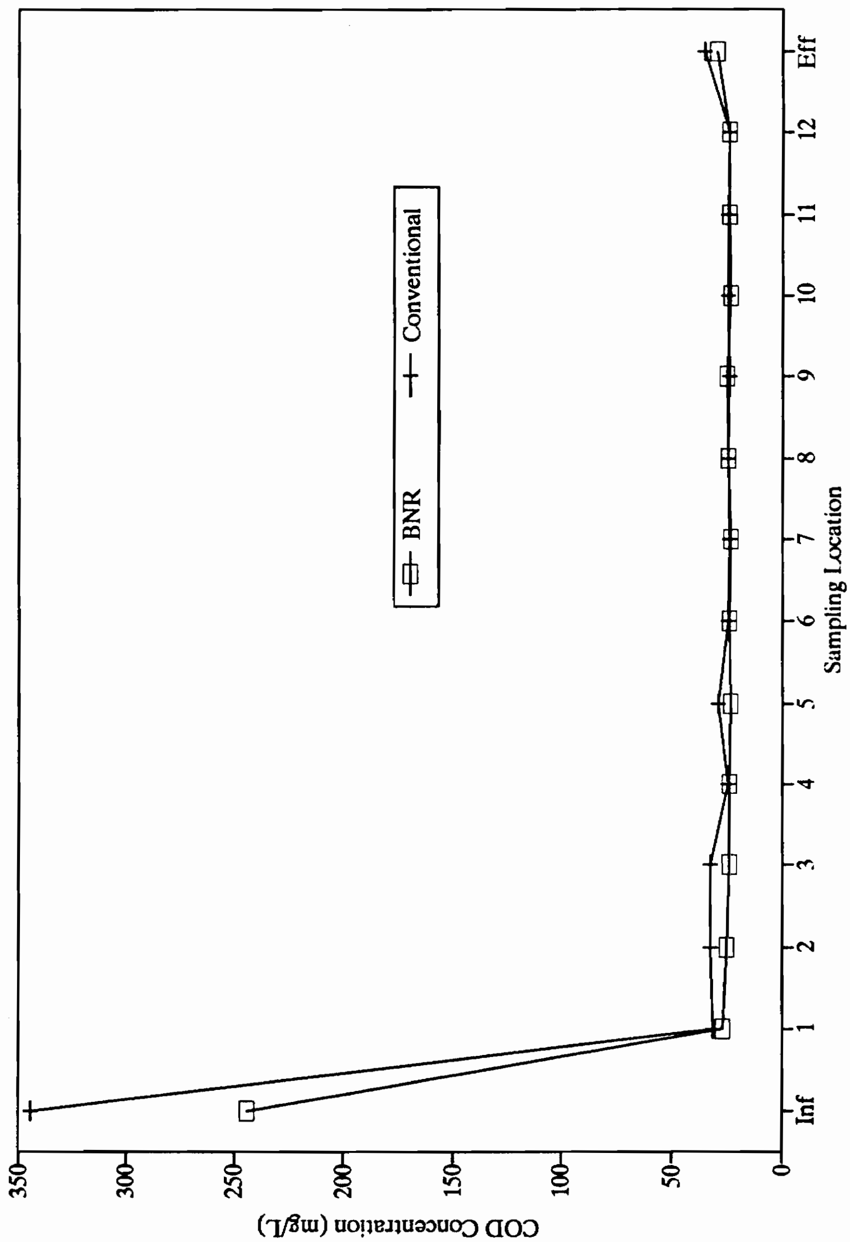

Figure 4-3. Steady State COD Profiles - 5 d MCRT, 20 C

The phosphorus and COD profiles of 5 d MCRT and 10 °C, as shown in Figures 4-4 and 4-5, respectively, are presented as examples illustrative of conditions unfavorable to biological phosphorus removal. Figure 4-4 shows that very little P release and uptake occurred under these conditions, resulting in removal of only 2.4 mg/l, even though the influent COD was relatively high at 283 mg/L. Figure 4-5 shows that all the COD was not removed in the first anaerobic zone of the BNR system, unlike at a 5 d MCRT and 20 °C where BPR was working well.

Operation of the BNR system at a 2.7 d MCRT and 20 °C provided good N and P removal. Although nitrification efficiency and %P in the sludge decreased from 5 d MCRT operation, increased amounts of waste sludge kept N and P removals high. At a 1.5 d MCRT, nitrification, total nitrogen removal, and P removal all decreased from levels seen at a 2.7 d MCRT.

Analysis of the conventional system showed that under all conditions, P removals of about 1 to 3 mg/L were achieved. This is considered typical for operation in this range of MCRTs and is achieved through daily wasting of conventional activated sludge containing 2 to 3% phosphorus. Nitrogen removals of about 20-40% were achieved, also through wasting of sludge. Nitrogen balances performed on the system showed that little denitrification occurred in the conventional system.

Complete nitrification was achieved in the conventional system at 15 d MCRT at all temperatures studied and at 5 d MCRT at 15 and 20 °C. At 5 d MCRT and 10 °C, nitrification decreased as indicated by an effluent NH_3-N of 8.3 mg/L. Operation at an MCRT of 2.7 d and 20 °C provided complete nitrification.

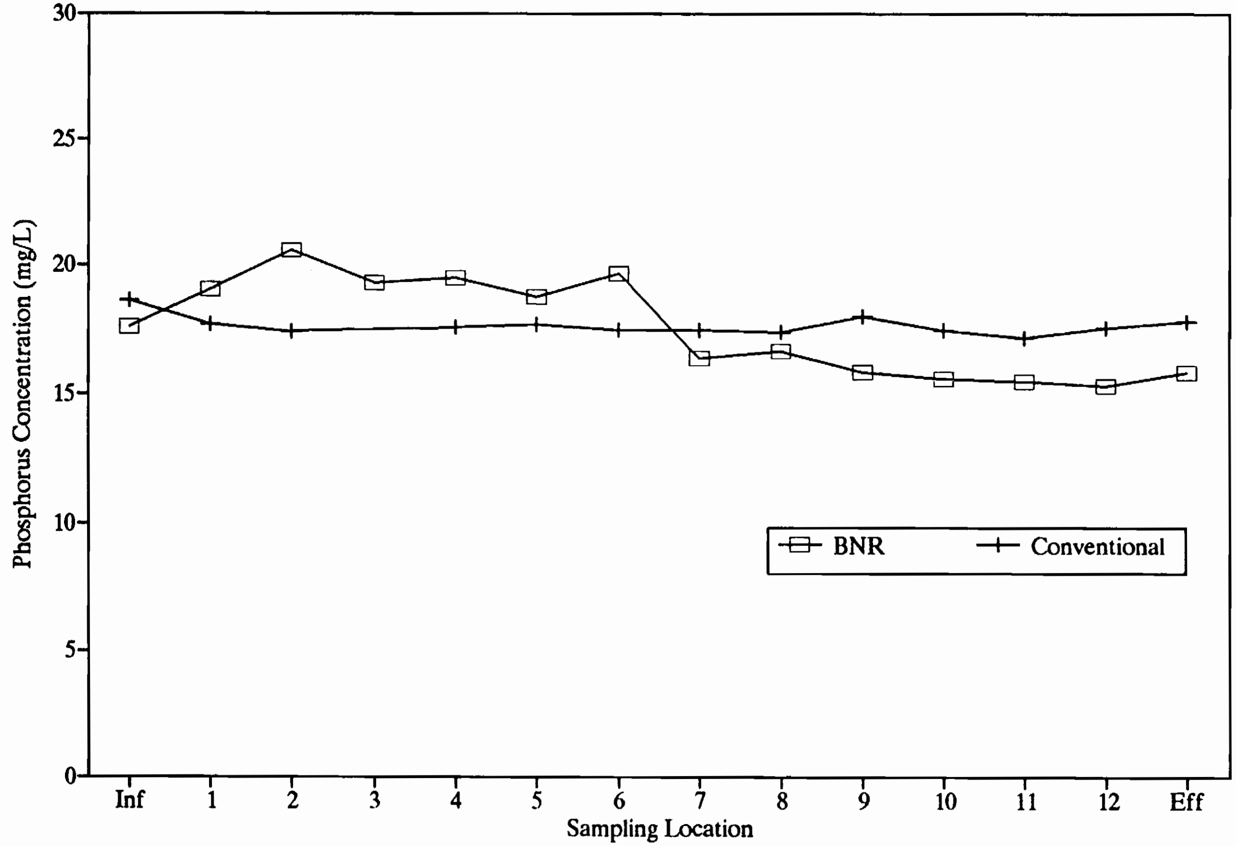

Figure 4-4. Steady State Phosphorus Profiles - 5 d MCRT, 10 C

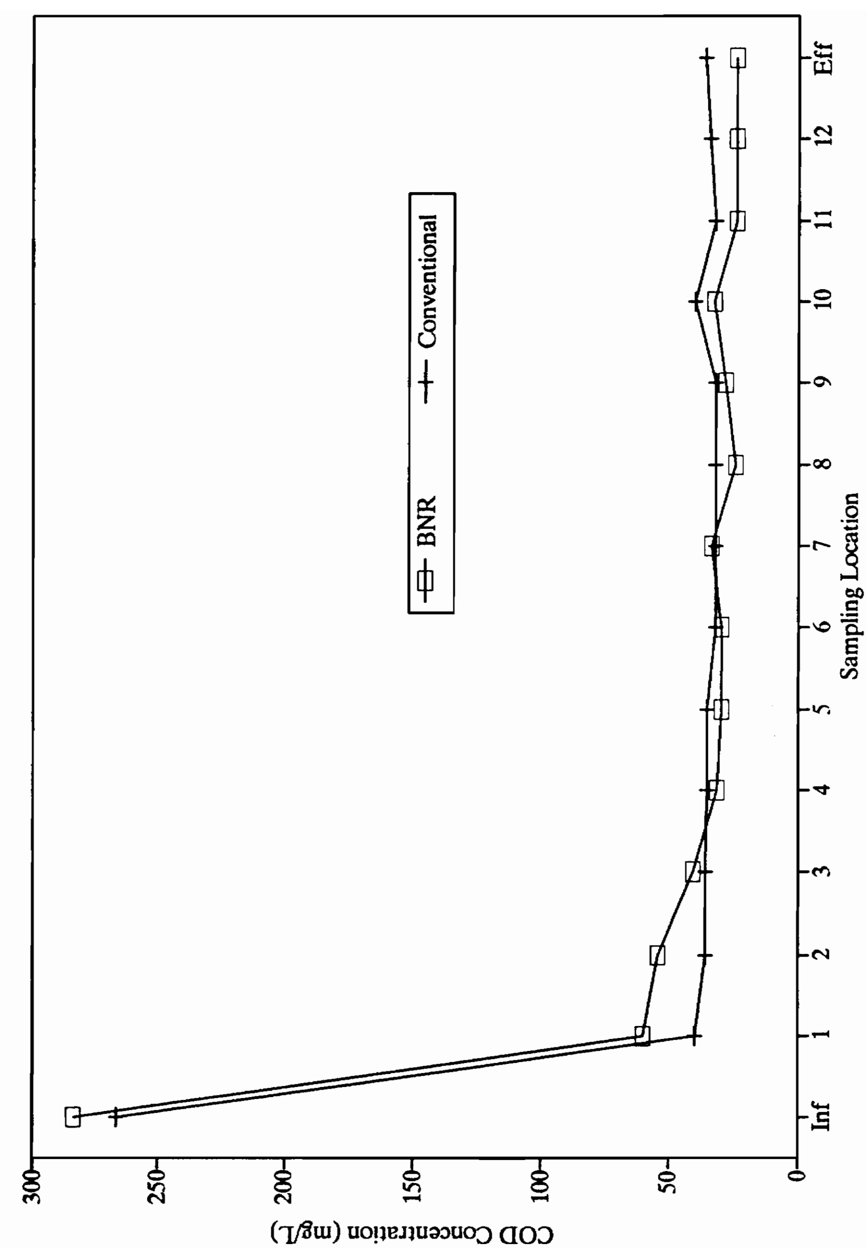

Figure 4-5. Steady State COD Profiles - 5 d MCRT, 10 C

However, at the 1.5 d MCRT nitrification decreased as indicated by effluent NH_3-N of 5.6 mg/L.

Removals of COD were greater than 85% under all operating conditions for both the BNR and conventional systems. It is believed that nearly complete removal of biodegradable organics was achieved, especially since soluble COD concentrations stopped decreasing by the last few sections.

Separate tests were run periodically throughout the study to determine the percent of nitrogen and the COD of the solids in the sludge. The results of these tests are presented in Table 4-2. Percent nitrogen was calculated on an MLVSS basis. Samples for these analyses were taken from the last aerobic section of each system. The MLVSS contained 9.8% nitrogen in both the BNR and conventional systems. The COD/MLVSS ratios were 1.34 and 1.30 for the BNR and the conventional systems, respectively.

Effects of Temperature on Total Nitrogen (TN) Removal

Total nitrogen (TN) removal is defined as removal of the influent total nitrogen. Since TN removal included nitrogen removed via sludge wasting, it was affected by influent COD and MCRT. TN removal increased as COD increased or as MCRT decreased. Therefore, these factors must be considered in addition to nitrification and denitrification when analyzing TN removal.

Table 4-2. COD and Percent Nitrogen of Sludge Solids

Date	BNR System		Conventional System	
	mgCOD/ mgMLVSS	%N/ MLVSS	mgCOD/ mgMLVSS	%N/ MLVSS
03JUL89		9.0		
04JUL89				10.3
17JUL89	1.52	9.3	1.21	
21JUL89	1.21		1.13	
26JUL89	1.29		1.30	9.5
31JUL89	1.40			
03AUG89	1.35	9.3	1.49	9.2
07AUG89	1.33		1.39	
08AUG89	1.25			
10AUG89			1.44	
21AUG89	1.27		1.20	
25AUG89	1.24		1.48	
29AUG89	1.47		1.17	
06SEP89	1.24			
11SEP89	1.49	10.1	1.08	10.1
15SEP89	1.29		1.15	
20SEP89	1.40		1.51	
25SEP89				
23OCT89		9.3		9.3
20NOV89				10.5
21NOV89		10.5		
07DEC89		11.0		
08DEC89				9.5
Average	1.34	9.8	1.3	9.8
# of Samples	14	7	12	7
Std. Deviation	0.16	0.7	0.5	0.7

TN removal for the BNR system is shown in Figure 4-6 as a function of temperature. Only one data point is included for 2.7 d and 1.5 d MCRT because they were evaluated at 20 °C only. High degrees of nitrogen removal (60 to 75%) were achieved at 20 °C for all MCRTs greater than or equal to 2.7 d. TN removals were most dependent on the degree of nitrification and denitrification achieved, and generally decreased as temperature decreased, with the removal at 5 d MCRT being more affected by lower temperatures than the 15 d MCRT. Nitrogen removals also generally decreased as MCRT decreased, with the exception of the 2.7 d MCRT, where nitrogen removal was higher at 75%. Examination of the last sampling day prior to the steady state sampling period indicate TN removal at the 2.7 d MCRT of approximately 62%. At first examination, nitrogen removal at the 2.7 d MCRT would not be expected to be as high as at higher MCRTs because nitrification was not complete. However, much more nitrogen was removed via waste sludge, which offset the effect of incomplete nitrfication. TN removal at the 1.5 d MCRT is low because very little nitrogen was removed via nitrification and denitrification.

Corresponding nitrogen removals in the conventional system are not pictured, but in general ranged from 20 to 40% and increased as MCRT decreased, as would be expected because more sludge was wasted at lower MCRTs.

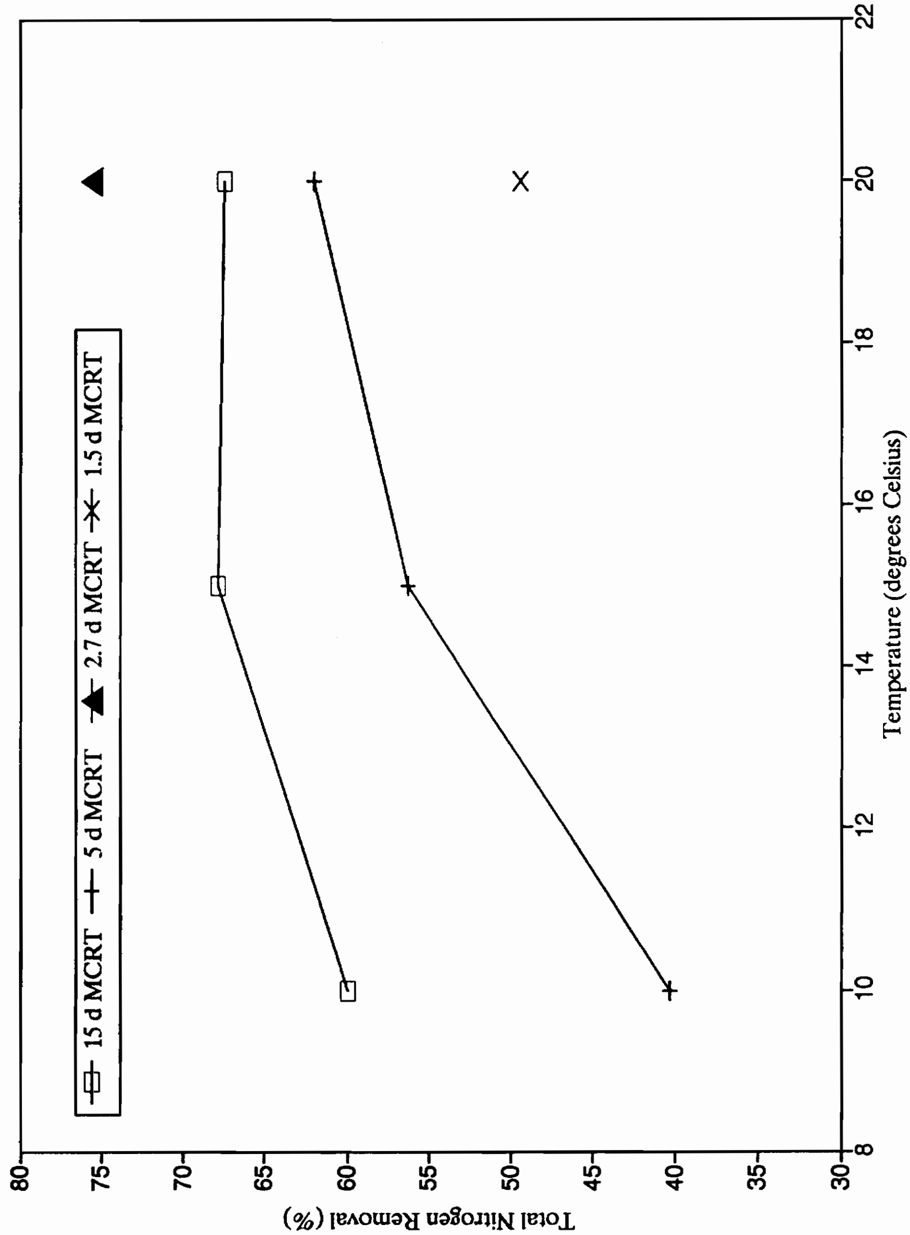

Figure 4-6. Total Nitrogen Removal from BNR Systems

Effects of Temperature on Phosphorus Removal

Phosphorus removal varied depending on MCRT, influent COD, and temperature. Because P removal was influenced by influent COD concentrations, the effects of temperature and MCRT on BPR were evaluated as described in the following sections.

COD-Limiting Conditions

As previously stated, because excess P was added to the influent wastewater, most of the experiment was performed under COD-limiting conditions with regard to BPR. Also, percent P in the sludge (%P/VSS) was used the indicator of BPR performance because it fluctuated less than day-to-day phosphorus removal results.

In order to more easily compare %P/VSS results, data were chosen with the same relative COD concentrations which were believed to be representative of the given condition of MCRT and temperature. These data are presented in Table 4-3, and come from time periods when steady state conditions existed with reference to solids production, degree of nitrification, and %P/VSS for the given MCRT and temperature. Also presented in Table 4-3 are P removal in mg/d and mg/L of wastewater calculated from the %P/VSS and the waste sludge for that day.

Figure 4-7 shows the effects of temperature and MCRT on %P/VSS under COD-limiting conditions. The data from Table 4-3 were used to develop this figure. Effluent P was not less than 3-4 mg/L for any of the data points. From Figure 4-7,

Table 4-3. Summary of Data Used in Determination of Temperature and MCRT Effects on %P/VSS

MCRT (d)	Temp (C)	Date	Average Influent COD (mg/L)	Percent P/VSS (%)	Calculated P Removal (mg/d)	Calculated P Removal (mg/L)
15	20	15SEP89	237	*11.0	1090	7.2
15	20	30JUN89	250	*8.9	690	4.6
15	15	02MAY89	235	8.8	926	6.1
15	10	08AUG89	262	6.1	502	3.3
5	20	28MAR90	244	12.4	1166	7.7
5	15	17NOV89	201	8.5	944	6.2
5	10	01DEC89	283	3.2	380	2.5
2.7	20	11APR90	263	9.4	1144	7.6
1.5	20	19APR90	247	5.6	706	4.7

* Data given equal weighting for purposes of analysis.

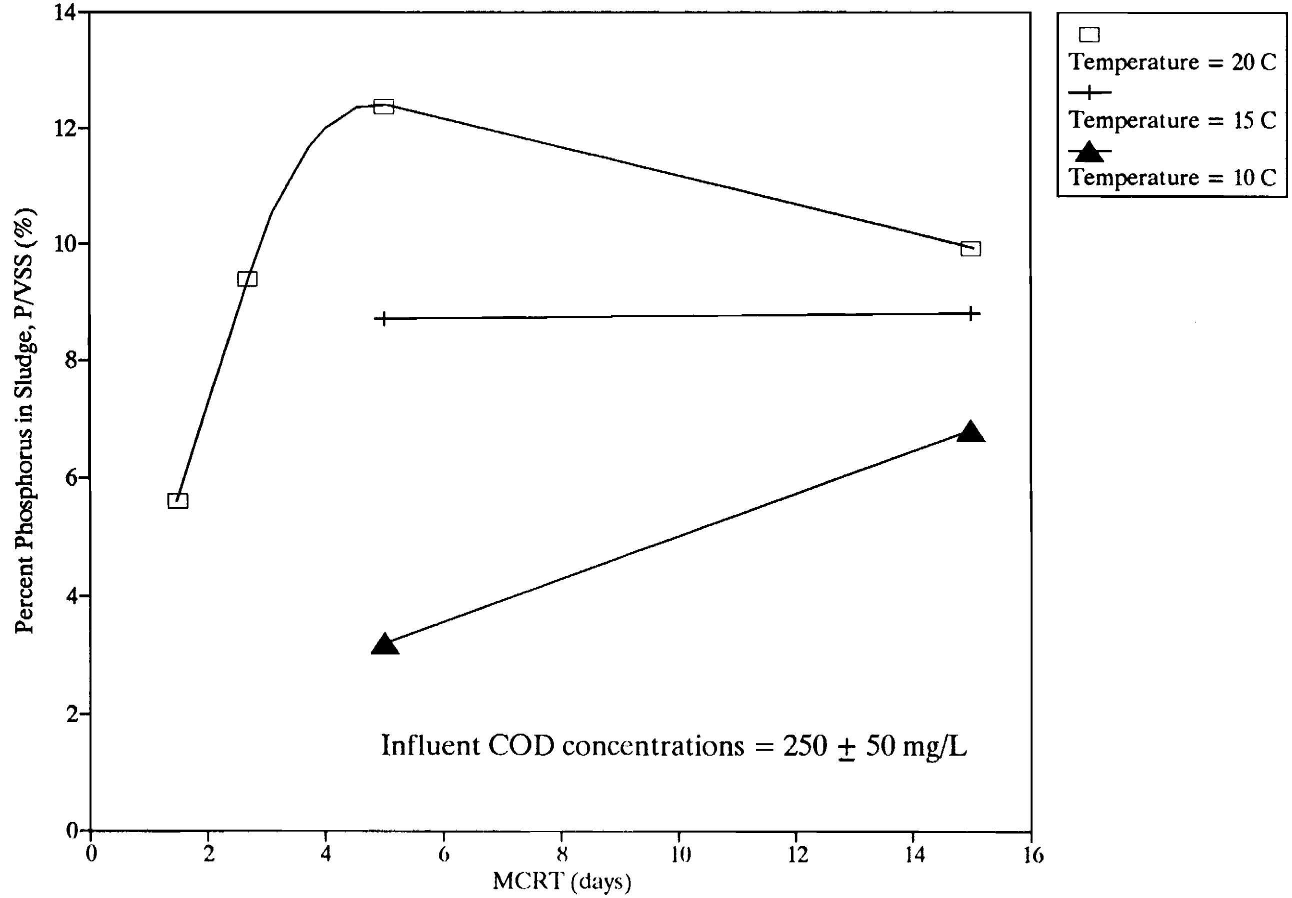

Figure 4-7. Effect of Temperature and MCRT on Percent Phosphorus in Sludge

it can be seen that %P in the sludge was highest at the 5 d MCRT and 20 °C, and was about 20% lower at 15 d MCRT. Percent P in the sludge decreased rapidly at MCRTs below 5 d. Temperature had a big effect on percent P, with 5 d MCRT being affected more severely than 15 d MCRT.

Figure 4-8 shows some of these same data plotted in a different manner to illustrate the temperature effects on %P/VSS at the MCRTs of 5 d and 15 d. Here it is clearer that %P at 5 d MCRT was more adversely affected by lower temperatures than at 15 D, as indicated by the higher slope on the 5 d MCRT line.

The change in %P/VSS with temperature could not be described with a temperature correction coefficient θ. It should be noted that %P/VSS was variable to an extent, and the values presented here are system-specific. The applicability of these data to other systems is therefore limited.

Phosphorus-Limiting Conditions

In order to see if %P in the sludge at 5 d MCRT and 10 °C could be increased by addition of acetate, a separate experiment was performed. As mentioned earlier, a second BNR system (operating at 15 d MCRT) was being operated along side of the previously described BNR and conventional systems (both operating at 5 d MCRT). Acetate (100 mg/L COD) was added to the wastewater, so that P removal would be limited by P rather than COD, and the %P in the sludge was monitored as a function of time.

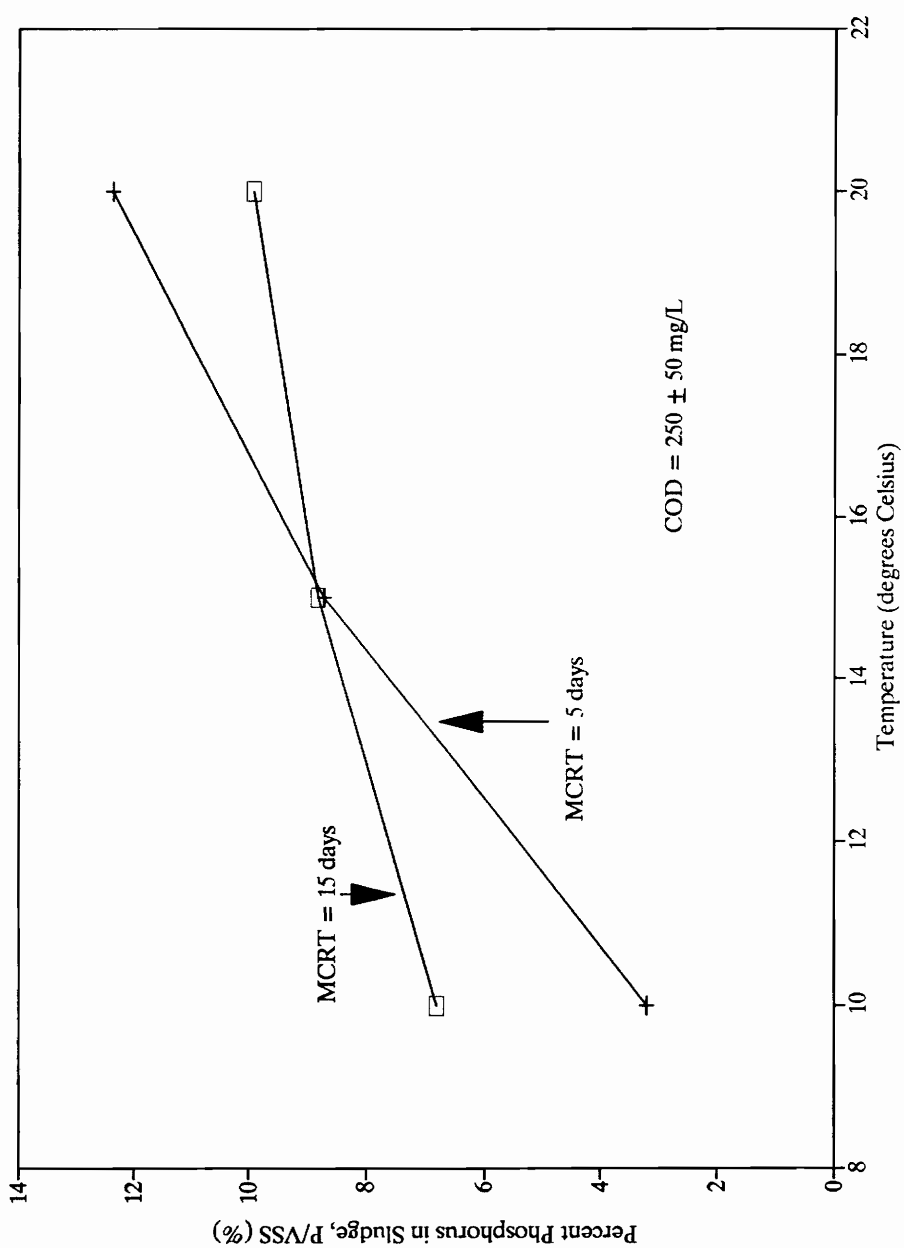

Figure 4-8. Effect of Temperature and MCRT on Percent P in Sludge: COD-Limiting Conditions

The results of the P-limiting experiment are presented in Figure 4-9, which includes some of the data presented in Figure 4-1. This figure shows the percentage of phosphorus of the sludges (%P/VSS) of the two BNR systems and one conventional system beginning from day 240 of operation to day 400. During this experiment, one BNR system (Reactor 2) was being operated at a 15 d MCRT, while the other BNR system (Reactor 1) and the conventional system (Reactor 3) were operated at a 5 d MCRT. Also shown on the graph are the additional COD added and the operating temperatures. It can be seen that as temperature decreased from 20 to 15 °C on day 263, and to 10 °C on day 281, %P in the sludge from both BNR systems decreased. After a few days operation at 10 °C, the %P in the sludge of the 5 d MCRT BNR system decreased to less than 4%, barely higher than that in the conventional system. On day 298, spiking with 100 mg/L of acetate as COD was begun. During one short period (days 315 to 325) shortly after the beginning of acetate addition, only 10 mg/L COD were added due to a calculation error in making up the acetate solution. Total influent COD concentrations ranged from approximately 300 to 400 mg/L throughout this part of the experiment except for the eleven days when only 10 mg/L extra COD was added.

At 15 d MCRT and 10 °C with acetate addition, %P varied from 5 to 11%. However, the sludge in the 5 d MCRT system could not be induced to take up more than 4% P at 10 °C, even with 100 mg/L of acetate as COD being added. This meant that fermentation of organics was not limiting anaerobic storage of organics and subsequent aerobic P uptake.

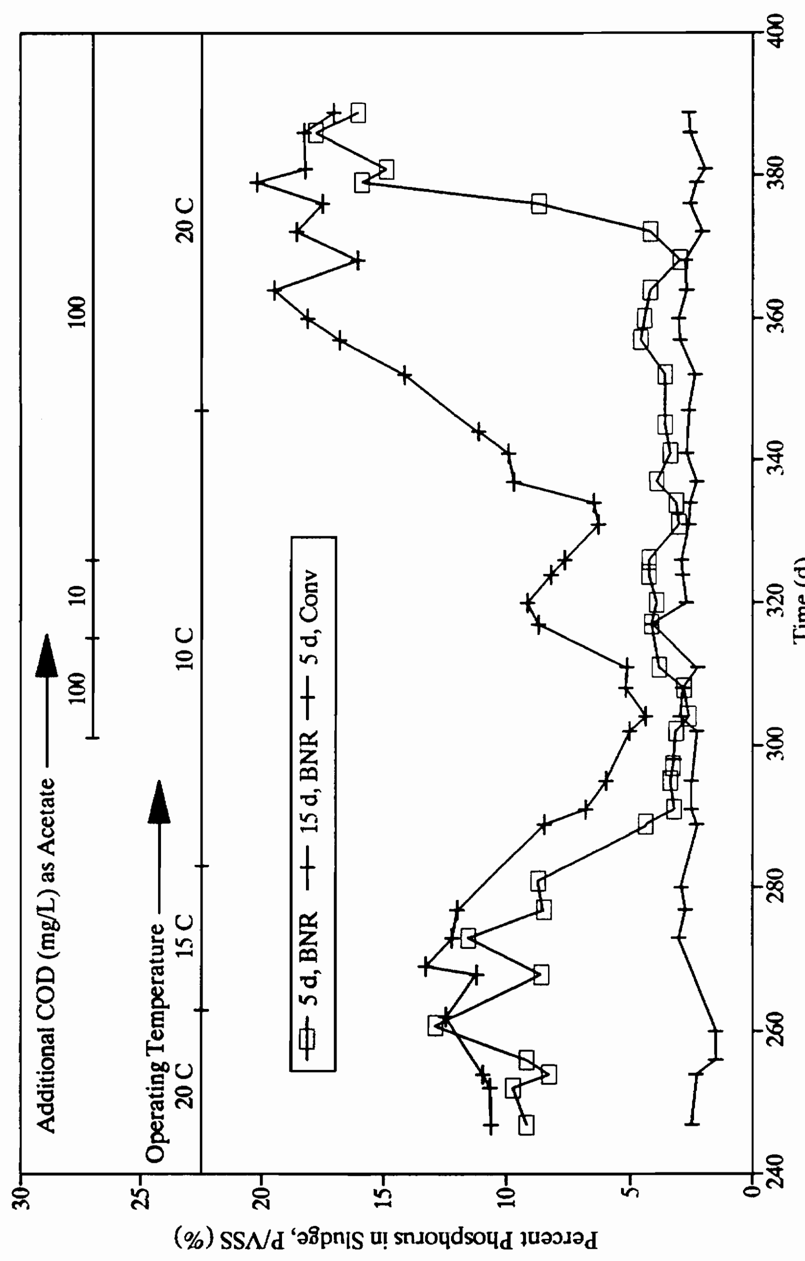

Figure 4-9. Effect of MCRT, Temperature, and Acetate Addition on Percent P in Sludge

The temperature was increased to 20 °C on day 347. Within a week, the 15 d MCRT sludge %P increased to 16 to 20% P, and the system was removing 18-19 mg/L of P to effluent OP concentrations of less than 0.2 mg/L. However, the 5 d MCRT system took over 20 days to begin recovery of excess P uptake. Once recovery began, it took only about a week until complete P removal (18-19 mg/L) was being achieved, at which point the sludge had a slightly smaller P content than the corresponding 15 d MCRT reactor.

Figure 4-10 shows %P in the sludge as a function of temperature when P is limiting. These data come from 20 °C operation during the acetate spiking period, when total influent COD concentrations were 300-400 mg/L. Effluent OP concentrations were less than 0.2 mg/L for all points except the 5 d MCRT and 10 °C point. Under P-limiting conditions, %P in the sludge was always higher at the 15 d MCRT, even at 20 °C. It can be seen that up to 11% P in the sludge was obtained at 10 °C if operating at a 15 d MCRT and influent COD is high enough, but it was not possible to attain more than 4% P in the sludge at a 5 d MCRT and 10 °C, even with a high influent COD including plenty of acetate.

Denitrification Batch Experiment

A denitrification batch experiment was performed to study the mechanisms of denitrification in the BNR system. In this test, mixed liquor from the last anoxic section of the BNR system was mixed with an equal volume of domestic wastewater

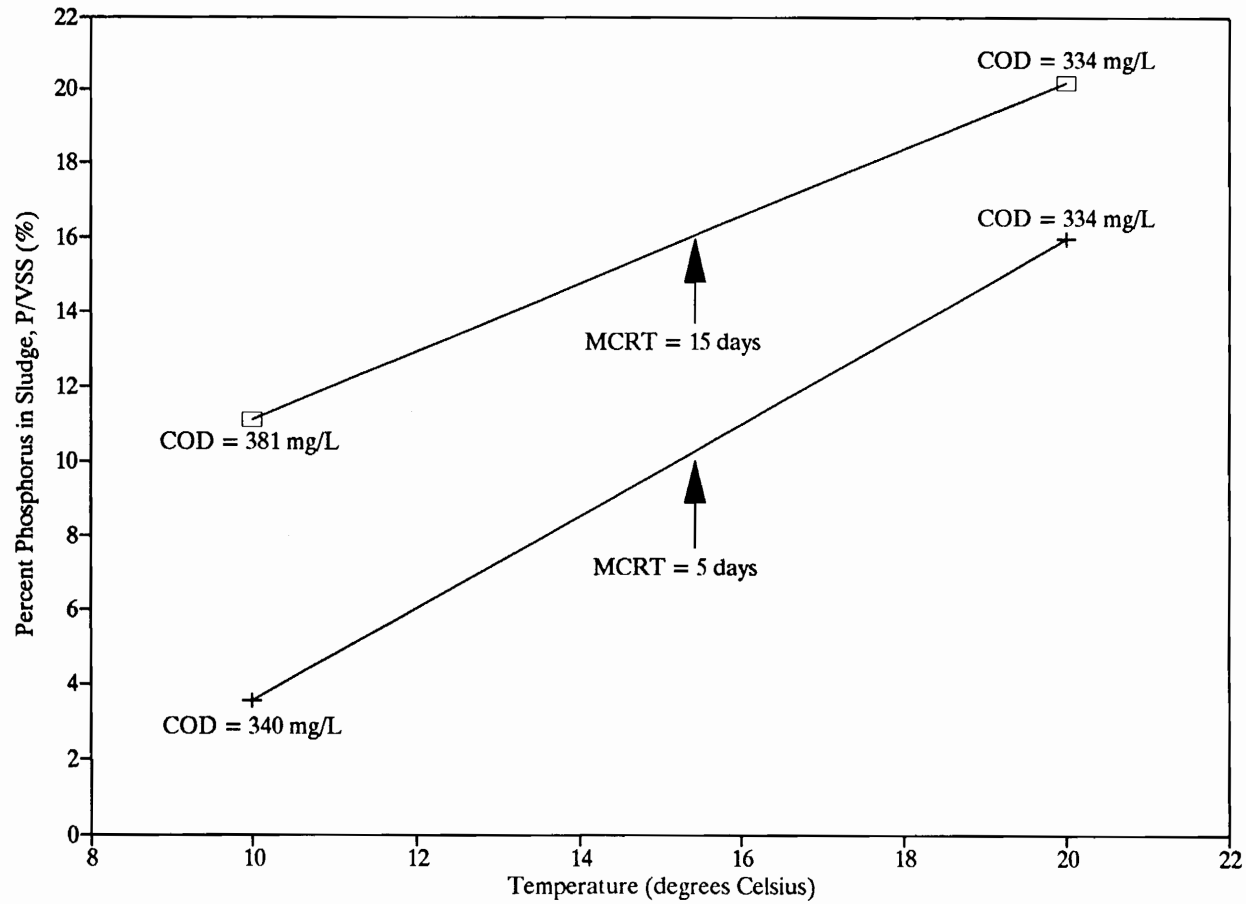

Figure 4-10. Effect of Temperature and MCRT on Percent P in Sludge: P-Limiting Conditions

with acetate added. The pH in the batch reactors ranged from 7 to 8.

The results of the denitrification batch test are shown in Figure 4-11. The figure shows phosphorus release occurred under anaerobic conditions. After 60 minutes of anaerobic stirring, soluble COD concentrations had decreased to less than 45 mg/L. The batch was then separated into two separate batches. One was aerated and one had 30 mg/L of NO_3^--N added. In the aerobic phase, P was removed from solution at a high rate. Denitrification occurred in the anoxic batch test, as indicated by the decrease in NO_x-N. Anoxic uptake of P occurred, but the rate was much slower than aerobic uptake. Denitrification ceased and soluble P began increasing after 40 minutes, even though 18 mg/L of NO_x-N remained. The denitrification rate observed during this time was 11.4 mgNO_3^--N removed/gMLVSS/h, which agreed well with denitrifcation rates observed in the continuous-flow system from which the sludge came. Similar results were obtained upon repeating the experiment.

Oxygen Utilization Rates

Oxygen utilization rates (OURs) were measured as described in the previous chapter. A summary of the results is presented in Appendix E. Each of the numbers in the table in Appendix E represents a separate OUR test. The plots resulting from individual tests turned out to be quite similar, so that one example can be used to illustrate the experimental results.

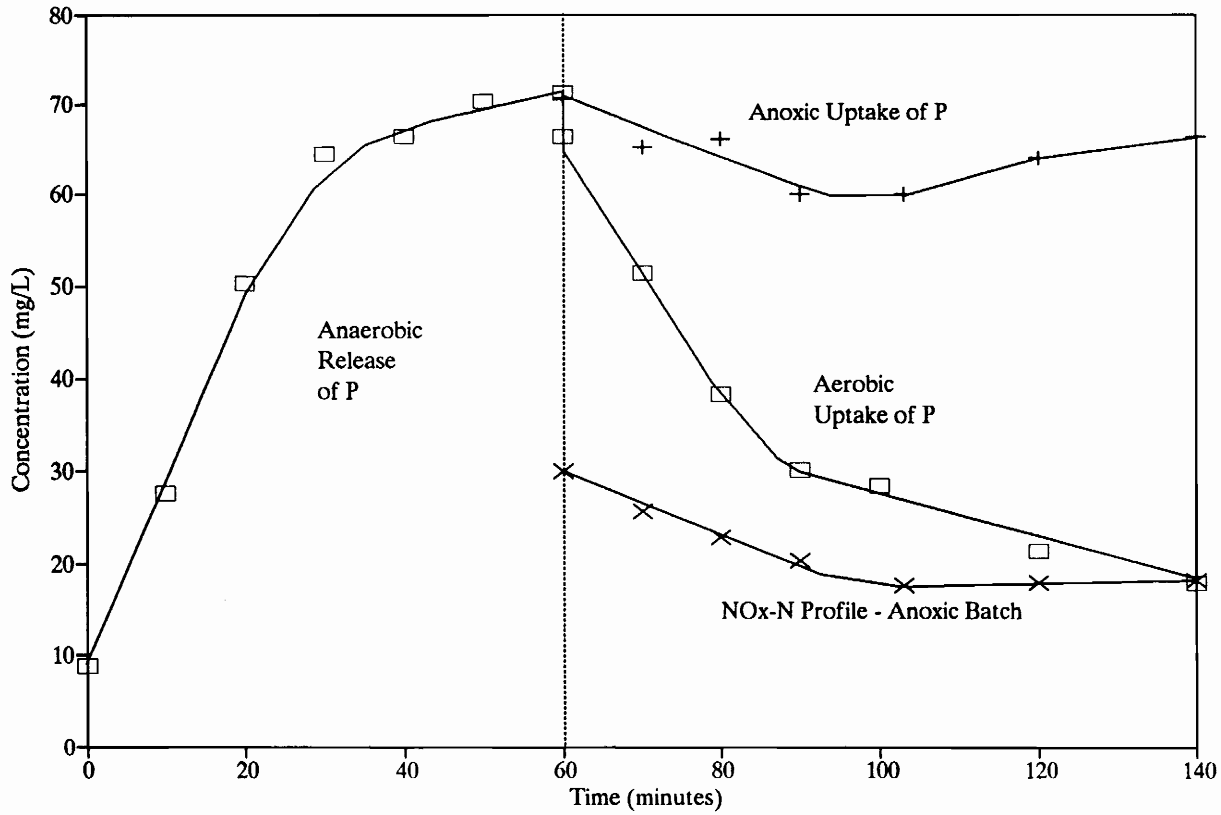

Figure 4-11. Results of Denitrification Batch Test

A good example of how the oxygen utilization rate raw data turned out is presented in Figure 4-12, which shows the raw oxygen utilization rate data for section 10 of the BNR system at a 15 d MCRT and 15 °C. This is typical of the OUR plots obtained from both the BNR and conventional systems, both *in situ* (15 d MCRT) and using the BOD bottle technique (5 d MCRT). From 0 to 1 minute, the rapid initial decline in dissolved oxygen (DO) indicates that the DO probe was not stabilized. The stabilization of the probe was followed by a linear decline in DO for the next 2.5 to 3 minutes. In most plots, this was followed by a declining rate of oxygen uptake. Therefore, oxygen utilization rates were determined by performing linear regression on the data over the period of 1 to 3.5 minutes. Good fits were obtained for the regression lines as indicated by R^2 values all greater than 0.97. The straight line drawn in Figure 4-12 was fit by linear regression, with oxygen utilization rate equal to the slope of the line. OUR data are used in the next chapter to perform oxygen balances on each system for each condition of MCRT and temperature studied to determine the amount of anaerobic stabilization, if any, which occurred in the BNR process.

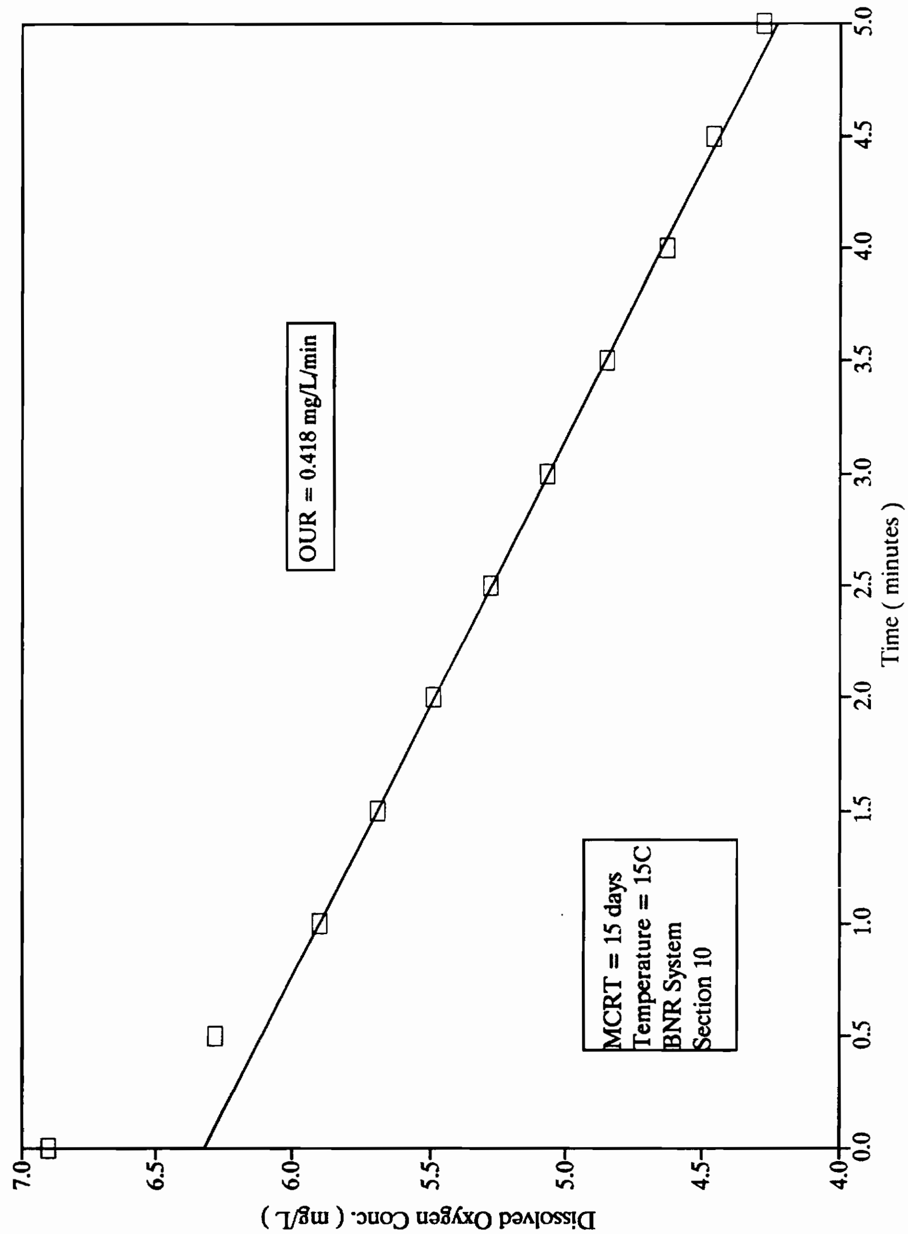

Figure 4-12. Typical Oxygen Utilization Rate Plot

V. Discussion

This chapter includes a discussion of all of the important research findings, including the effects of temperature on nitrification rates, denitrification rates, nitrogen removal, phosphorus removal, and oxygen utilization rates. Also presented are the determination and discussion of kinetic coefficients for both systems, and a discussion of the results of a batch experiment relating to the mechanisms of denitrification in a BNR process.

Yield and Decay Coefficients

Table 5-1 presents data which are used for the following discussion. All data presented here are for 20 °C. Two data sets for the 15 d mean cell residence time (MCRT) and the 5 d MCRT are presented, representing two separate steady state data points. All data were given equal weighting in the following analysis, except for one point where a partial solids washout occurred prior to sampling, because the variation in influent COD concentrations caused some calculated values to be low and some to be high. The specific COD utilization rates were calculated using Equation 2.4. The hydraulic retention time (HRT) of both systems was equal to 0.33 days. (~8 hrs)

Figure 5-1 shows the specific COD utilization rates, q, of the two systems versus MCRT. These curves follow a pattern typical to that normally found in the

Table 5-1. Summary of Raw Data Used for Calculation of the Specific COD Utilization Rate (q) for Yield Plots, Temperature = 20 C

System	MCRT (d)	Date	Average Inf.COD (mg/L)	Eff.COD (mg/L)	Average MLVSS (mg/L)	q (1/d)
BNR	15	03JUL89	176	12	2373	0.207
	15	27SEP89	351	20	2385	0.416
	5	28MAR90	244	29	933	0.691
	5	01NOV90	291	21	1395	0.581
	2.7	11APR90	263	*26	652	1.090
	1.5	19APR90	247	33	375	1.712
Conventional	15	04JUL89	281	35	1348	0.547
	15	28SEP89	236	19	1598	0.407
	5	29MAR90	344	*24	1284	0.748
	5	31OCT90	325	21	837	**1.090
	2.7	10APR90	257	*27	658	1.049
	1.5	17APR90	306	31	424	1.946

* Section 12 COD values substituted for suspected erroneous effluent values.

** Not included in graphs. MLVSS washout prior to sampling.

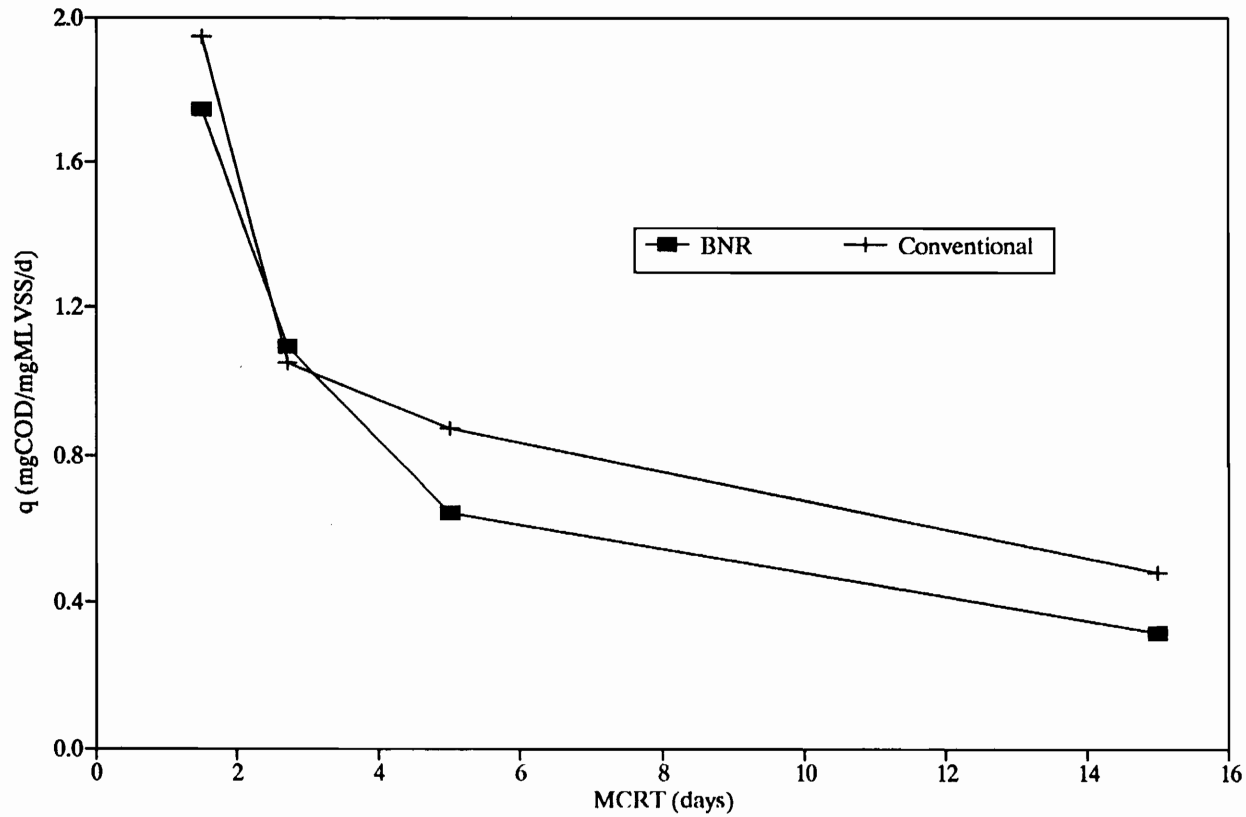

Figure 5-1. Specific COD Utilization Rates Versus MCRT, T = 20 C

operation of activated sludge treatment systems. The rate in the conventional system was somewhat higher than in the BNR system at all MCRTs except for 2.7 d MCRT. This is because the MLVSS concentration of the BNR system was always higher than in the conventional system. Theoretically, this could be either because the BNR system yield coefficient was greater, the decay rate was lower, or a combination of the two.

Yield plots for the conventional system and the BNR system are presented in Figures 5-2 and 5-3 respectively, by plotting the reciprocal of the MCRT (called the specific growth rate) versus the specific COD utilization rate, q. Lines of best fit were determined by linear regression. The kinetic coefficient for yield, Y_{max}, is equal to the slope of this line, and the decay rate, b, is equal to the y-intercept. Figure 5-2 shows that the yield coefficient for the conventional system was equal to 0.408 and the decay rate was equal to 0.110 d^{-1}. One of the points at a 5 d MCRT was included, and one was discarded because a slight washout of solids had occurred prior to sampling, causing an inaccurate value for q.

In Figure 5-3, the yield plot for the BNR system, there were two steady state periods each for 15 d and 5 d MCRT and all are included and are equally weighted for purposes of this figure. The yield coefficient was equal to 0.409 and b was equal to 0.063 d^{-1}.

The yield coefficients for the two systems were equal but the decay rate in the BNR system was less than in the conventional system. The lower decay rate explains why solids production (in terms of VSS) was greater for the BNR system, and why

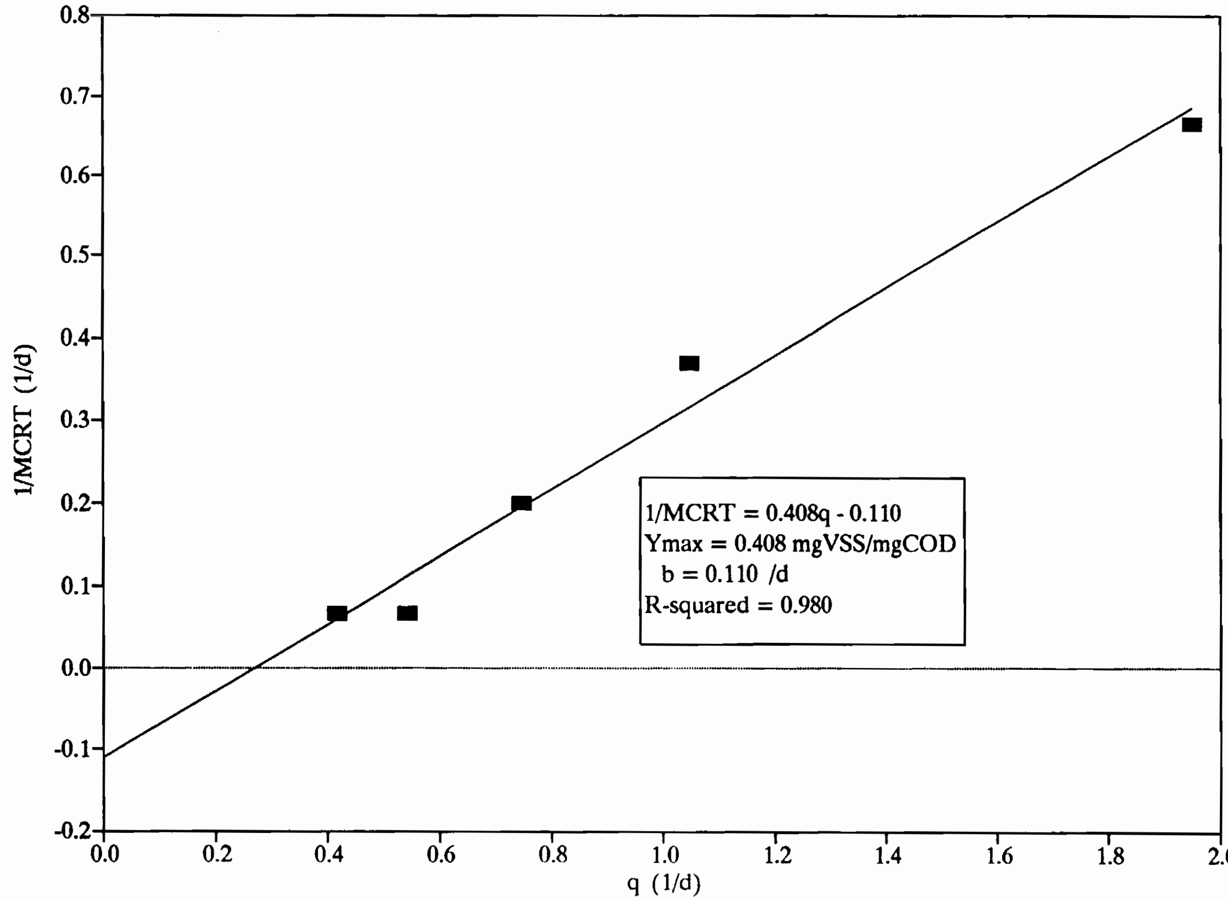

Figure 5-2. Determination of Yield and Decay Coefficients for the Conventional System

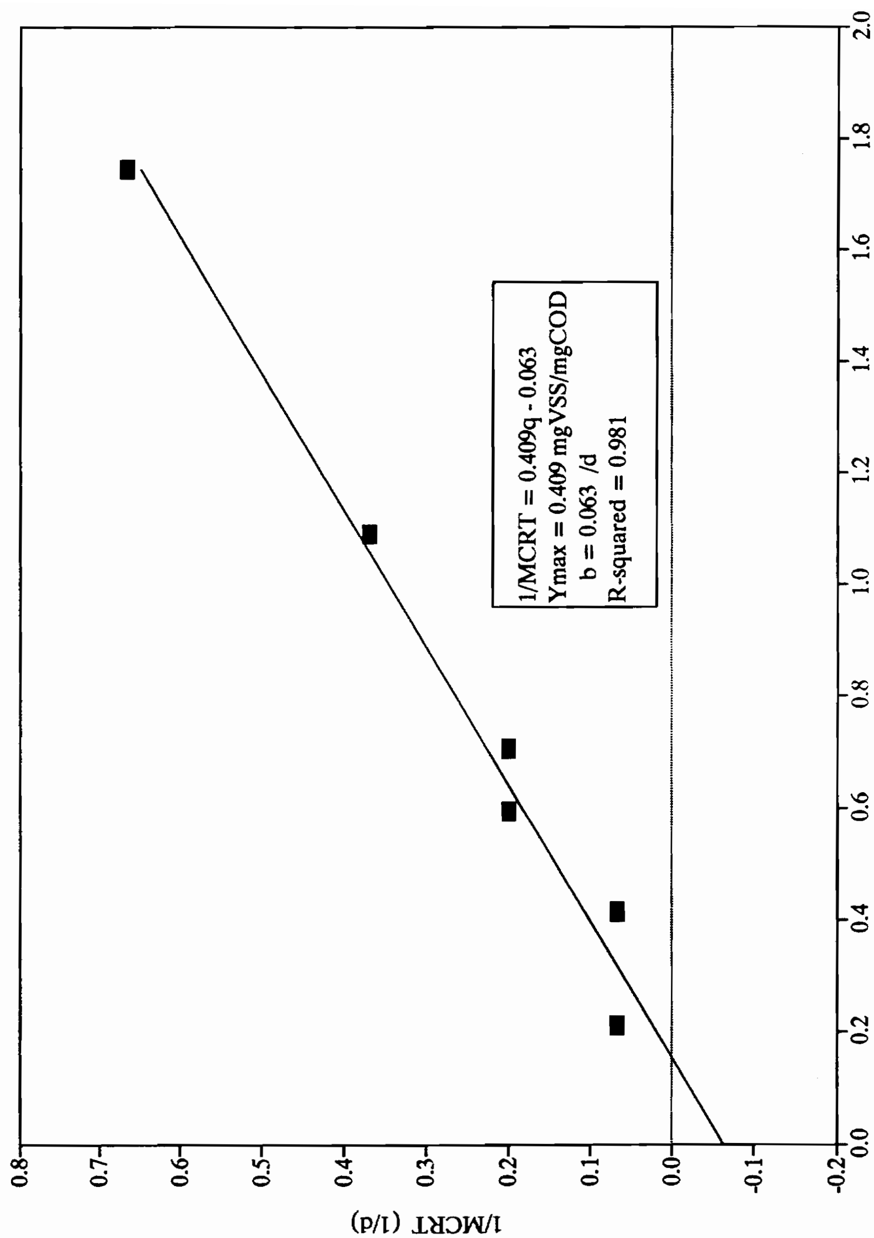

Figure 5-3. Determination of Yield and Decay Coefficients for the BNR System

it was more pronounced at higher MCRTs.

If the decay rate obtained from the conventional system is multiplied by the aerobic mass fraction of the BNR system, the value of 0.059 d^{-1} is obtained, which is very close to the decay rate determined for the BNR system. It is believed that decay in the BNR system was significantly reduced under anaerobic and anoxic conditions, and occurred at approximately the same rate as in the conventional system under aerobic conditions.

The MLVSS/MLSS ratio for the BNR system was lower than for the conventional system. The low ratio in the BNR system was because stored phosphate contained in the cells is not volatile, and was measured in the MLSS but not in the MLVSS. The MLVSS/MLSS ratio decreased as %P in the sludge increased, and therefore may be used as a crude indicator of the extent of BPR in a given system. MLVSS/MLSS ratios of approximately 0.7 in this study indicated a high %P in the sludge (>10 %P/VSS) , whereas ratios of > 0.8 (5 d MCRT, 10 °C) indicate low %P (<4 %P/VSS). Since the %P in sludge will vary from system to system, nitrification rates and denitrification rates should be reported in terms of MLVSS instead of MLSS in order to be more comparable.

Nitrification Efficiency

Presented in Table 5-2 are data which are pertinent to the following discussions on nitrification. These data are based on steady state data. Comparing

Table 5-2. Aerobic HRT Needed for Nitrification

System	MCRT (d)	Aerobic MCRT (d)	Temp (C)	Total NH3-N Available (mg/L)	Effluent NH3-N (mg/L)	Percent Nitrification (%)	Influent COD (mg/L)	Effluent pH	Aerobic HRT to 1 mg/L NH3-N (hours)	g N Oxidized per hour
BNR	15	8.33	20	18.8	0.0	100	176	7.2	1.7	10.5
	15	8.89	15	26.5	0.0	100	235	6.8	3.3	7.7
	15	8.31	10	20.5	0.0	100	166	7.1	2.2	8.9
	5	2.72	20	23.2	0.0	100	244	7.2	2.3	9.7
	5	2.80	15	28.3	5.9	100	201	7.4	-	-
	5	2.87	10	27.5	19.4	29	283	7.5	-	-
	2.7	1.55	20	23.2	1.6	100	263	7.4	*5	*4.4
	1.5	0.89	20	27.7	15.4	44	247	7.5	-	-
Conv.	15	15	20	21.2	0.0	100	281	7.2	3.2	6.3
	15	15	15	26.6	0.0	100	176	6.4	4.6	5.6
	15	15	10	22.5	0.0	100	173	6.9	3.2	6.7
	5	5	20	26.5	0.0	100	344	6.8	3.8	6.7
	5	5	15	21.9	0.0	100	110	7.0	6.0	3.5
	5	5	10	23.1	8.1	100	266	7.2	-	-
	2.7	2.7	20	27.1	0.0	100	257	7.1	6.0	4.4
	1.5	1.5	20	26.1	5.6	100	263	7.3	*10	*2.1

* Estimated values.

higher for BNR

the BNR system nitrification efficiency to the conventional system is possible on an aerobic MCRT basis, suggesting that aerobic MCRT governs nitrification performance. All of the effluent NH_3-N data from both systems is easily plotted together versus aerobic MCRT, resulting in Figure 5-4. Complete nitrification as indicated by non-detectable concentrations of NH_3-N was achieved at MCRTs of 5 d and higher at 20 °C, while increasingly higher MCRTs were needed as temperature decreased.

Figure 5-5 shows percentages of nitrification achieved for both the conventional and BNR systems as a function of temperature and aerobic MCRT. The numbers in the figure represent actual data. From this figure, it can be seen that an aerobic MCRT greater than 5 d was needed to maintain 100% nitrification at 10 °C, while 2.7 d MCRT provided complete nitrification at 20 °C.

Operation at higher MCRTs was required to counteract the effects of lower temperatures on nitrification efficiency in the BNR system. Nitrification efficiency deteriorated rapidly at 20 °C as aerobic MCRT decreased below 2.7 d. Temperature had a greater adverse effect on nitrification efficiency as MCRT decreased.

Aerobic Volume Needed for Nitrification

Shown in Figures 5-6 through 5-13 are the available NH_3-N concentrations in the reactor sections plotted versus the aerobic hydraulic retention times (HRT) at that point for the BNR and conventional systems. Ammonia-nitrogen (NH_3-N) which was available for nitrification was determined at time = 0 in the conventional system

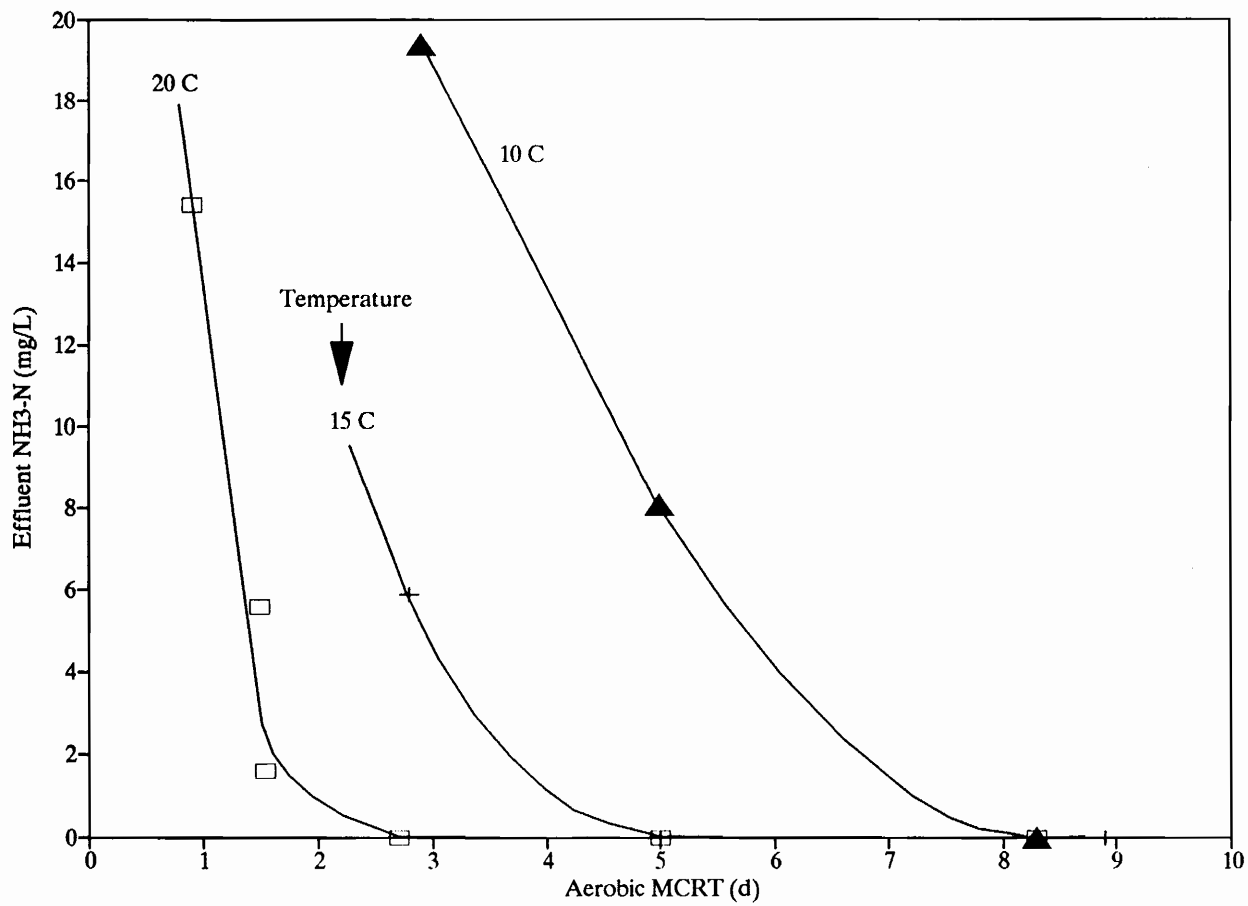

Figure 5-4. Effluent NH3-N Concentration as a Function of Temperature and Aerobic MCRT

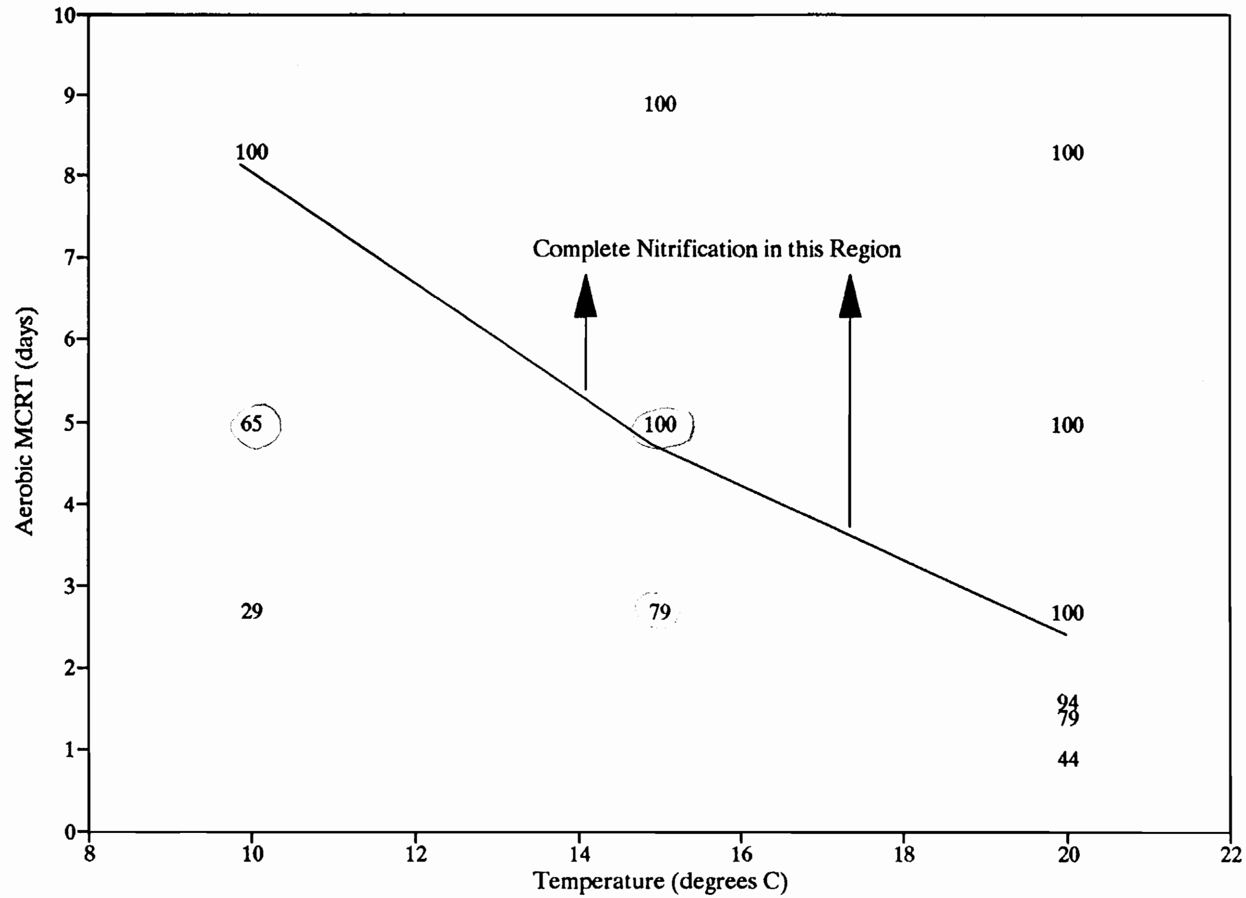

Figure 5-5. Percent Nitrification as a Function of Temperature and Aerobic MCRT

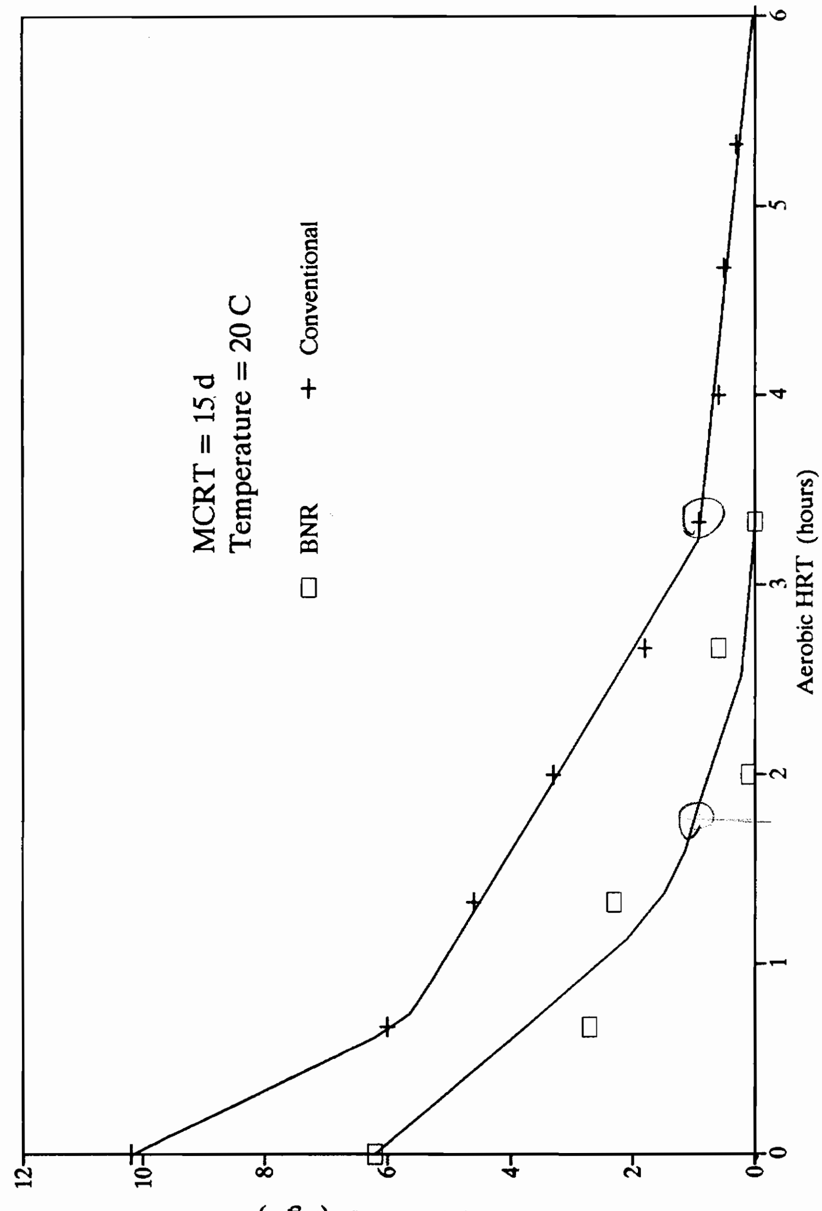

Figure 5-6. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrification

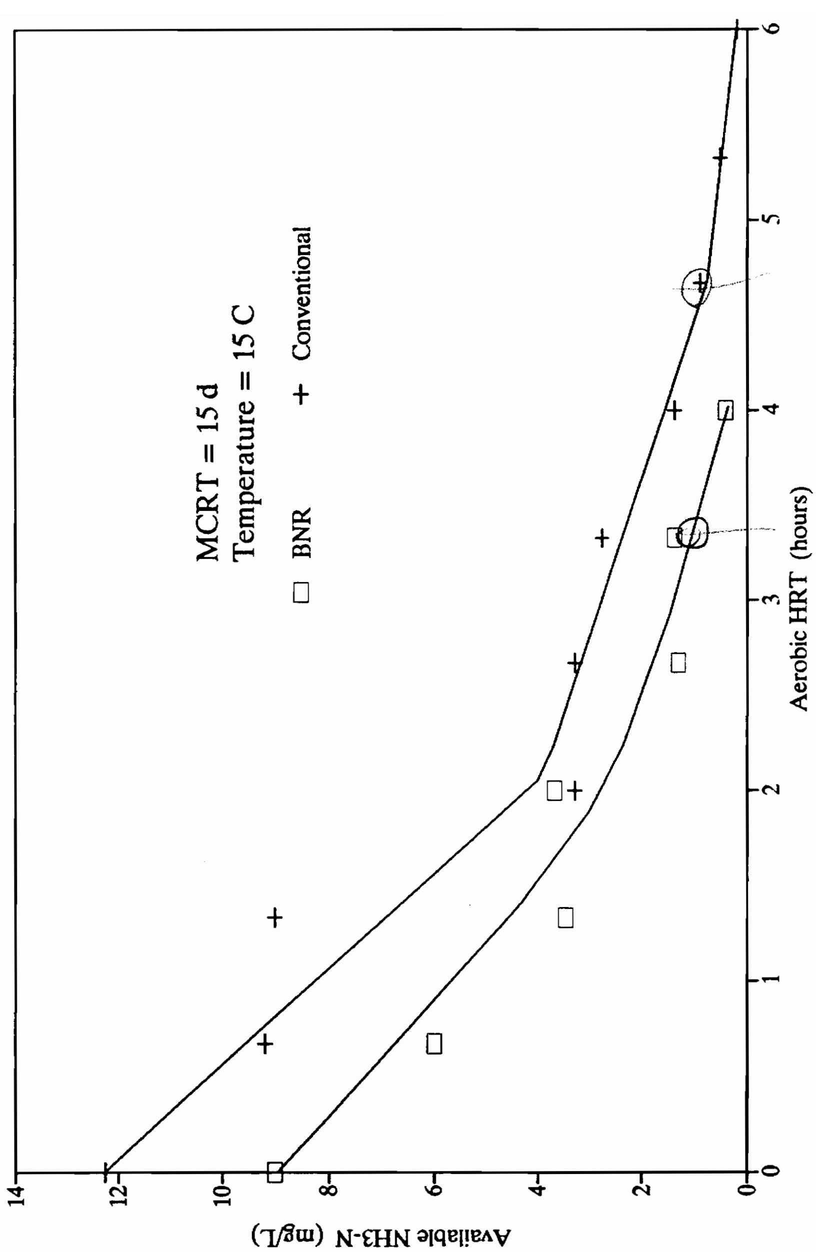

Figure 5-7. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrification

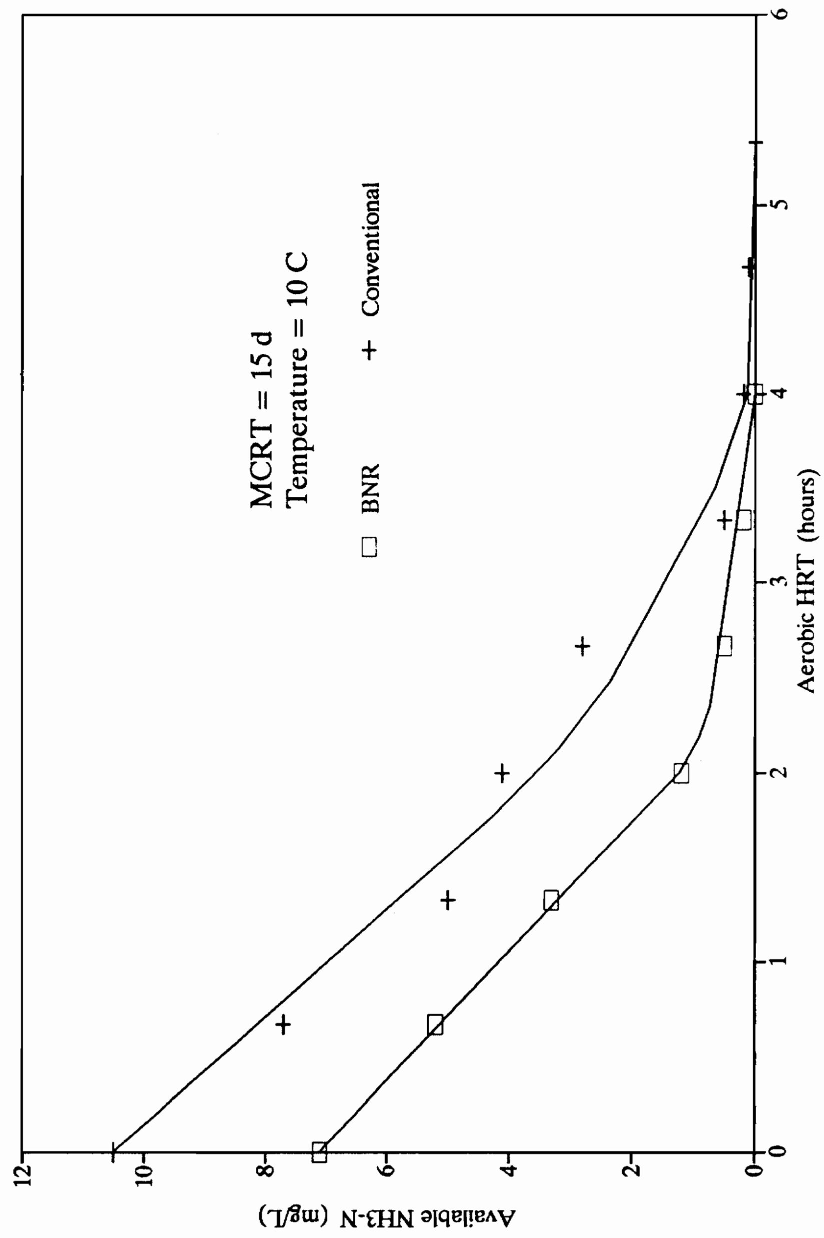

Figure 5-8. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrification

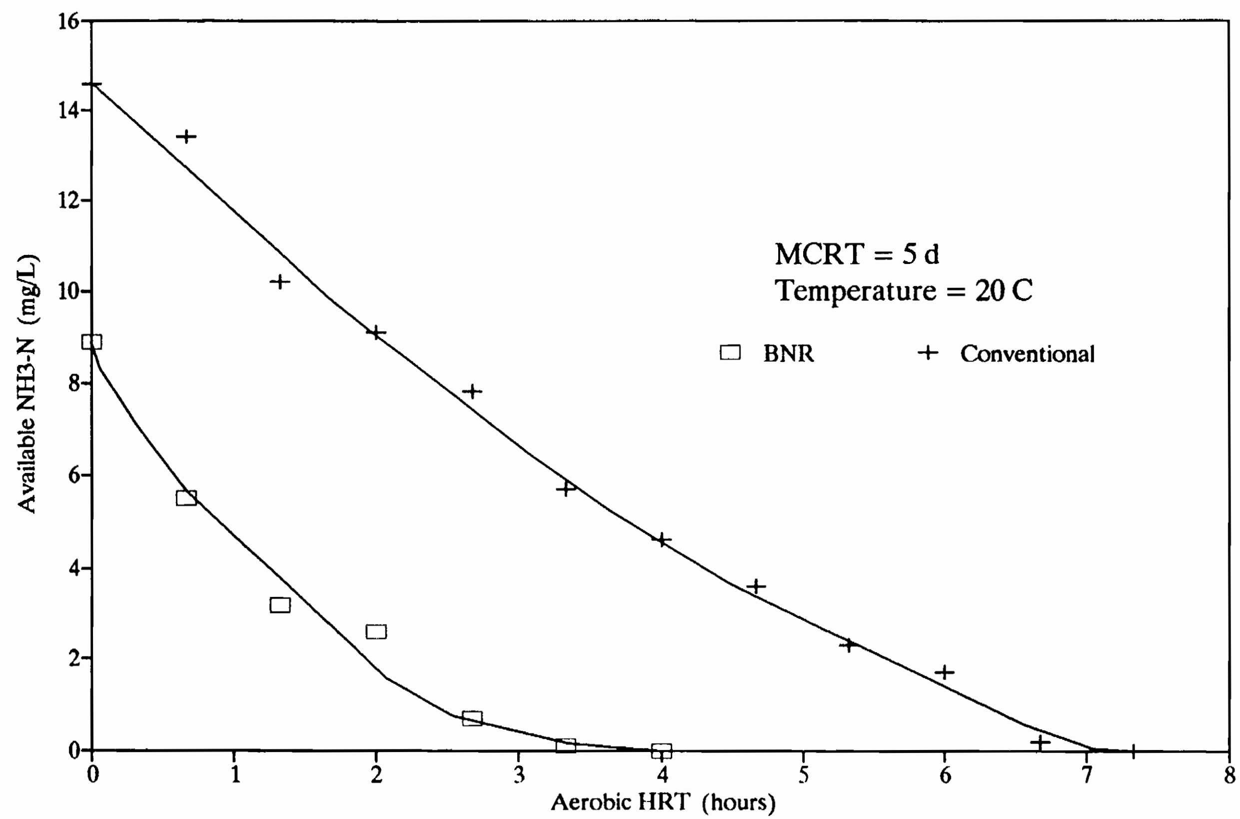

Figure 5-9. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrification

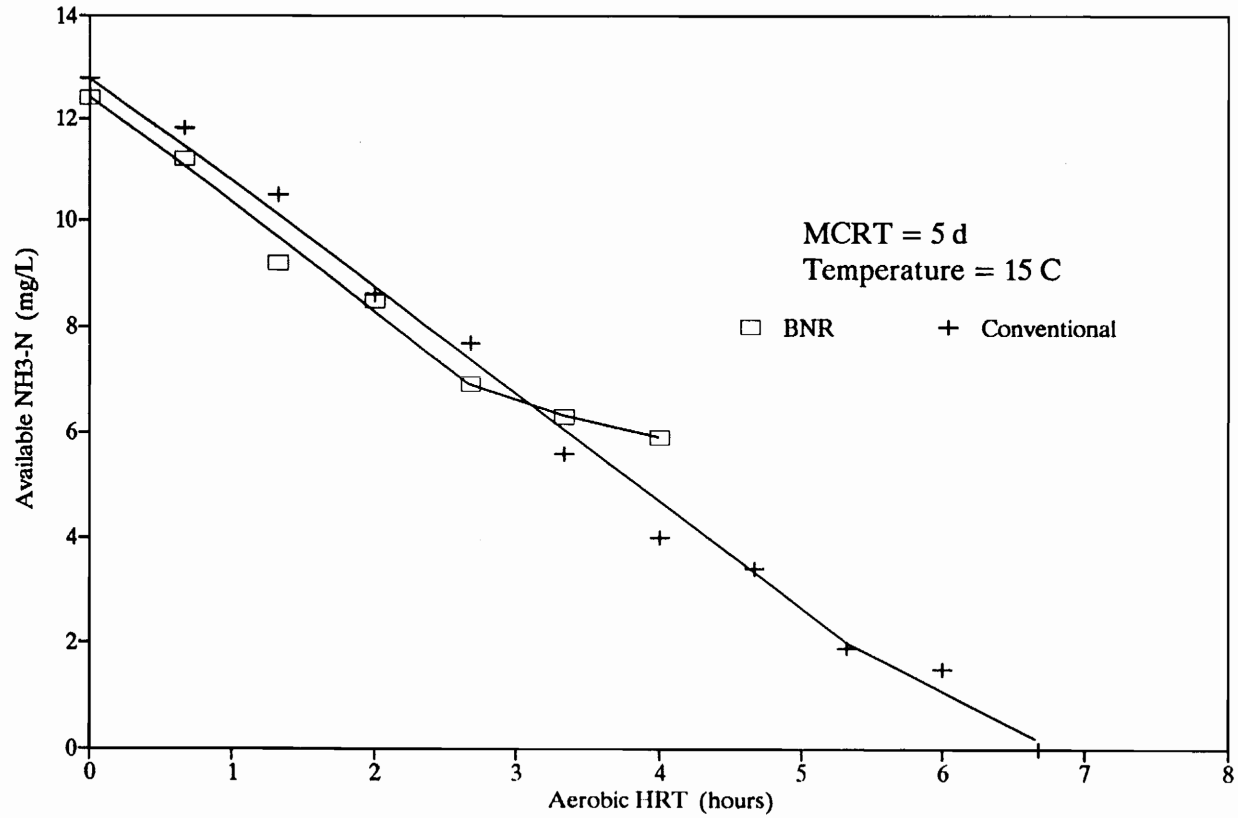

Figure 5-10. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrifcation

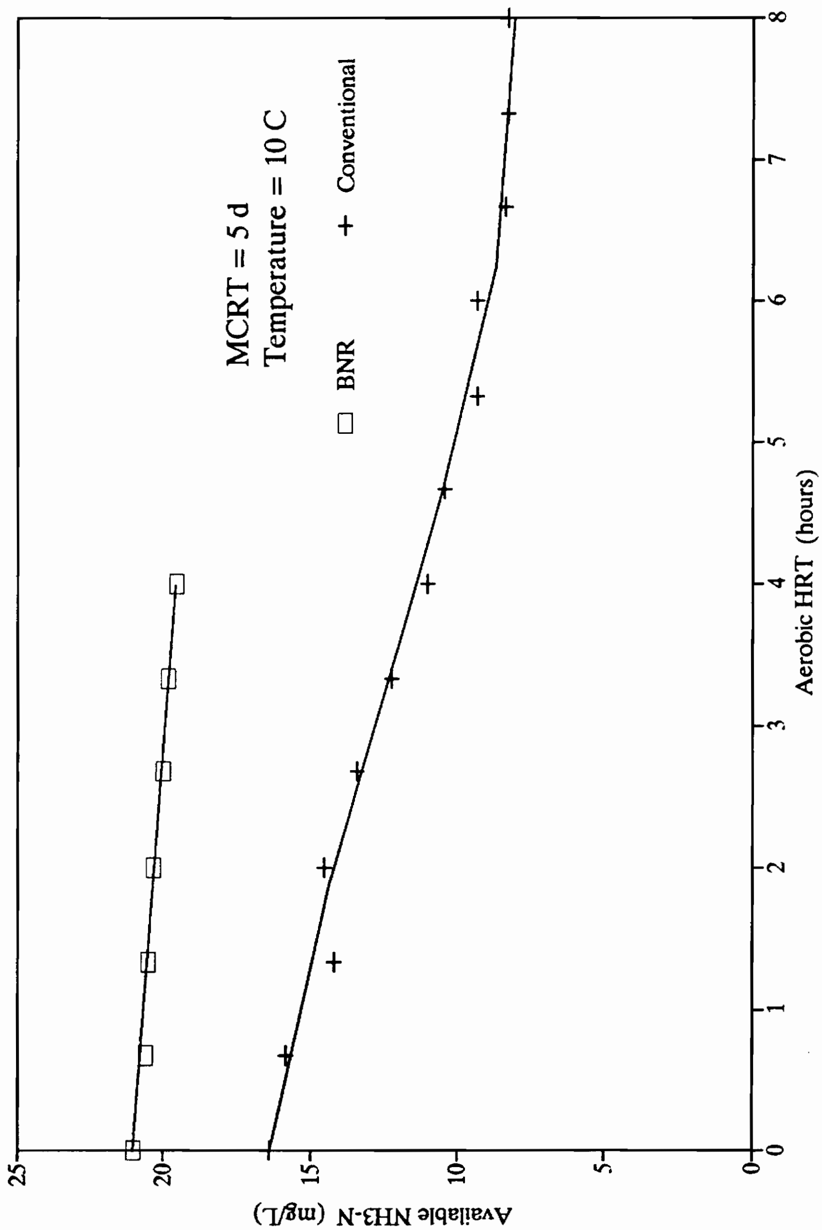

Figure 5-11. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrification

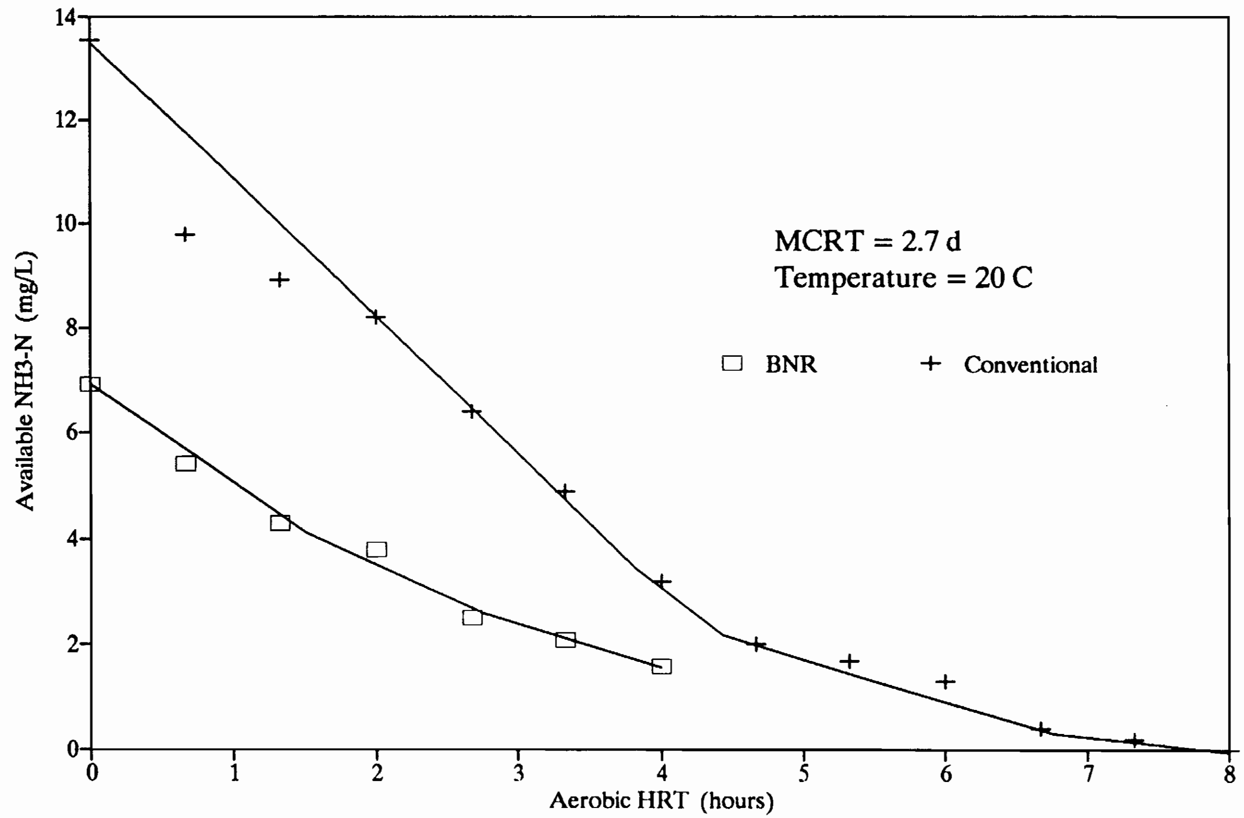

Figure 5-12. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrification

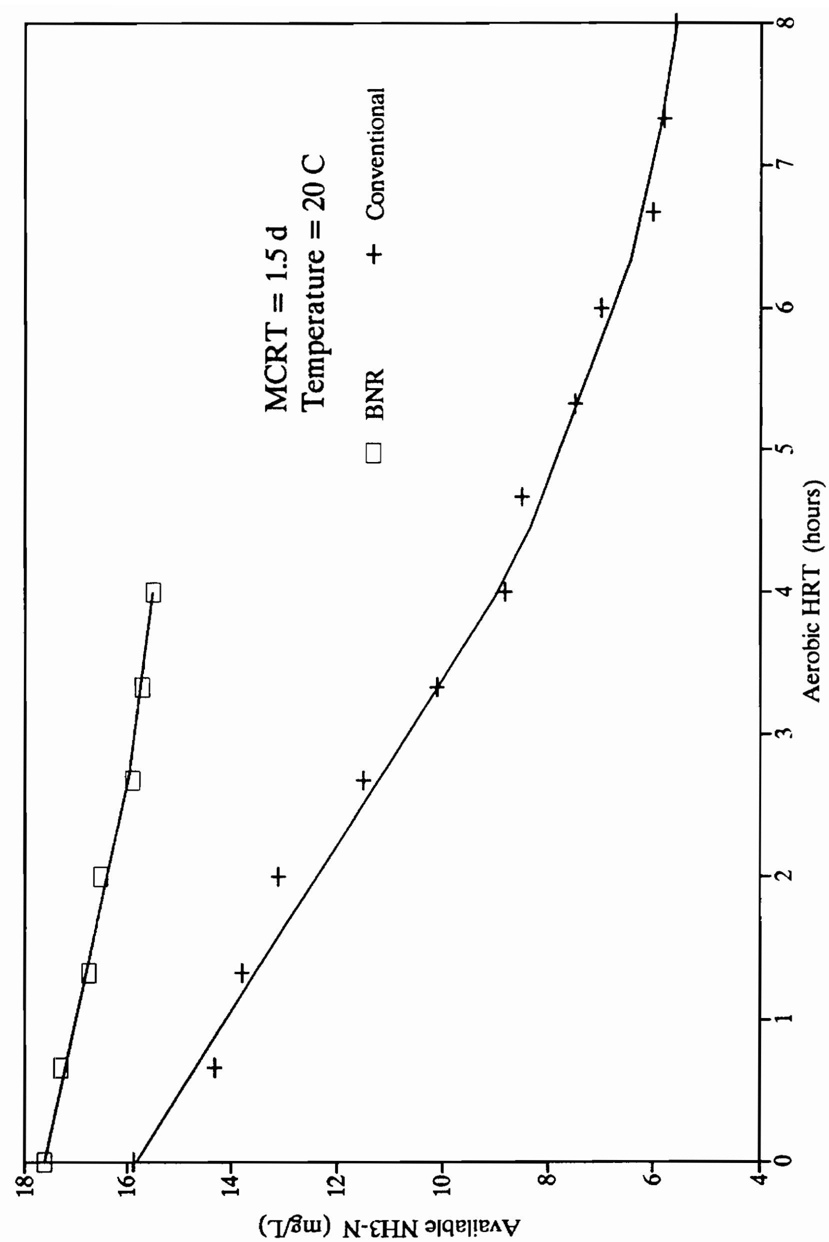

Figure 5-13. Aerobic Hydraulic Retention Time (HRT) Needed for Nitrification

indirectly from the following calculation:

$$\text{Available } NH_3\text{-N} = [(\text{Inf. TKN - Eff. Organic N - Syn. N}) + NH_3\text{-N recycle})]/2 \qquad (5.1)$$

where Syn. N = (Observed Yield)(COD Removed)(0.1 mgN/mgVSS), and

all nitrogen concentrations are in mg/L.

Observed yield was calculated from the kinetic coefficients Y_{max} and b as determined in the first part of this chapter. The value of 0.1 for mgN/mgVSS is the measured value as reported in Table 4-2. The available NH_3-N in the sections of the BNR system and the conventional system were determined from the following equation:

$$\text{Available } NH_3\text{-N} = \text{Eff. } NO_x\text{-N} - NO_x\text{-N (section)} + \text{Eff. } NH_3\text{-N} \qquad (5.2)$$

Analysis of the figures provides some very interesting results. In all cases where nitrification was 100% in both systems, the BNR system required less aerobic HRT, and therefore less volume, than the conventional system to achieve nitrification. For example, consider the aerobic HRT needed for nitrification to 1 mg/L NH_3-N. By finding the points on the curves in the Figures 5-6 through 5-13 which correspond to 1 mg/L NH_3-N, values for aerobic HRT were determined. The aerobic HRTs needed for nitrification to 1 mg/L NH_3-N are listed in Table 5-2. Less aerobic HRT was required for nitrification in the BNR system at the 15 d MCRT at all temperatures studied, and at the 5 d MCRT at 20 °C. Under these conditions, many conventional plants capable of nitrification could be converted to BNR with little or no increase in reactor volume.

Also shown in Table 5-2 are the observed rates of nitrification in g N oxidized per hour, for nitrification to 1 mg/L. This rate is independent of MLVSS concentrations. This rate was higher for the BNR system when conditions were suitable for complete nitrification.

The dilution of the NH3-N concentration entering the aerobic zone by recycles in the BNR system may have played a role in why nitrification proceeded at a faster rate under conditions favorable for complete nitrification. Stratton and McCarty (1972) showed that the half saturation constant, K_s, was lower when initial NH3-N concentrations were lower. This could be one reason why there was a higher net rate of nitrification in the BNR system under these conditions. It appears form Figures 5-6 through 5-9 that the rate begins to decrease at higher NH3-N concentrations in the conventional system, where the initial NH3-N concentraions are higher.

It should be noted that the aerobic HRT for nitrification is dependent on many factors in addition to temperature and MCRT, *i. e.*, influent TKN, pH, *etc.* The available NH3-N is less at 15 d MCRT and 10 °C than at 15 d MCRT and 15 °C, which explains why aerobic HRT decreased instead of increased with the drop in temperature.

Presented in Table 5-3 are total HRTs needed for a BNR system accomplishing complete nitrification compared to total HRTs needed in a conventional system for nitrification only. Total HRTs for BNR include time for anaerobic zones and anoxic zones, in addition to time for the aerobic zone. Aerobic HRTs were taken from Table 5-2, and were affected by influent TKN, reactor pH, and perhaps other

Table 5-3. Total Hydraulic Retention Times (HRTs) Needed for BNR Compared to HRTs Needed for Nitrification Only - Based on Steady State Results

			HRT (h)				Additional HRT Needed for BNR
System	MCRT	Temp.	Anaerobic	Anoxic	Aerobic	Total	
Conventional	15	20			3.2	3.2	
BNR	15	20	1.0	1.0	1.7	3.7	0.5
Conventional	15	15			4.6	4.6	
BNR	15	15	1.2	1.2	3.3	5.7	1.1
Conventional	15	10			3.2	3.2	
BNR	15	10	1.5	1.5	*2.2	5.7	2.5
Conventional	5	20			3.8	3.8	
BNR	5	20	1.0	1.5	2.3	4.8	1.0
Conventional	2.7	20			6.0	6.0	
BNR	2.7	20	1.0	1.5	**5.0	~~2.5~~ 7.5	1.5

* Must increase aerobic HRT to 2.7 h (5.7 h total HRT) to maintain aerobic mass fraction of 0.50.
** Estimated from Figure F-7 in Appendix F.

factors in addition to temperature and pH. At the 15 d MCRT and 20 °C, only 0.5 h additional HRT is needed for BNR. This means that if an existing plant has excess HRT of 0.5 h, it can be converted to BNR with no additional reactor volume needed. Similarly, only 1.0 h additional is needed at an MCRT of 5 d and 20 °C, 1.1 h at 15 d MCRT and 15 °C, and 2.5 h at 15 d MCRT and 10 °C.

Anoxic and anaerobic volumes were determined from reactor data as the approximate volumes needed for complete denitrification and phosphorus release, respectively. Higher anoxic and anaerobic volumes were needed at the colder temperatures because of decreased reaction rates. In some cases, aerobic volume would have to be greater than that predicted to provide complete nitrification to maintain an aerobic mass fraction of 0.5, which is recommended to maintain good nitrification (Marais and Ekama, 1984).

Referring again Figures 5-6 through 5-13, at 5 d MCRT and 15 °C, complete nitrification was achieved in the conventional system, but not in the BNR system. At 5 d MCRT and 10 °C, there was incomplete nitrification in both systems, but it was more severely inhibited in the BNR system. At a 2.7 d MCRT and 20 °C, complete nitrification was attained in the conventional system, but not in the BNR system. Yet, for the total aerobic HRT of 4 hours the NH_3-N concentration in the BNR system was less than in the conventional system. At a 1.5 d MCRT, the nitrification profiles looked similar to those at a 5 d MCRT and 10 °C where nitrification was inhibited in both systems, but was more drastically affected in the BNR system. These things occurred because the aerobic MCRT was less in the BNR system when total MCRTs were equal for the two systems. Therefore, the BNR system was more susceptible to nitrifier washout.

It is clear from these results that under conditions favorable for nitrification in the BNR system, less aerobic volume was needed for nitrification than in the conventional system. This is because the MLVSS concentrations were higher in the aerobic zone of the BNR system than in the conventional system for the same organic loading and total MCRT. This implies that many conventional activated sludge systems capable of performing nitrification can convert part of their volumes to anaerobic and anoxic zones without sacrificing nitrification efficiency. Many more plants can be retrofitted for BNR than was previously thought, with little or no additional reactor volume, because of the decrease in aerobic volume that is possible.

Specific Nitrification Rates and Ammonia Oxidation Rates

Data used in the following discussion are presented in Table 5-4. Specific nitrification rates, q_N, were calculated from the equation:

$$q_N = (N_o - N)/[(\text{Aerobic MLVSS})(\text{Aerobic HRT})] \quad (5.3)$$

In Figure 5-14, the specific nitrification rates versus MCRT for the two systems for 20 °C are presented. The specific nitrification rate for the BNR system was higher at all MCRTs except at 15 d where the rates of the two systems were nearly equivalent. No clear pattern can be seen in the trend of specific nitrification

Table 5-4. Summary of Specific Nitrification Rates and Ammonia Oxidation Rates

System	MCRT (d)	Aerobic MCRT (d)	Temp (C)	Total NH3-N Oxidized (mg/L)	Aerobic MLVSS (mg/L)	Specific Nitrification Rate (mgN /gMLVSS /h)	*Nitrosomonas** VSS (mg/L)	Ammonia Oxidation Rate (mgN/mg *Nitrosomonas** /d)
BNR	15	8.3	20	18.8	2636	1.783	122	0.834
	15	8.9	15	26.5	3457	1.916	191	0.703
	15	8.3	10	20.5	2538	2.019	161	0.687
	5	2.7	20	23.2	1014	5.720	74	1.729
	5	2.8	15	22.4	1207	4.640	75	1.593
	5	2.9	10	8.1	1352	1.498	28	1.494
	2.7	1.5	20	21.6	749	7.210	42	2.695
	1.5	0.9	20	12.3	446	6.895	14	4.382
Conv.	15	15	20	21.2	1348	1.966	101	0.631
	15	15	15	26.6	2177	1.527	143	0.560
	15	15	10	22.5	2092	1.344	133	0.506
	5	5	20	26.5	1284	2.580	72	1.107
	5	5	15	21.9	1050	3.095	75	1.036
	5	5	10	15.0	1373	1.366	46	0.982
	2.7	2.7	20	27.1	658	5.148	47	1.716
	1.5	1.5	20	20.5	424	6.044	22	2.774

* Based on calculated values.

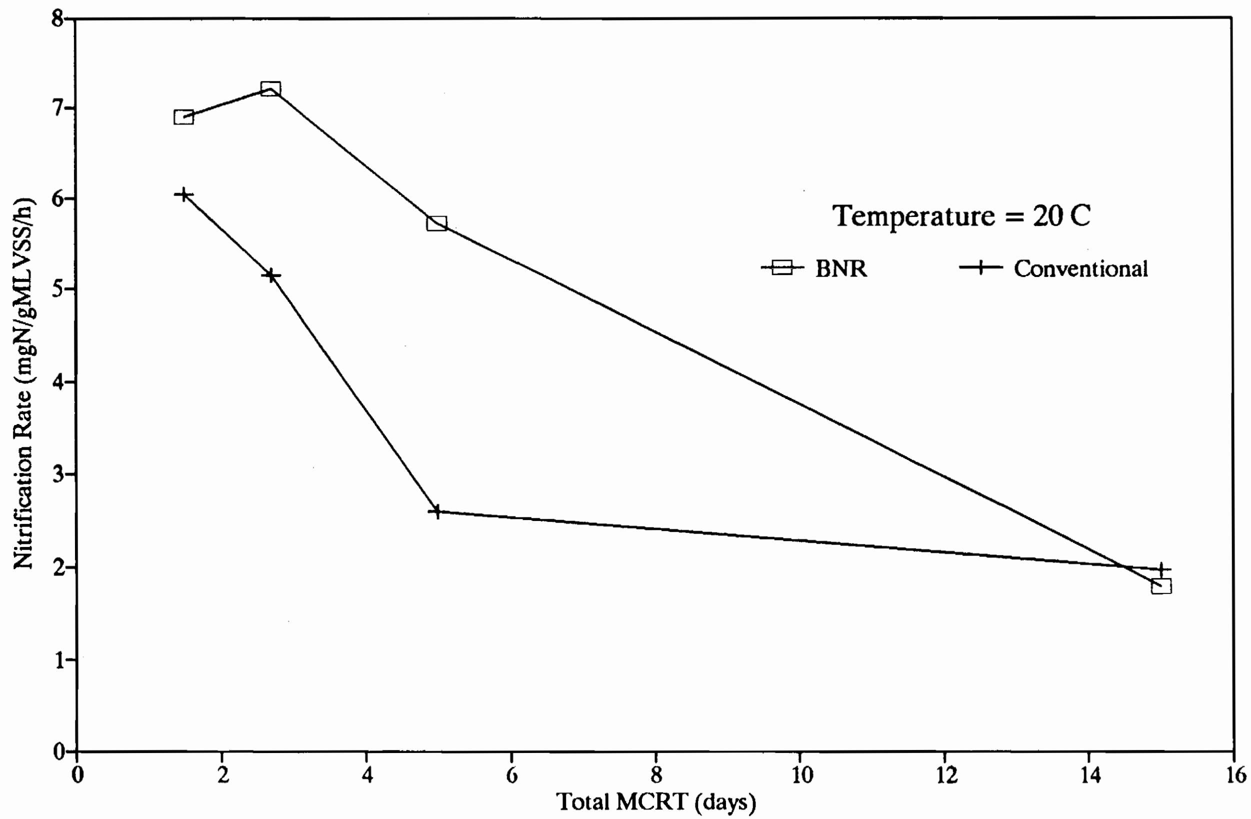

Figure 5-14. Comparison of Nitrification Rates Versus Total MCRT

rates versus MCRT, except that they generally increased as MCRT decreased. When the specific nitrification rates are plotted against the aerobic MCRT as shown in Figure 5-15, a more clear trend becomes apparent and is represented by a single curve. Specific nitrification rates were approximately equal when compared on the basis of aerobic MCRT.

Ammonia oxidation rates were calculated by using *Nitrosomonas* VSS concentrations instead of total aerobic MLVSS concentrations in Equation 5.3. The *Nitrosomonas* VSS concentrations were determined by calculation using the kinetic coefficients and the method given in Table F-1 in Appendix F, and are listed in Table 5-4. It should be noted that the conclusions that can be made from ammonia oxidation rates as calculated in this manner are limited, because *Nitrosomonas* VSS concentrations were calculated from literature yield coefficients, with the assumption that the net decay rates of *Nitrosomonas* were equal to the net decay rates found in Figures 5-2 and 5-3 for the conventional system and the BNR system, respectively. Direct measurement of nitrifier populations would be more accurate, but the technology for this measurement is undeveloped. It is believed that the calculation provides good estimates of *Nitrosomonas* populations, and that the trends seen in ammonia oxidation rates are valid.

Some interesting trends become obvious when plotting ammonia oxidation rates by *Nitrosomonas* as a function of MCRT and temperature. Figure 5-16 shows ammonia oxidation rates plotted versus the total system MCRT. Ammonia oxidation rates of the two systems follow similar trends, increasing as MCRT decreases, with

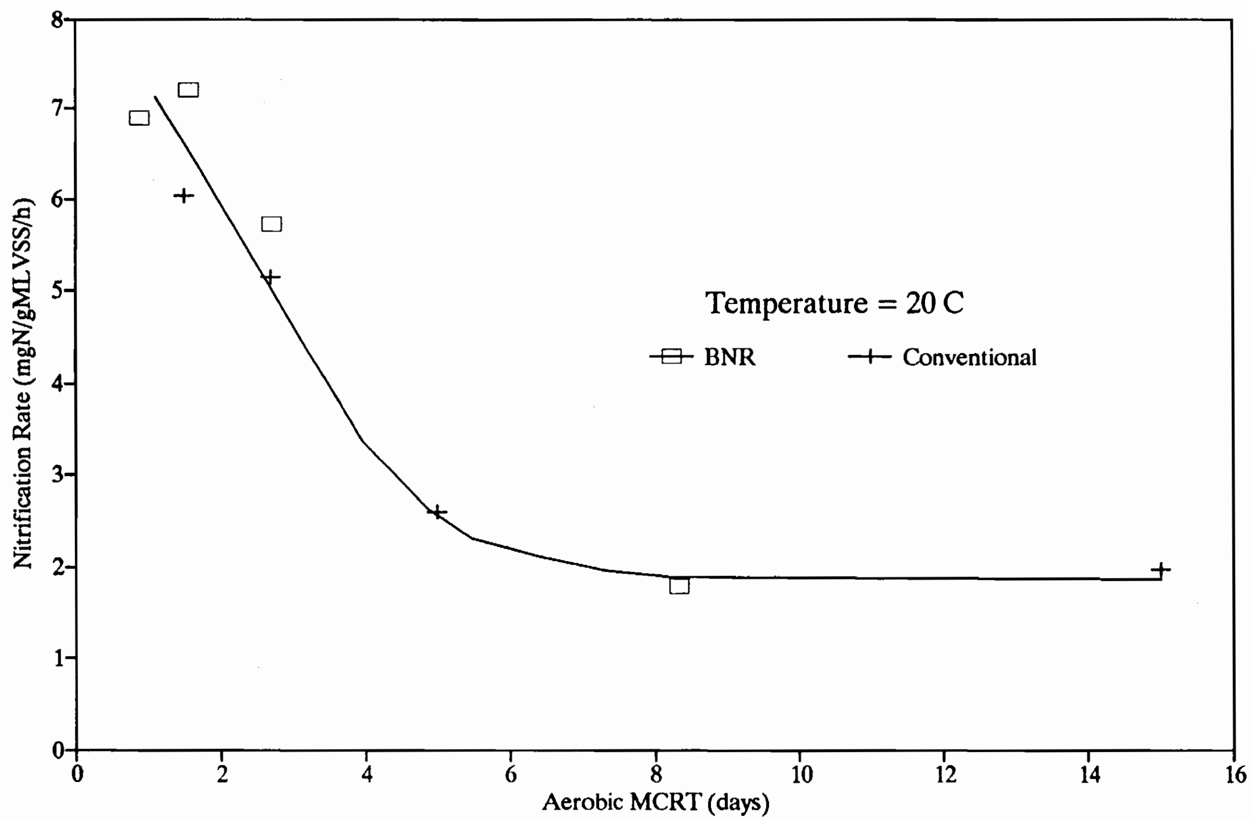

Figure 5-15. Comparison of Nitrification Rates Versus Aerobic MCRT

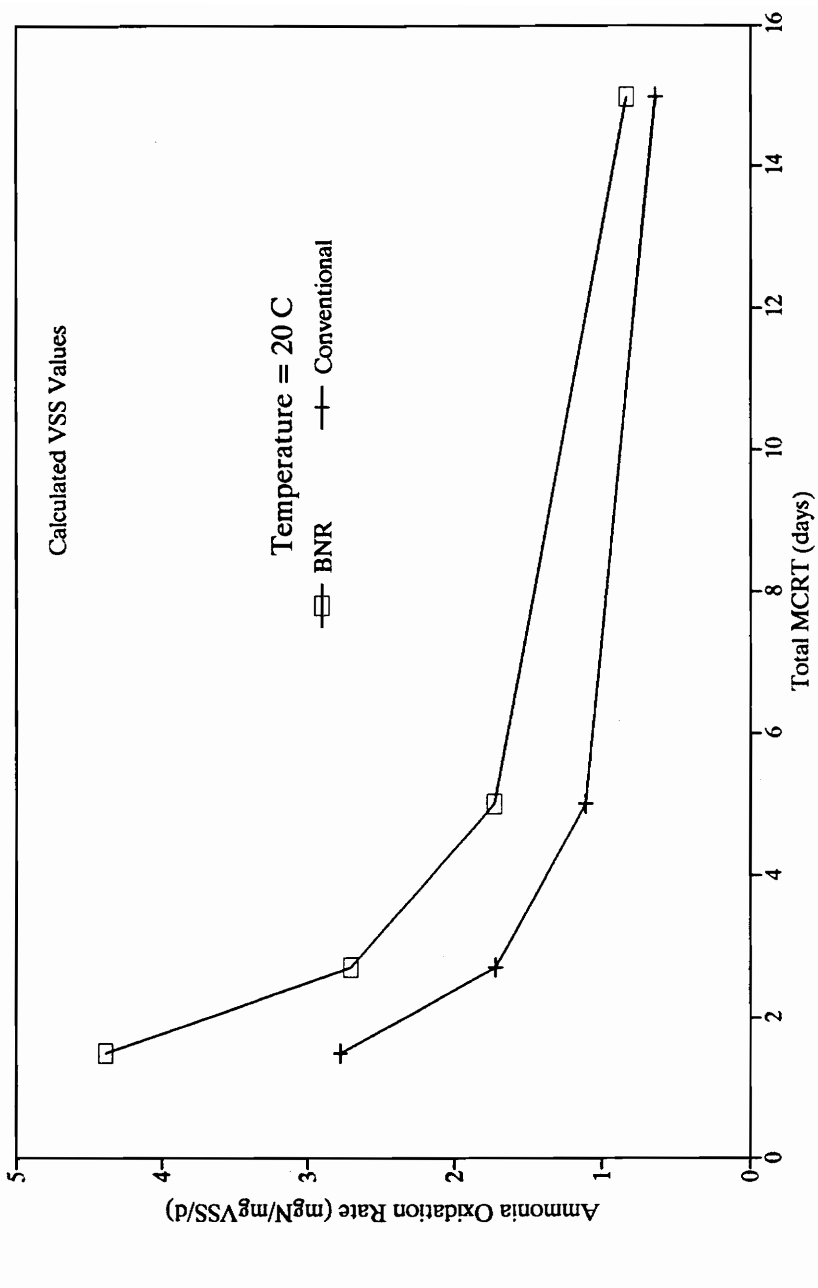

Figure 5-16. Comparison of Ammonia Oxidation Rates by *Nitrosomonas* Versus Total MCRT

the BNR system having higher ammonia oxidation rates for a given total MCRT. When ammonia oxidation rates are plotted versus aerobic MCRT, as shown in Figure 5-17, the results from both systems can be described with one remarkably smooth curve. This indicates that the assumptions that nitrifiers grow only under aerobic conditions, and that aerobic MCRT governs nitrification design, are valid for use in the design of BNR systems (Barnard *et al.*, 1985; Grady *et al.*, 1986).

Temperature Effects on Nitrification Rates

Figure 5-18 shows the effect of temperature on specific nitrification rates. In this figure, no clear trend is discernable except that temperature had a great effect on rates at 5 d total MCRT; however, when the same data are normalized to *Nitrosomonas* concentrations instead of total MLVSS concentrations, as previously described, a trend becomes obvious in the ammonia oxidation rates as shown in Figure 5-19. The effect of temperature on ammonia oxidation rates was not as severe as would be predicted by accepted temperature correction equations (USEPA, 1975; Benefield and Randall, 1980). The figure shows that ammonia oxidation rates decreased less than 10% for a 5 °C drop in temperature.

The effect of temperature on the ammonia oxidation rate can be adequately described by the following equation:

$$Rate_T = Rate_{20}\, \theta^{(T-20)} \qquad (5.4)$$

where $Rate_T$ = Ammonia oxidation rate at T °C,

$Rate_{20}$ = Ammonia oxidation rate at 20 °C, and

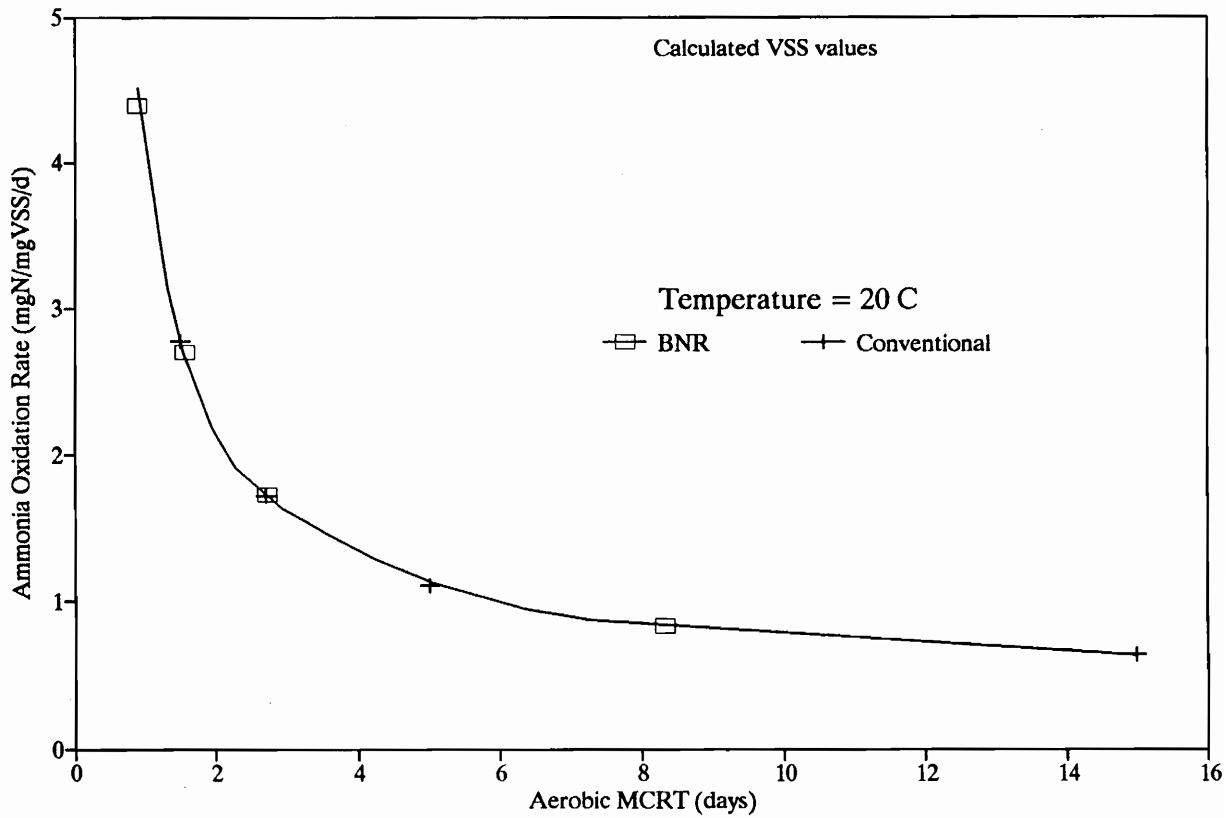

Figure 5-17. Ammonia Oxidation Rates by *Nitrosomonas* Versus Aerobic MCRT

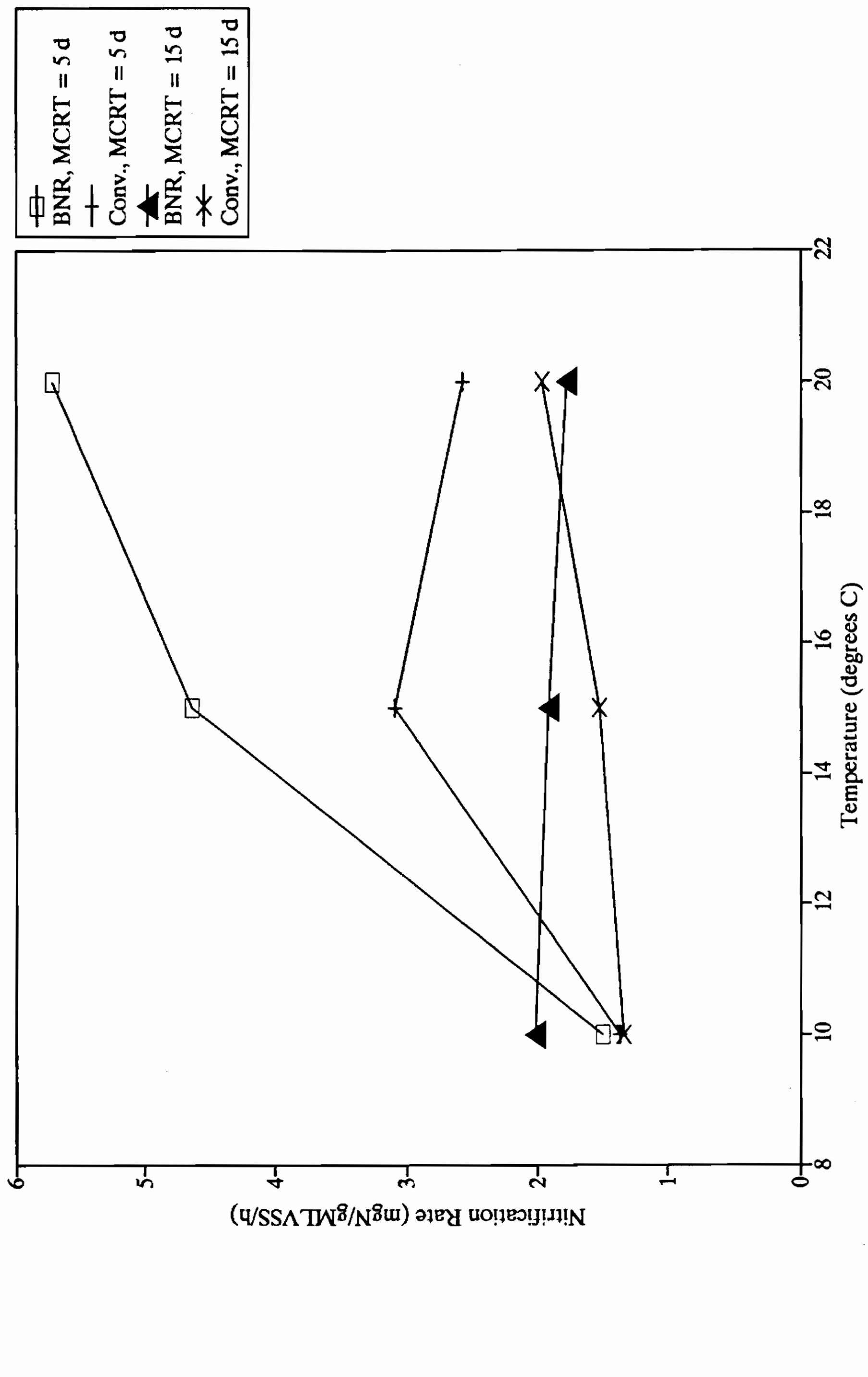

Figure 5-18. Effect of Temperature on Specific Nitrification Rates

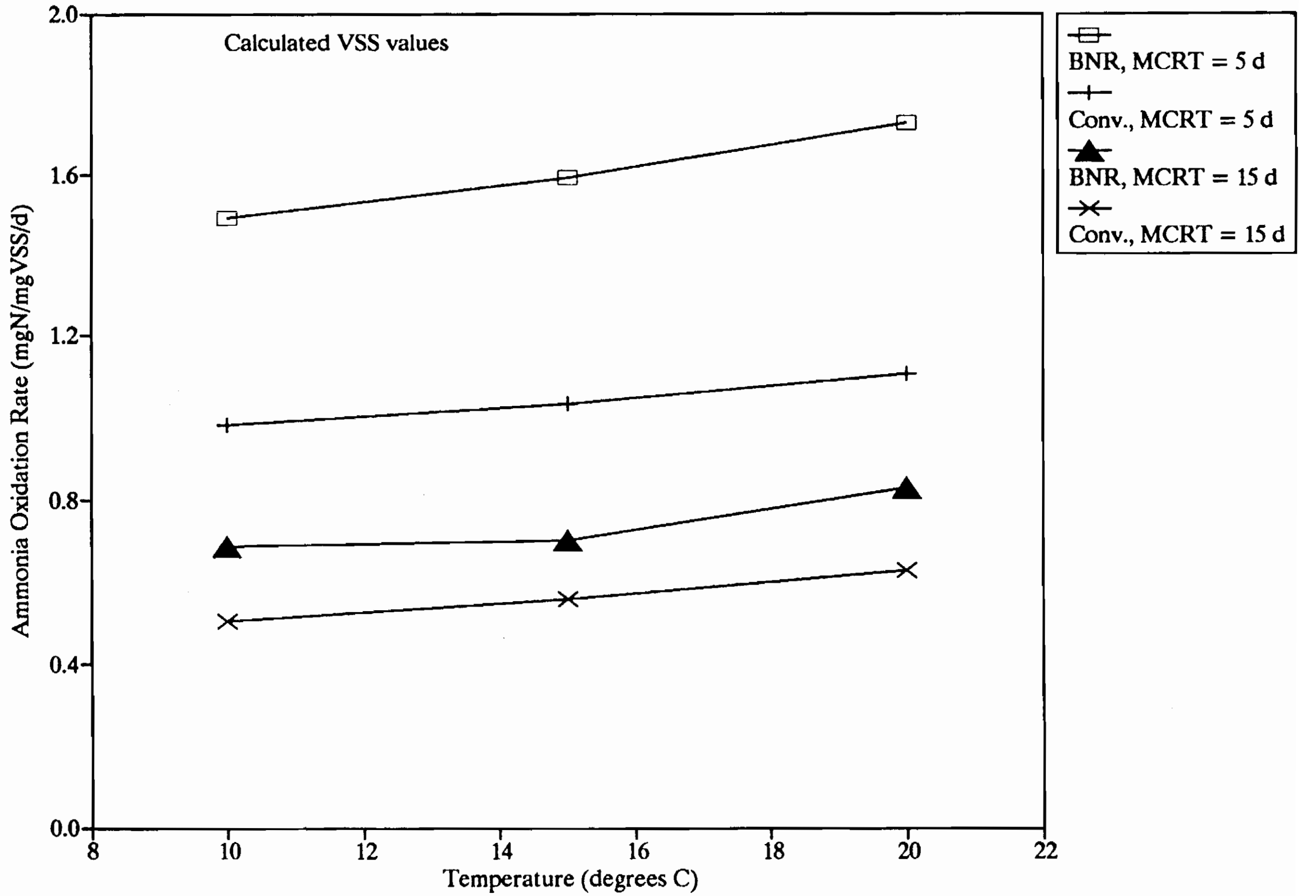

Figure 5-19. Effect of Temperature on Ammonia Oxidation Rates by *Nitrosomonas*

θ = temperature correction factor = 1.02.

In Figure 5-20, the effect of temperature on ammonia oxidation rates can be viewed differently by plotting ammonia oxidation rates versus aerobic MCRT. The data at different temperatures follow a curve of the same shape, and temperature had only a small detrimental effect on the observed ammonia oxidation rates.

Although ammonia oxidation rates decrease as MCRT increases, the degree of nitrification increases. At low MCRTs, even though rates are high, *Nitrosomonas* VSS concentrations are too low to provide complete nitrification. This means that aerobic MCRT is more important than HRT in determining the degree of nitrification achievable.

Ammonia oxidation rates by *Nitrosomonas*, based on aerobic MCRT, appear to be a much better way of reporting nitrification rates than the conventional way of calculating specific nitrification rates using total MLVSS concentrations. Total MLVSS is more dependent on the COD removed than the nitrogen oxidized.

These results can be misleading if not interpreted properly. High specific nitrification rates and ammonia oxidation rates do not necessarily mean high degrees of nitrification were achieved. For example, at 5 d MCRT and 10 °C in the BNR system, ammonia oxidation rates were high, yet the degree of nitrification achieved was very low because of low concentrations of *Nitrosomonas*. The MCRT and temperature conditions were unsuitable for nitrifier growth, and the low VSS concentrations outweighed the high specific rates.

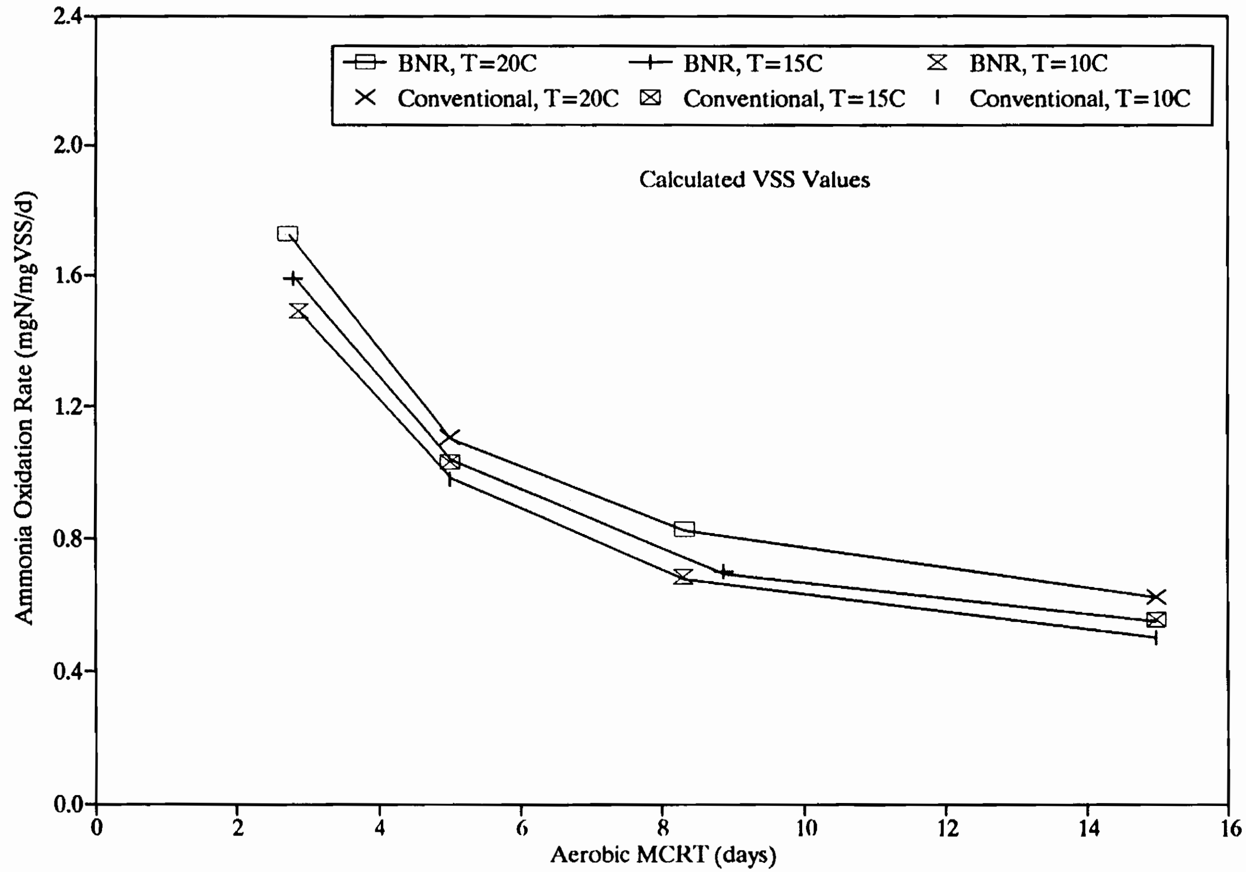

Figure 5-20. Ammonia Oxidation Rates by *Nitrosomonas* at Various Temperatures Versus Aerobic MCRT

Also possibly misleading was that although specific nitrification rates and the degrees of nitrification achieved were equal in the BNR and conventional systems on an aerobic MCRT basis, less aerobic volume was needed for nitrification in the BNR system when temperature and MCRT conditions were suitable for complete nitrification. This phenomenon occurred because, under those conditions, the MLVSS concentrations were higher in the aerobic zone of the BNR system than in the conventional system for the same organic loading and MCRT.

Specific Denitrification Rates

For purposes of this and subsequent sections of this chapter, only the BNR system is discussed. All MCRTs are reported as total MCRTs. Raw data used for calculation of specific denitrification rates are presented in Table 5-5.

Figure 5-21 shows the specific denitrification rate, q_{DN}, at different temperatures versus MCRT, with the corresponding oxidized nitrogen concentration for each data point. These rates were determined from nitrogen balances around the first anoxic section of the BNR system, *i. e.*, section 4 of Reactor 1. A slight amount of backmixing from the first aerobic section into sections 6 and 5 occurred, preventing accurate analysis of rates in these sections.

Specific denitrification rates increased as MCRT decreased except at 1.5 d MCRT, and ranged from 6 to 19.6 mgNO_3^--N removed/gMLVSS/h at MCRTs of 15 and 2.7 d, respectively, values much greater than those previously reported (Gerber *et al.*, 1986; Comeau *et al.*, 1987; Winter, 1989). It should be noted that at 1.5 d

Table 5-5. Raw Data Used for Calculation of Specific Denitrification Rates

System	MCRT (d)	T (C)	Date	NOx-N Concentration (mg/L) Sec.3	Sec.4	Sec.12	RAS	Sec.4 MLVSS (mg/L)	Specific Denitrification Rate (mgN/gMLVSS/h)
BNR	15	20	03JUL89	0.2	1.5	7.8	8.4	2590	*6.1
	15	20	15SEP89	0.3	0.9	12.2	9.0	3150	*8.7
	15	15	02MAY89	0.1	0.1	9.4	9.4	4510	6.2
	15	10	08AUG89	0.9	2.9	9.6	10.3	2525	6.0
	5	20	28MAR90	0.6	3.4	11.6	11.5	1020	15.7
	5	15	21NOV89	0.8	2.4	8.8	8.6	1300	10.8
	5	10	07DEC89	0.0	0.3	1.5	1.9	1110	3.1
	2.7	20	11APR90	0.1	0.8	6.1	5.8	673	19.7
	1.5	20	19APR90	0.0	0.0	2.3	2.0	340	18.8

* Data given equal weighting for purposes of analysis.

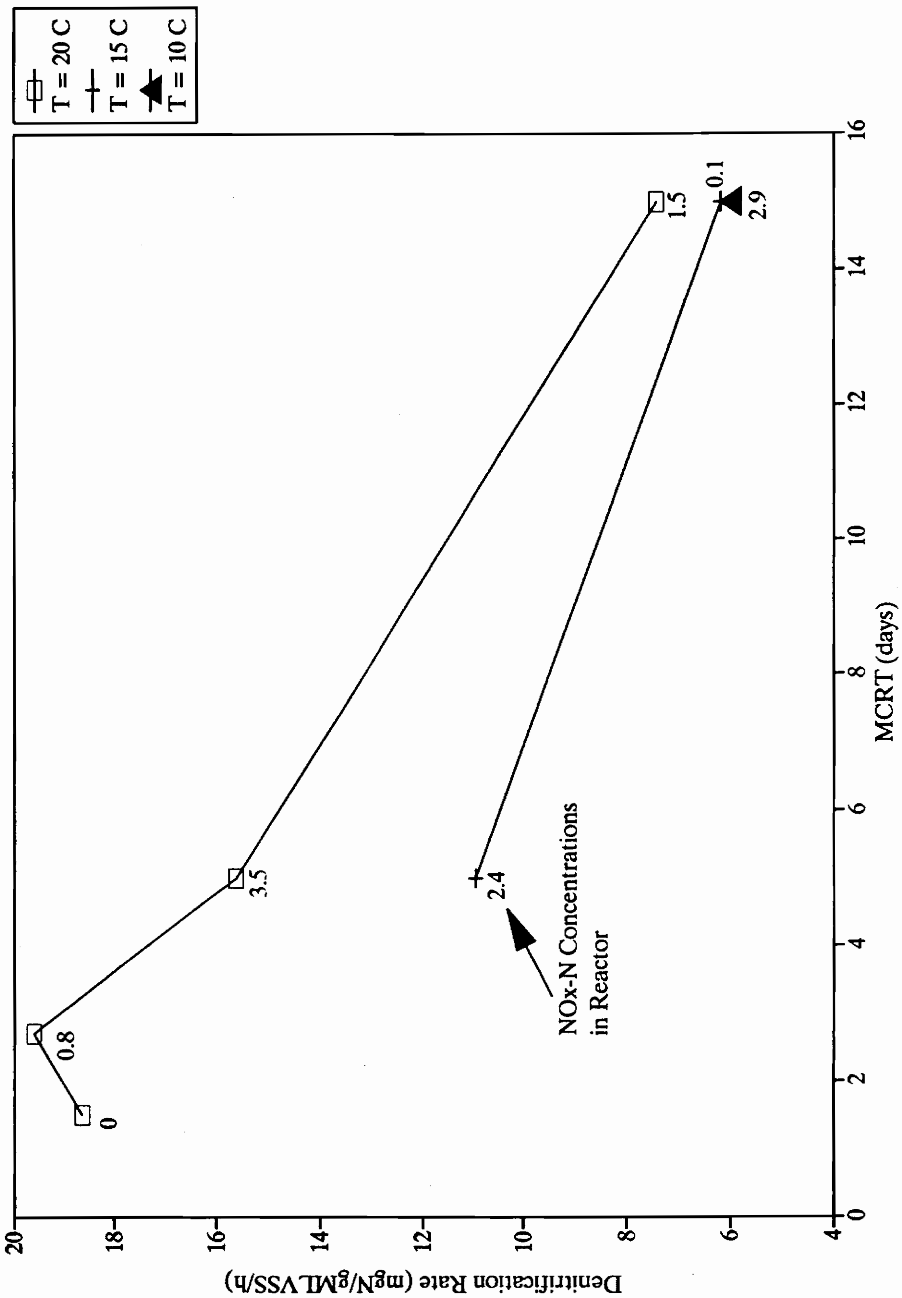

Figure 5-21. Specific Denitrification Rates at Various Temperatures and MCRTs

MCRT, the nitrate concentration in the anoxic reactor was 0 mg/L, therefore denitrification rate was limited by the nitrate available. Temperature had an adverse effect on denitrification, with a greater effect at the lower MCRT of 5 d.

In Figure 5-22 are plotted the observed specific denitrification rates versus temperature. At an MCRT of 15 d and a temperature of 15 °C, and at 5 d MCRT and 10 °C, denitrification rates were limited by the nitrate concentration. Denitrification rate increased sharply with temperature at 5 d MCRT. However, temperature had little effect at 15 d MCRT. It was not possible to develop a temperature correction coefficient for denitrification rates because some points were limited by nitrate concentrations while others were not, and the 5 d MCRT denitrification rate was more affected by temperature than the 15 d MCRT.

Figure 4-6 showed that N removal was greater at the 15 d MCRT than at the 5 d MCRT at all temperatures studied. Although denitrification rates were higher at lower MCRTs, the MLVSS concentrations were too low to provide complete denitrification. The higher MLVSS concentrations more than compensated for the lower denitrification rates at 15 d MCRT, resulting in greater denitrification capacities.

Denitrification Batch Experiment

It was desired to determine if polyP organisms were performing the denitrification in the BNR process. If the polyP organisms used nitrate as an electron acceptor, stored organics must have been used as the carbon source, since

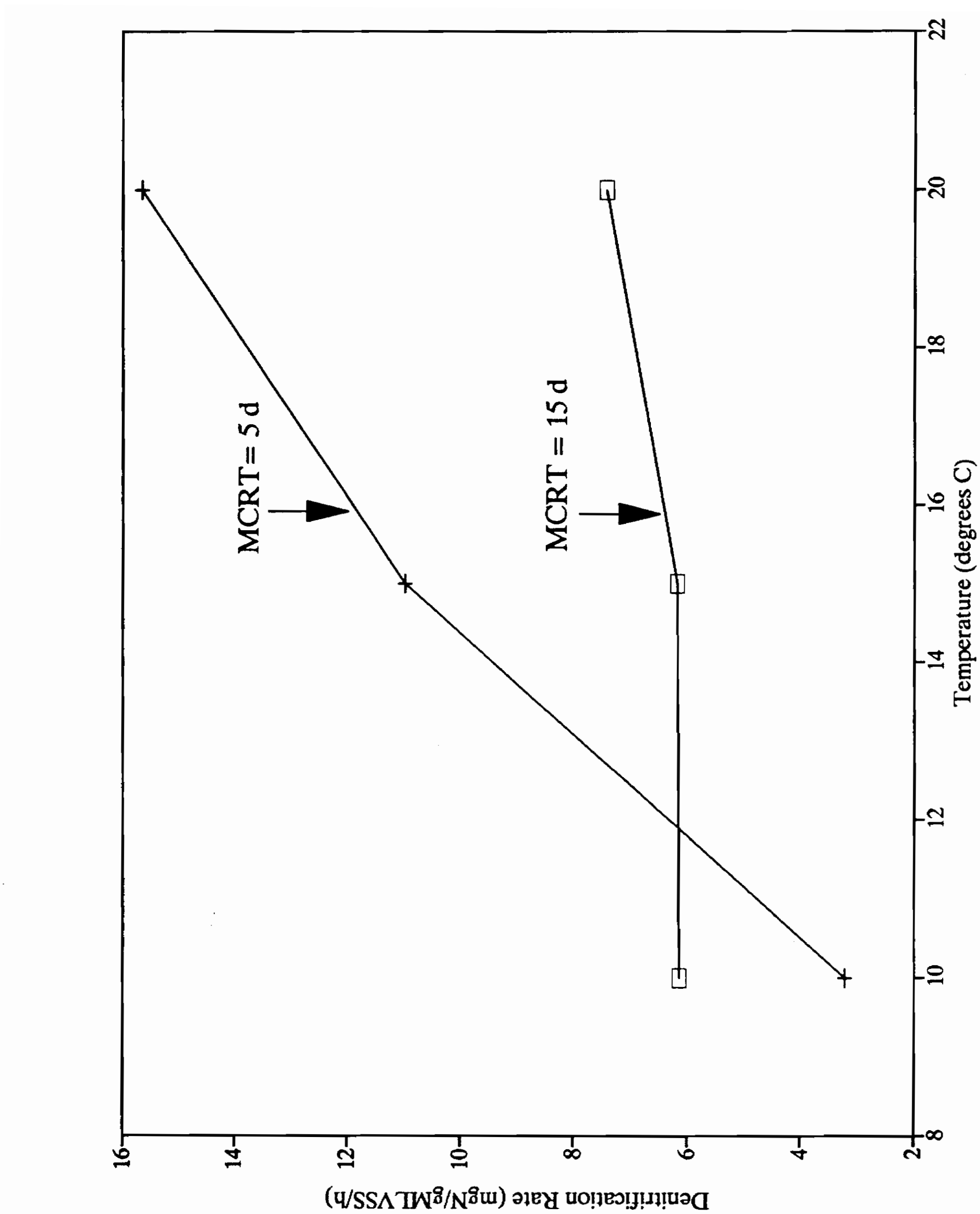

Figure 5-22. Observed Specific Denitrification Rates

no soluble COD was available. Further, if stored organics were oxidized, phosphorus was probably stored. Phosphorus balances around the first section of the anoxic zone of the continuous-flow BNR process were unclear in showing whether a net uptake or release of phosphorus occurred under anoxic conditions. It was not possible to determine if the P uptake which seemingly occurred in subsequent anoxic sections was due to anoxic uptake or to backmixing from the aerobic zone into the anoxic zone which had occurred. Therefore, a denitrification batch experiment was designed to study the mechanisms of denitrification in a BNR system under COD-limiting conditions, when all of the influent organics are stored inside the cells before they enter the anoxic zone.

The purpose of the denitrification batch experiment was to determine if polyP organisms were able to use nitrate as an electron acceptor. It was expected that denitrification could occur at the high rates observed in the continuous process only if polyP organisms were able to use nitrate as an electron acceptor to metabolize stored organics as the carbon source. Also, if stored organics were oxidized, it was expected that phosphorus uptake would occur.

The results of the experiment, as shown in Figure 4-11, showed that a rapid and steady denitrification rate (11.4 mgNO_3^--N removed/gMLVSS/h) was observed for the first 40 minutes. Phosphorus uptake did indeed occur, although at a much lower rate than under aerobic conditions. This could be because some of the polyP organisms were not denitrifying and were releasing P simultaneously with anoxic uptake of P by other organisms. Also, less energy is made available through anoxic oxidation of organics, therefore it takes more oxidation to stimulate P storage. These results are consistent with the results of other researchers (Comeau *et al.*, 1987; Mostert *et al.*, 1987).

The significance of these results is that denitrification abruptly stopped and net P release began, although nitrate (18 mg/L as N) was still present. In previously reported experiments, nitrate was not added in excess, and P release coincided with the disappearance of nitrate (Comeau *et al.*, 1987; Mostert *et al.*, 1987).

It was determined that the amount of COD that could be attributed to oxidation using nitrate in the batch test was equivalent to approximately 20% of the total stored organics. Interestingly, this was about the same percentage of COD stabilization due to denitrification in the continuous process from which the sludge came. It is believed that a fraction of the polyP organisms used nitrate as electron acceptor and stored phosphorus under anoxic conditions, and that the fraction of denitrifying polyP organisms is determined by the amount of nitrate being denitrified in a given system. In other words, in a process where an anoxic zone follows the anaerobic zone, the fraction of denitrifying polyP organisms in the system will be determined by the nitrate that is made available.

It is proposed that polyP organisms which are not denitrifiers behave as if under anaerobic conditions while in anoxic conditions, and that the polyP organisms which stored P under anoxic conditions begin slowly releasing P back into solution once either the nitrate or their stored COD was depleted. Therefore, simultaneous release and uptake of P can occur in the anoxic zone by different microorganisms, depending on whether they can utilize nitrate or not. This would explain why reactor data usually showed a net release of P in the first anoxic zone, even though the batch test showed that uptake occurred during denitrification.

Steady State Phosphorus Profiles

Interpretation of the steady state P profiles was particularly difficult. Large releases of P in the anaerobic zone did not always occur simultaneously with large uptakes of P in the aerobic zone (15 d MCRT, 20 °C), and large uptakes of P did not always occur simultaneously with large releases (5 d MCRT, 20 °C). The reason for this is that large uptakes of P by the sludge typically occurred 12 to 24 hours after large releases were seen in the anaerobic zone. A high influent COD caused large P releases, followed by large uptake (high P removal) about 12 to 24 hours later. Influent COD values fluctuated a great deal, which was unavoidable considering the set-up of the experiment, and P removal fluctuated accordingly. The %P in the sludge, however, did not fluctuate as much, and was thus used as an indicator of BPR performance.

Effects of Temperature on BPR

All of the results concerning effects of temperature on BPR were presented in the *Results* chapter. It was obvious from the results that colder temperatures have an adverse effect on P release and uptake, %P in the sludge and P removal, and that

5 d MCRT operation was more affected than 15 d operation. From these results, Figure 5-23 was developed. Actual data are shown in parentheses in the figure. This figure shows the percent P/VSS as a function of temperature and MCRT for influent COD concentrations around 250 mg/L. The trends that these data follow is believed to be typical of conditions where biological phosphorus removal is COD-limited. The highest percent P/VSS was obtained at a 5 d MCRT and 20 °C, indicating 5 d is the optimum MCRT at this temperature. Colder temperatures had an adverse effect on %P/VSS, with lower MCRTs being more affected than higher MCRTs. Relatively high %P/VSS (>8%) values were maintained at 15 °C at both 5 and 15 d MCRTs. At 10 °C, higher MCRTs provided the highest %P/VSS.

Phosphorus removal is dependent on influent COD as well as temperature and MCRT. At different MCRTs and temperatures, different amounts of COD are needed to remove a given amount of phosphorus. The amount of influent COD (as concentration in mg/L) needed to remove 1 mg/L of phosphorus was a function of temperature and MCRT. The optimum conditions for BPR were an MCRT of 5 d at a temperature of 20 °C, where one mg/L of P is removed for every 30 mg/L COD contained in the influent wastewater. Other conditions required more COD. Temperature had a greater effect on the COD required at 5 d MCRT than at 15 d MCRT.

BPR is possible at temperatures as low as 10 °C, but caution should be used if operating at MCRTs less than 15 d. A maximum of 4% P in the sludge (%P/VSS) is all that should be expected at 5 d MCRT and 10 °C. Operation at MCRTs

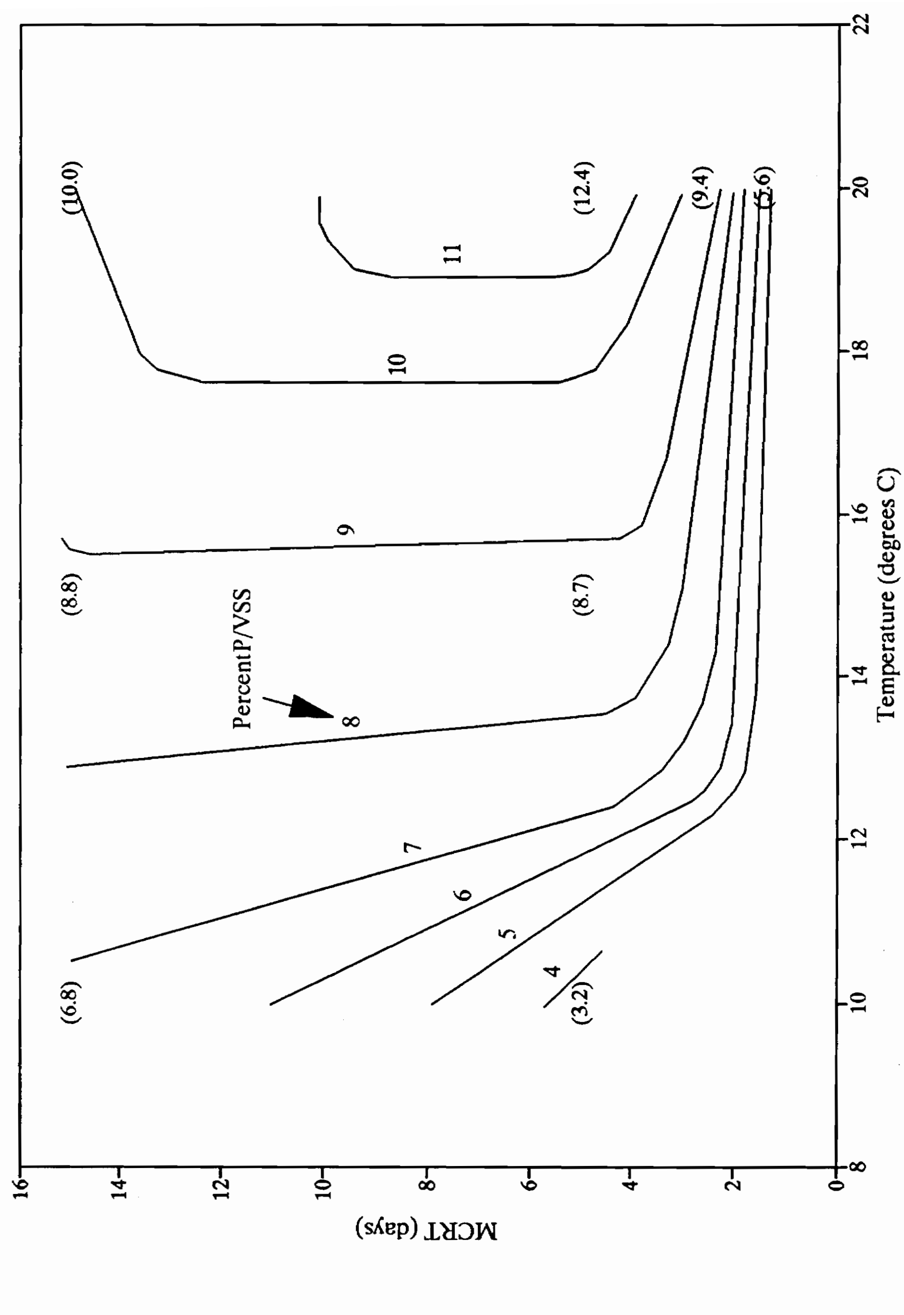

Figure 5-23. Percent P/VSS as a Function of Temperature and MCRT for COD = 250 + 50 mg/L

greater than 5 d is recommended for BPR if temperatures below 15 °C are anticipated. A maximum of 11% P in the sludge was achieved at 15 d MCRT and 10 °C, and an influent COD of approximately 400 mg/L was required. Chemical addition may be used as necessary to meet effluent P requirements in cold temperatures (Spatzierer *et al.*, 1987).

Phosphorus removal happened to be best at the lowest MCRT which provided complete nitrification at the temperature of 20 °C. Data from Table 4-3 was used in Figure 5-24, which plots percent nitrification, %P/VSS, and P removal versus MCRT. The %P/VSS and P removal were highest at an MCRT of 5 d, the lowest total MCRT where complete nitrification was achieved.

Temperature had a slightly more adverse effect on nitrification efficiency than on %P/VSS (and P removal). For example, at the 5 d MCRT and 15 °C, and at 2.7 d MCRT and 20 °C, high %P/VSS (8 to 9%) values were maintained although nitrification was incomplete. Operation under conditions of incomplete nitrification is risky for total nitrogen removal, because nitrification may be completely lost at even a slight change in conditions, resulting in a large decrease in total nitrogen removal.

Taking these factors into account, some important conclusions can be made. Operation of a biological nutrient removal (BNR) process at the lowest MCRT that provides complete nitrification is optimum for providing the best combined nitrogen and phosphorus removal when phosphorus removal is COD-limited. Under P-limiting conditions, however, a higher MCRT would be optimal because better nitrogen removal can be achieved without any loss in P removal efficiency. As MCRT

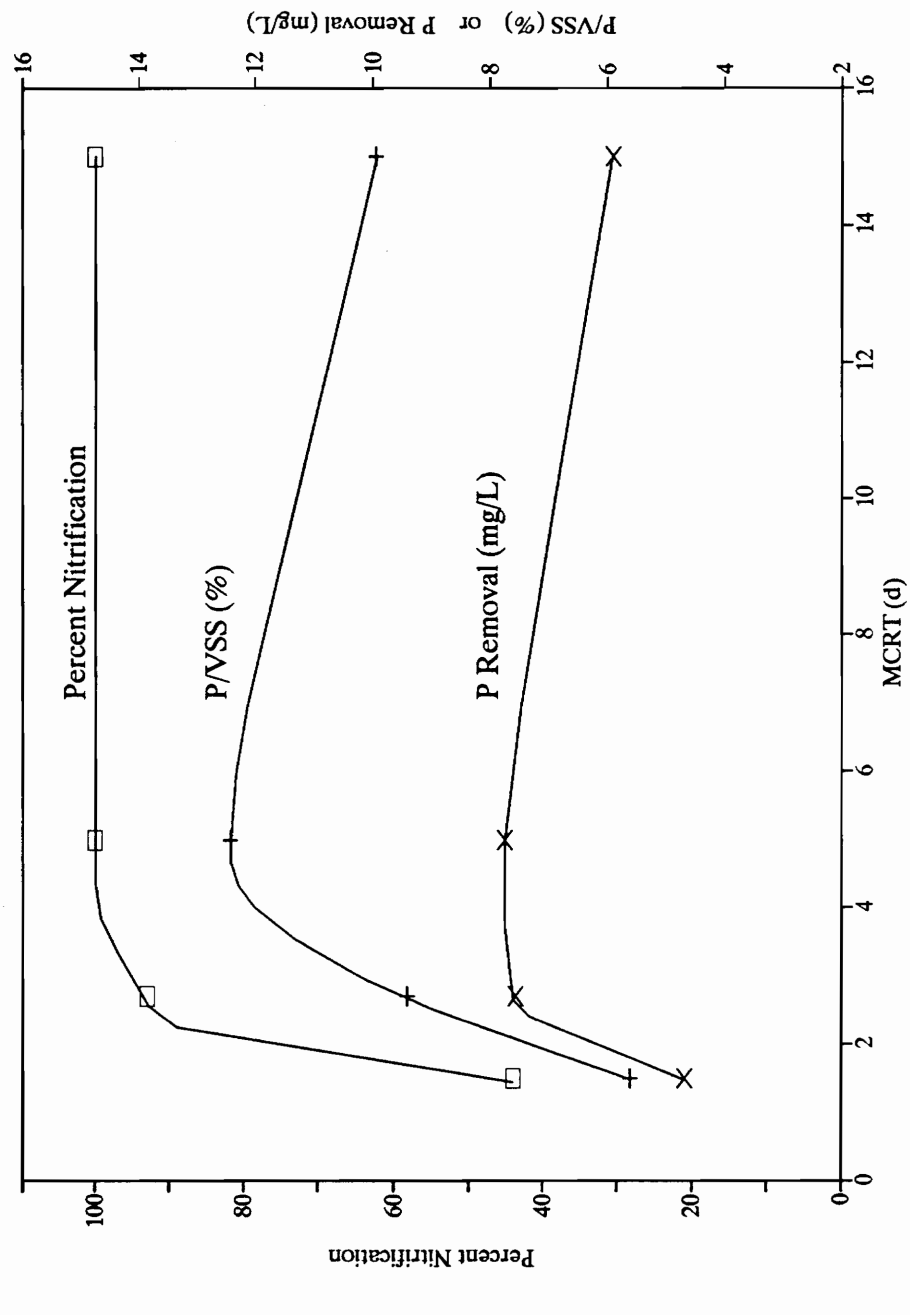

Figure 5-24. Effect of MCRT on Percent Nitrification and Phosphorus Removal - T = 20 C

increases under P-limiting conditions for a given concentration of influent P, an MCRT will eventually be reached where COD becomes limiting instead of P. Operation above this critical MCRT will result in a decrease in P removal.

Anaerobic Stabilization

The amount of anaerobic stabilization which occurred under a given set of conditions was determined by performing an oxygen balance on the system using the method described by Brannan (1986). Shown in Figure 5-25 is a diagram depicting the oxygen balance around an activated sludge wastewater treatment system. The abbreviations used in this figure are defined in the following equation.

From the oxygen balance presented in Figure 5-25, the following equation is developed:

$$COD_i + NOD = COD_e + COD_w + TOR \tag{5.6}$$

where COD_i = influent COD,

NOD = nitrogenous oxygen demand,

COD_e = effluent COD,

COD_w = COD of solids removed via waste sludge, and

TOR = total oxygen requirement for the system.

Total oxygen requirement (TOR) for the system can be determined by multiplying the oxygen uptake rate (OUR), $mgO_2/L/min$, of a section by the volume of that section and then summing the values obtained. Added to this is the oxygen consumed in the recycles and the final clarifier, which is small compared to oxygen

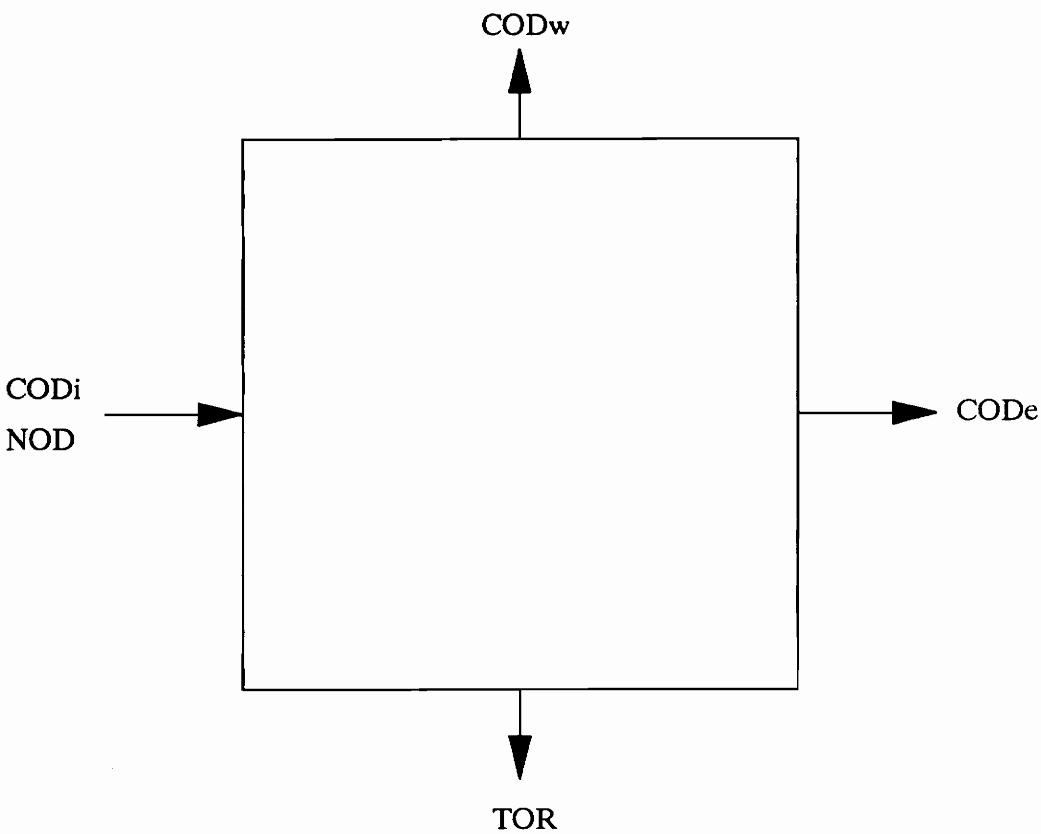

Figure 5-25. Oxygen Balance of an Activated Sludge Wastewater Treatment System

used in the reactors but still significant. If the TOR measured and calculated in this manner is less than the predicted TOR, the difference can be attributed to anaerobic stabilization, *i. e.*, a reduction in subsequent oxygen requirements through some anaerobic mechanism.

The following equation is a more specific form of the oxygen mass balance equation (Equation 5.6) which is used for quantifying anaerobic stabilization:

$$\begin{aligned} AnS &= COD_i - COD_e + 4.57(\Delta NO_3^- \text{-} N)_p + 3.43(\Delta NO_2^- \text{-} N)_p \\ &\quad - 2.86(\Delta NO_3^- \text{-} N)_u - 1.71(\Delta NO_2^- \text{-} N)_u - (COD/VSS)(\Delta X)_w \\ &\quad - (COD/VSS)(\Delta X)_e - TOR \end{aligned} \tag{5.7}$$

where $(\Delta NO_3^- \text{-} N)_p$ = nitrate nitrogen created in the system,

$(\Delta NO_2^- \text{-} N)_p$ = nitrite nitrogen created in the system,

$(\Delta NO_3^- \text{-} N)_u$ = nitrate nitrogen denitrified,

$(\Delta NO_2^- \text{-} N)_u$ = nitrite nitrogen denitrified,

(COD/VSS) = measured value of COD per VSS,

$(\Delta X)_w$ = VSS in waste sludge, and

$(\Delta X)_e$ = effluent VSS.

The results of the anaerobic stabilization experiments are presented in Table 5-6. Tables with the raw data and equations used for calculating the variables used in the equations are presented in tables in Appendix E. Anaerobic stabilization was observed under all conditions observed and varied from 8.4% to 27.3%. OUR data were obtained for 5 d MCRT with the BOD bottle technique, and the data did not appear to be accurate at 15 °C. No relationship was seen between anaerobic stabi-

Table 5-6. Anaerobic Stabilization

MCRT = 5 days (OURs measured in BOD bottle)				
Temp (°C)	System	TOR (Predicted) (g/d)	TOR (Measured) (g/d)	Anaerobic Stabilization (%)
10	Conventional	23.9	25.0	
	BNR	20.2	16.5	18.3
15	Conventional	31.9	27.4	
	BNR	19.9	18.2	8.4
20	Conventional	43.3	42.4	
	BNR	36.2	32.6	10.0
MCRT = 15 days (OURs measured *in situ*)				
Temp (°C)	System	TOR (Predicted) (g/d)	TOR (Measured) (g/d)	Anaerobic Stabilization (%)
10	Conventional	26.1	25.6	
	BNR	22.0	19.4	11.6
15	Conventional	34.9	34.1	
	BNR	28.7	21.7	24.6
20	Conventional	33.8	34.2	
	BNR	29.5	21.4	27.3

Where TOR = Total Oxygen Requirement

lization and temperature.

Data obtained at 15 d MCRT, where it was possible to measure OURs *in situ*, provided what is believed to be a much more accurate picture of oxygen requirements for the two systems. The conventional system actual oxygen requirements were almost exactly equal to theoretical predictions in all cases. The BNR system, on the other hand, showed anaerobic stabilization of 11.6% at 10 °C, increasing to 27.3% at 20 °C. The degree of anaerobic stabilization increased with temperature and with the predicted TOR (which is proportional to the influent COD). It was not possible to separate the effects of temperature from the effect of influent COD.

It should be noted that the anaerobic stabilization observed here was in addition to oxygen savings resulting from denitrification, which provided about 15% additional oxygen savings except at 5 d MCRT and 10 °C where nitrification was poor. Anaerobic stabilization combined with denitrification in the BNR system provided 22 to 42% total oxygen savings over a conventional system performing nitrification.

It was shown in Equations 2.17 through 2.19 how fermentation of glucose by facultatively anaerobic bacteria could theoretically account for up to 33% anaerobic stabilization. A stoichiometric equation for fermentation of domestic wastewater organics similar to Equation 2.19 can be developed using the chemical formula of domestic wastewater organics proposed by McCarty (1970):

$$C_{10}H_{19}O_3N + 7\,H_2O \rightarrow 5\,CH_3COOH + 5\,H_2 + NH_3 \qquad (5.8)$$

According to this equation, a reduction in oxygen requirements of 20% is theoretically possible.

There appears to be a lot of evidence that the mechanism of anaerobic stabilization could be through H^+ ions accepting electrons. Short chain fatty acids such as acetate are produced in the anaerobic zone of a BNR system by facultatively anaerobic bacteria. Many facultative anaerobic bacteria found in BPR sludge, *i. e.*, *Aeromonas punctata*, *E. coli*, and *Bacillus* spp., are known to produce hydrogen gas through fermentation. The amount of anaerobic stabilization found in this and other studies is close to the theoretically predicted stabilization possible through this mechanism.

Production of hydrogen gas in the anaerobic zone of a BNR process would be proof of this theory. Research is now being performed here at Virginia Tech in an effort to measure and quantify gas production in the anaerobic zone of a BPR process.

VI. Summary and Conclusions

This research produced many important results. Most important was the fact that less aerobic volume was needed to achieve complete nitrification in the BNR system than in the conventional system when mean cell residence time (MCRT) and temperature conditions were suitable for complete nitrification. This occurred at 15 d MCRT and temperatures from 10 to 20 °C, and at 5 d MCRT and 20 °C. This means that many existing conventional activated sludge wastewater treatment systems can be converted to BNR operation with little or no increase in reactor volume. It should be noted, however, that the BNR system was more susceptible to nitrifier washout than the conventional system because specific nitrification rates and the degree of nitrification achieved were equal compared on the basis of aerobic MCRT. This phenomenon of less aerobic volume being required in the BNR system occurred because the MLVSS concentrations were higher in the aerobic zone of the BNR system than in the conventional system.

Another important finding was the adverse effect of colder temperatures on biological phosphorus removal (BPR). PolyP organisms were washed out of the BNR system at 5 d MCRT and 10 °C, and the propensity for phosphorus removal at 15 d MCRT decreased as temperature decreased. This means that operation at MCRTs greater than 5 d is recommended when mixed liquor temperatures below 15 °C are expected, and chemical addition may be necessary to achieve low effluent phosphorus concentrations at low temperatures even at higher MCRT operation. Higher phosphorus removals were achieved at 15 d MCRT and 10 °C when additional acetate was added to the influent wastewater.

Also found was that the effective decay rate in the BNR system was less than in the conventional system, which led to significantly higher observed yields of MLVSS (in addition to stored phosphate, which is not volatile) in the BNR system compared to the conventional system at 15 d MCRT.

The following conclusions were made from the results of this study:

1. Nitrification rates, ammonia oxidation rates, and the degree of nitrification achieved were equal for the BNR and the conventional system when compared on an aerobic MCRT basis.
2. Under conditions where complete nitrification was achieved in the biological nutrient removal (BNR) system, *i. e.*, 15 d total MCRT and mixed liquor temperatures from 10 to 20 °C, and 5 d MCRT and 20 °C, less aerobic volume was needed for nitrification than in the conventional system. This was possibly because there were higher MLVSS concentrations in the aerobic zone of the BNR system than in the conventional system.
3. Ammonia oxidation rates were more strongly affected by aerobic MCRT than by MLSS temperature change over the temperature range from 10 to 20 °C.

4. Specific denitrification rates of 8 to 19 mgN/gMLVSS/h were observed at 20 °C, and were found to be a function of MCRT and temperature. The effect of temperature was small at a total MCRT of 15 d, but substantial at a total MCRT of 5 d.

5. Biological phosphorus removal (BPR) was adversely affected by colder temperatures, and the magnitude of the effect was also a function of the MCRT. BPR at 5 d total MCRT was more sensitive to temperature than at 15 d MCRT. Washout of polyP organisms occurred at a 5 d MCRT and 10 °C.

6. Operation of the BNR system at the lowest MCRT that provided complete nitrification prevented washout of polyP organisms, and provided the best combined nitrogen and phosphorus removal when phosphorus removal was limited by influent COD.

7. Anaerobic stabilization of 8% to 27% occurred in the BNR system, and was a function of temperature at a 15 d MCRT.

8. Anoxic uptake of P occurred in denitrification batch tests, although at a much lower rate than under aerobic conditions.

9. The yield coefficients were equal and were 0.41 mgVSS/mgCOD the BNR and conventional systems. The decay rate of the BNR system, 0.063 d^{-1}, was less than the decay rate in the conventional system, 0.110 d^{-1}.

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Appendices

Appendix A

Summary of Activities

1989

Phase 1

Feb 13:	Operation at 15 d MCRT and 10°C was begun.
Mar 8 - 10:	Steady state data for 15 d MCRT and 10°C were collected.

Phase 2

Mar 11:	Temperature was changed to 15°C.
May 2 - 6:	Steady state data for 15 d MCRT and 15°C were collected.
May 29 - Jun 1:	Control BNR system (Reactor 1) influent was spiked with acetic acid and test BNR system (Reactor 2) influent was spiked with isovaleric acid (additional 100 mg/L COD in each), and measurement of PHB and PHV in the sludge was attempted.

Phase 3

Jun 3:	Temperature was changed to 20°C.
Jul 2 - 7:	Steady state data for 15 d MCRT and 20°C were collected.

Phase 4

Jul 8:	Temperature was changed to 10°C.
Aug 8 - 16:	Steady state data for 15 d MCRT and 10°C were collected.

Phase 5

Aug 17:	Temperature was changed to 20°C.

Sep 8:	Batch experiment was conducted to study phosphorus and metals release and uptake using sludge from control BNR system (Reactor 1).
Sep 15:	Phosphorus and metals profiles on control BNR system (Reactor 1) at 15 d MCRT and 20°C were monitored.
Sep 27 - 30:	Steady state data for 15 d MCRT and 20°C were collected.
Oct 2:	Spiking of test BNR system (Reactor 2) influent with 5 mg/L Fe as $FeCl_3$ was started.
Oct 6:	Phosphorus fractionation experiments were conducted with 0.85% NaCl and 50 mM EDTA as washing media.
Oct 9:	Spiking of test BNR system (Reactor 2) influent with 10 mg/L Fe as $FeCl_3$.
Oct 11:	Batch experiment was conducted to study phosphorus release kinetics using sludge from control BNR system (Reactor 1).
Oct 13 - 14:	Phosphorus fractionation experiments were conducted with 0.85% NaCl and 50 mM EDTA as washing media.

Phase 6

Oct 15:	MCRT was changed to 5 d for control BNR system (Reactor 1) and for aerobic system (Reactor 3). Test BNR system (Reactor 2) operation was continued at 15 d MCRT.
Oct 30:	Spiking of test BNR system (Reactor 2) with 4.45 mg/L Fe as $FeCl_2$ was started.
Oct 31 - Nov 3:	Steady state data for 5 d MCRT and 20°C were collected.
Nov 3:	Phosphorus fractionation experiment was conducted with distilled water as the washing medium.

Phase 7

Nov 3 (8 p.m.):	Temperature was changed to 15°C.
Nov 20 - 22:	Steady state data for 5 d MCRT and 15°C were collected.

Phase 8

Nov 23:	Temperature was changed to 10°C.
Dec 7 - 9:	Steady state data for 5 d MCRT and 10°C were collected.

Phase 9

Dec 11:	Spiking of influent with 100 mg/L COD as sodium acetate was started.

Phase 10

Dec 25:	Spiking of influent (inadvertently) with 10 mg/L COD as sodium acetate was started.

1990

Phase 11

Jan 5 (8 p.m.):	Spiking influent with 100 mg/L COD as sodium acetate was started.
Jan 17:	Phosphorus fractionation experiment was conducted on sludge from test BNR system (Reactor 2) with distilled water as the washing medium.
Jan 23 - 26:	Steady state data were collected for all reactors.

Phase 12

Jan 26 (8 p.m.):	Temperature was changed to 20°C.
Feb 2:	Phosphorus fractionation experiment was conducted on sludge from conventional control system (Reactor 3) with distilled water as the washing medium.
Feb 14:	Batch experiment was conducted to study phosphorus release kinetics.
Feb 22:	Batch experiment was conducted to study role of nitrate in EBPR.

Feb 24:	Control BNR system (Reactor 1) started exhibiting EBPR at 5 d MCRT.
Feb 28:	Spiking influent with acetate was stopped.
Mar 4:	Batch experiment was conducted to study Phosphorus release and COD uptake under anaerobic conditions.
Mar 11:	Selective cation addition batch experiment was conducted.
Mar 18:	Spiking of test BNR system (Reactor 2) influent with 18 mg/L Fe as $FeCl_2$ was started.
Mar 24:	Phosphorus fractionation experiment was conducted using distilled water as the washing medium.
Mar 27 - 30:	Steady state data for the 5 d MCRT systems (Reactors 1 and 3) were collected.

Phase 13

Mar 30 (8 p.m.):	MCRT for Reactors 1 and 3 was changed to 2.7 d.
Apr 1:	Phosphorus fractionation experiment was conducted using 5 mM EDTA as the washing medium.
Apr 10 - 11:	Steady state data for the 2.7 d MCRT systems (Reactors 1 and 3) were collected.

Phase 14

Apr 10 (8 p.m.):	MCRT for Reactor 3 was changed to 1.5 d.
Apr 11 (8 p.m.):	MCRT for Reactor 1 was changed to 1.5 d.
Apr 15:	Selective cation addition batch experiment was conducted.
Apr 17 - 19:	Steady state data for the 1.5 d MCRT systems (Reactors 1 and 3) were collected.

Appendix B

Summary of Steady State Data

Table B-1. Summary of Steady State Data: BNR System (Reactor 1)

MCRT	Temp (C)	Parameter	Units	Inf''' Total	Inf'' Total	Inf' Total	Inf Total	Inf Sol	Sec1 Sol	Sec2 Sol	Sec3 Sol	Sec4 Sol	Sec5 Sol	Sec6 Sol	Sec7 Sol	Sec8 Sol	Sec9 Sol	Sec10 Sol	Sec11 Sol	Sec12 Sol	Eff Sol	RAS Sol
15	20	COD	mg/L		207	146	142	60	17	17	12	8	8	8	16	8	7	8	8	8	12	12
		TKN	mg/L				22.4				10.4			5.2	0.9		0.5				0.1	
03JUL89		NH3-N	mg/L				15.9				7.3											
		NO2-N	mg/L				0.0		0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0
		NO3-N	mg/L				0.0		0.0	0.0	0.1	1.4	1.2	1.0	4.5	4.8	7.0	6.6	7.5	7.8	7.3	8.4
		P	mg/L	16.5	18.2	16.8	15.9	13.8	22.5	23.2	19.7	18.3	17.9	15.7	14.3	13.0	11.6	12.5	12.1	11.5	11.7	13.1
		MLSS	mg/L				26		1860	2040	2230	3490	3405	3705	3520	3495	3685	3610	3490	3630	16	2655
		MLVSS	mg/L				29		1475	1615	1735	2590	2540	2705	2590	2595	2705	2655	2610	2660	14	2010
		pH	pH Units				6.8			6.8		6.8				6.7		6.9		6.9	7.2	
		Alkalinity	mgCaCO3/L																		101	
		ORP	mV							-350		-30								+100		
		SVI	mL/g																	725		
		P/VSS	%																	6.3		
15	15	COD	mg/L	265	231	227	218	81	25	20	19	12	16	11	12	11	11	18	15	14	19	30
		TKN	mg/L				30.4		14.1	15.1	14.8	8.4	8.4	7.2	3.1	0.9	0.9	0.9	0.9	0.1	0.1	
02MAY89		NH3-N	mg/L				22.0								1.9	0.2	0.0					
		NO2-N	mg/L				0.0		0.1	0.0	0.1	0.0	0.3	0.4	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.3
		NO3-N	mg/L				0.3		0.0	0.1	0.0	0.1	0.1	0.3	3.4	5.9	5.7	8.1	8.3	9.4	9.7	9.1
		P	mg/L	16.2	15.9	17.7	17.7	16.3	27.1	27.5	25.7	21.6	20.8	16.0	15.5	14.4	13.8	13.0	12.8	12.8	13.5	11.2
		MLSS	mg/L				46		2290	2370	2400	6190	4880	4620	4690	4670	5120	4970	4570	4410	11	8610
		MLVSS	mg/L				35		1720	1810	1810	4510	3600	3380	3420	3410	3720	3610	3340	3240	7	6240
		pH	pH Units				7.0		6.9	6.9	6.9	6.9	6.9	6.9	6.7	6.7	6.7	6.6	6.6	6.6	6.8	
		Alkalinity	mgCaCO3/L				166														57	
		ORP	mV							-110		-70								+130		
		SVI	mL/g																	950		
		P/VSS	%																	8.8		
15	10	COD	mg/L	194	180	157	134	66	39	19	25	14	12	20	10	15	9	12	15	17	17	22
		TKN	mg/L				24.5		12.9		10.8	6.5		7.0	3.8	1.0	0.8	0.6			0.2	
08AUG89		NH3-N	mg/L				17.8															
		NO2-N	mg/L				0.0		0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.0	0.1	0.1
		NO3-N	mg/L				0.0		0.1	0.1	0.8	2.8	2.5	2.4	4.3	6.1	8.3	8.9	9.3	9.6	9.5	10.2
		P	mg/L	14.5	14.3	14.3	14.2	14.8	23.8	22.5	20.6	17.9	18.3	17.2	14.5	12.9	12.7	12.1	11.3	10.9	12.6	11.6
		MLSS	mg/L				25		2080	2003	2315	3430	3205	3365	3280	3250	3260	3560	3610	3785	10	6673
		MLVSS	mg/L				19		1597	1507	1740	2525	2410	2465	2425	2355	2400	2625	2670	2755	7	5130
		pH	pH Units				6.9														7.1	
		Alkalinity	mgCaCO3/L																		85	
		ORP	mV							-275		-180								+60		
		SVI	mL/g																	610		
		P/VSS	%																	6.1		

Table B-1 (Continued). Summary of Steady State Data: BNR System (Reactor 1)

MCRT	Temp (C)	Parameter	Units	Inf''' Total	Inf'' Total	Inf' Total	Inf Total	Inf Sol	Sec1 Sol	Sec2 Sol	Sec3 Sol	Sec4 Sol	Sec5 Sol	Sec6 Sol	Sec7 Sol	Sec8 Sol	Sec9 Sol	Sec10 Sol	Sec11 Sol	Sec12 Sol	Eff Sol	RAS Sol
5	20	COD	mg/L	289	202	271	204	76	27	25	24	24	23	24	23	25	25	23	24	24	29	33
		TKN	mg/L	26.7			30.0							6.3	2.9	1.9					0.0	
28MAR90		NH3-N	mg/L				27.5							4.9	2.9	1.1						
		NO2-N	mg/L				0.0		0.1	0.1	0.2	0.3	0.2	0.3	0.5	0.5	0.6	0.2	0.2	0.1	0.4	0.1
		NO3-N	mg/L				0.1		0.4	0.1	0.5	3.2	3.3	4.3	7.4	8.7	9.1	10.8	10.9	11.5	11.0	11.4
		P	mg/L	19.6	20.7	19.5	21.0	19.0	24.5	23.1	21.7	18.2	19.0	16.3	14.4	13.6	13.7	13.3	12.6	12.9	12.8	12.9
		MLSS	mg/L				75		805	925	930	1485	1410	1830	1500	1500	1450	1645	1445	1575	14	2790
		MLVSS	mg/L				69		565	675	665	1020	945	1240	990	995	955	1110	970	1065	10	1860
		pH	pH Units				7.2			7.3			7.2				7.1				7.2	
		Alkalinity	mgCaCO3/L				179														58	
		ORP	mV																			
		SVI	mL/g																	350		
		P/VSS	%																	12.4		
5	15	COD	mg/L	223	205	205	170	92	31	26	24	25	23	22	23	20	25	24	23	27	27	27
		TKN	mg/L	24.6			34.3														6.2	
21NOV89		NH3-N	mg/L	20.1			27.2								10.1						5.9	
		NO2-N	mg/L				0.0		0.0	0.0	0.3	0.6	0.5	0.6	1.3	1.5	1.9	2.3	2.5	2.7	2.5	2.4
		NO3-N	mg/L				0.1		0.1	0.1	0.5	1.8	1.6	1.7	3.0	3.4	4.3	5.5	5.9	6.1	6.3	6.2
		P	mg/L	17.5	17.2	19.1	18.9	17.7	26.8	28.3	26.3	22.9	22.2	22.3	19.3	19.5	18.4	17.9	17.6	17.9	18.5	18.3
		MLSS	mg/L				29		840	910	1120	1510	1515	1630	1590	1580	1560	1745	1625	1875	11	2190
		MLVSS	mg/L				28		690	720	850	1110	1120	1195	1145	1140	1130	1265	1185	1375	8	1575
		pH	pH Units				7.1		7.3		7.2	7.4		7.5	7.7						7.4	
		Alkalinity	mgCaCO3/L				187														96	
		ORP	mV																			
		SVI	mL/g																	210		
		P/VSS	%																	8.7		
5	10	COD	mg/L	351	327	239	213	112	60	54	40	31	30	30	33	24	28	32	24	24	24	24
		TKN	mg/L	33.7			38.0								24.0						21.1	
07DEC89		NH3-N	mg/L				28.4								21.2						19.4	
		NO2-N	mg/L				0.0		0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.2	0.3	0.4	0.5	0.6	0.5	0.7
		NO3-N	mg/L				0.0		0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.2
		P	mg/L	19.1	18.9	17.5	17.7	17.5	19.0	20.6	19.3	19.5	18.7	19.7	16.4	16.7	15.9	15.6	15.5	15.4	15.9	15.4
		MLSS	mg/L				41		785	900	1065	1525	1290	1465	1385	1585	1440	1610	1680	1845	7	2620
		MLVSS	mg/L				34		685	770	915	1300	1105	1250	1200	1335	1220	1380	1420	1555	7	2220
		pH	pH Units				7.0								7.4						7.5	
		Alkalinity	mgCaCO3/L				175														163	
		ORP	mV							-150		-75								+60		
		SVI	mL/g																	420		
		P/VSS	%																	3.2		

Table B-1 (Continued). Summary of Steady State Data: BNR System (Reactor 1)

MCRT	Temp (C)	Parameter	Units	Inf''' Total	Inf'' Total	Inf' Total	Inf Total	Inf Sol	Sec1 Sol	Sec2 Sol	Sec3 Sol	Sec4 Sol	Sec5 Sol	Sec6 Sol	Sec7 Sol	Sec8 Sol	Sec9 Sol	Sec10 Sol	Sec11 Sol	Sec12 Sol	Eff Sol	RAS Sol
2.7	20	COD	mg/L		264	262	240	129	53	49	41	26	25	26	24	24	24	24	25	26	41	27
		TKN	mg/L				31.5								6.8	5.1	5.1				1.6	
11APR90		NH3-N	mg/L				23.8							6.0	5.0	4.1					1.6	
		NO2-N	mg/L				0.0		0.0	0.0	0.0	0.3	0.4	0.0	0.7	1.1	1.1	1.1	1.1	1.1	1.0	1.2
		NO3-N	mg/L				0.0		0.1	0.0	0.1	0.5	0.4	0.8	1.6	2.3	2.8	4.2	4.5	5.0	5.1	4.6
		P	mg/L		17.8	18.8	18.6	17.7	25.1	25.6	24.8	19.7	19.0	17.6	14.4	13.0	12.6	11.5	11.7	11.6	11.6	10.8
		MLSS	mg/L				46		540	567	530	897	830	910	937	1027	1043	1053	963	1070	5	2220
		MLVSS	mg/L				39		433	450	420	673	633	723	700	760	770	763	710	790	5	1630
		pH	pH Units				6.8				7.2			7.4			7.4			7.4	7.4	
		Alkalinity	mgCaCO3/L				180														110	
		ORP	mV																			
		SVI	mL/g																	120		
		P/VSS	%																	9.4		
1.5	20	COD	mg/L	293	270	220	203	100	57	55	43	37	33	30	30	29	29	30	32	29	33	33
		TKN	mg/L				36.6							22.5	21.0	19.5	19.9				16.2	
19APR90		NH3-N	mg/L				29.8							19.9	18.8	15.1	17.0				15.4	
		NO2-N	mg/L				0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.6	0.7	0.8	0.9	0.9	0.9
		NO3-N	mg/L				0.0		0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	1.1	1.3	1.4	1.4	1.1
		P	mg/L	19.4	19.2	19.5	19.5	18.3	20.6	21.3	20.6	19.4	18.8	17.2	16.4	15.3	15.0	14.7	14.7	14.7	14.9	14.3
		MLSS	mg/L				41		302	292	318	423	400	515	500	540	535	595	590	618	11	998
		MLVSS	mg/L				34		250	240	258	340	318	415	405	435	423	468	463	484	8	780
		pH	pH Units				7.2		7.4		7.5			7.6			7.6				7.5	
		Alkalinity	mgCaCO3/L				182														110	
		ORP	mV							-115		-115								-30		
		SVI	mL/g																			
		P/VSS	%																	5.6		

Table B-1 (Continued). Summary of Steady State Data: Conventional System (Reactor 3)

MCRT	Temp (C)	Para meter	Units	Inf''' Total	Inf'' Total	Inf' Total	Inf Total	Inf Sol	Sec1 Sol	Sec2 Sol	Sec3 Sol	Sec4 Sol	Sec5 Sol	Sec6 Sol	Sec7 Sol	Sec8 Sol	Sec9 Sol	Sec10 Sol	Sec11 Sol	Sec12 Sol	Eff Sol	RAS Sol
15	20	COD	mg/L	207	191	379	347	215	52	52	41	46	42	44	39	36	37	37	37	37	35	62
		TKN	mg/L				25.6		6.2	4.9	4.1			1.6			1.4				0.6	
04JUL89		NH3-N	mg/L				17.4															
		NO2-N	mg/L				0.0		1.2	1.3	1.3	1.2	1.1	0.9	0.6	0.6	0.4	0.4	0.4	0.5	0.2	0.4
		NO3-N	mg/L				0.0		5.4	6.7	8.0	9.6	10.6	11.1	11.5	11.7	12.2	12.1	12.2	12.1	13.6	12.1
		P	mg/L	16.9	14.7	15.3	15.2	13.2	13.3	13.1	13.0	12.8	13.0	12.9	13.1	13.2	12.9	12.0	12.7	12.9	13.0	13.3
		MLSS	mg/L				59		1515	1630	1455	1625	1625	1810	1655	1790	1660	1950	1810	1675	23	6050
		MLVSS	mg/L				58		1270	1430	1290	1260	1275	1430	1335	1375	1310	1505	1355	1340	14	4590
		pH	pH Units				6.0			7.0		7.0		7.2		7.1		7.1		7.1	7.2	
		Alkalinity	mgCaCO3/L				108														70	
		ORP	mV																			
		SVI	mL/g																	250		
		P/VSS	%																	1.5		
15	15	COD	mg/L				176	75.0	21	15	17	18	24	19	15	22	19	19	22	20	15	17
		TKN	mg/L				29.3		1.5	1.2	0.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
06MAY89		NH3-N	mg/L							0.0												
		NO2-N	mg/L				0.0		2.5	3.0	1.4	1.5	1.3	1.1	0.9	0.6	0.3	0.3	0.4	0.4	0.0	0.2
		NO3-N	mg/L				0.0		12.4	14.8	19.4	19.3	20.0	21.6	22.3	23.0	23.6	23.8	23.4	23.5	24.1	22.2
		P	mg/L				16.8	16.1	15.4	15.6	15.7	16.0	15.9	16.1	16.1	16.1	16.1	16.2	15.8	15.9	15.3	16.1
		MLSS	mg/L				31		2445	2590	2540	2680	3030	2495	2475	2520	2755	2655	2460	2460	18	4380
		MLVSS	mg/L				31		2045	2170	2115	2250	2505	2080	2070	2105	2310	2215	2085	2115	16	3730
		pH	pH Units				7.0		6.6		6.4			6.4			6.3				6.4	
		Alkalinity	mgCaCO3/L				171													23	23	
		ORP	mV																			
		SVI	mL/g																	410		
		P/VSS	%																	2.3		
15	10	COD	mg/L	225	209	136	123	64	27	29	33	31	32	25	26	25	25	25	25	24	23	27
		TKN	mg/L				25.4		8.6	3.6	1.9	1.7		0.5			0.1				0.0	
10AUG89		NH3-N	mg/L				17.6															
		NO2-N	mg/L				0.0		1.7	1.9	1.8	1.7	0.9	0.4	0.3	0.3	0.3	0.2	0.1	0.2	0.0	0.1
		NO3-N	mg/L				0.1		8.4	11.9	12.9	14.3	17.4	18.2	18.4	18.5	18.5	18.8	18.9	18.8	18.8	18.8
		P	mg/L	15.6	15.5	15.7	15.8	14.5	14.3	14.8	15.0	14.7	14.6	14.8	14.6	14.7	14.6	14.6	14.5	14.5	14.1	14.5
		MLSS	mg/L				30		2255	2825	3265	2975	2770	2670	2505	2440	2430	2520	2370	2330	2	4025
		MLVSS	mg/L				22		1830	2215	2580	2355	2215	2145	2015	1980	1960	1995	1925	1890	1	3330
		pH	pH Units				7.0														6.9	
		Alkalinity	mgCaCO3/L				164														43	
		ORP	mV																	+75		
		SVI	mL/g																	825		
		P/VSS	%																	2.4		

Table B-1 (Continued). Summary of Steady State Data: Conventional System (Reactor 3)

MCRT	Temp (C)	Parameter	Units	Inf''' Total	Inf'' Total	Inf' Total	Inf Total	Inf Sol	Sec1 Sol	Sec2 Sol	Sec3 Sol	Sec4 Sol	Sec5 Sol	Sec6 Sol	Sec7 Sol	Sec8 Sol	Sec9 Sol	Sec10 Sol	Sec11 Sol	Sec12 Sol	Eff Sol	RAS Sol
5	20	COD	mg/L		454	224	201	92	31	33	33	25	29	25	24	25	24	25	25	24	35	25
		TKN	mg/L	30.9			35.0		10.3	7.7	6.0			0.4							0.0	
29MAR90		NH3-N	mg/L				28.9		7.4	6.4	5.2			0.2								
		NO2-N	mg/L				0.0		1.4	1.5	1.4	1.3	1.0	0.7	0.6	0.4	0.3	0.1	0.1	0.2	0.1	0.0
		NO3-N	mg/L				0.3		11.1	13.4	14.7	17.4	18.6	19.8	21.1	21.7	21.7	21.9	22.2	21.9	21.4	21.5
		P	mg/L	20.8	20.7	20.4	20.1	19.1	18.7	18.6	18.3	18.7	18.4	17.8	18.5	18.6	18.7	18.7	19.2	19.3	18.5	18.5
		MLSS	mg/L				33		1360	1725	1535	1635	1470	1315	1320	1305	1270	1435	1800	1615	19	2395
		MLVSS	mg/L				30		1175	1480	1340	1415	1260	1140	1135	1115	1085	1245	1645	1375	16	2070
		pH	pH Units				7.3		7.0			6.8				6.6				6.6	6.8	
		Alkalinity	mgCaCO3/L				175														24	
		ORP	mV																			
		SVI	mL/g																	70		
		P/VSS	%																	1.9		
5	15	COD	mg/L	142		100	77	29	34	17	9	7	10	8	6	5	5	4	5	5	4	2
		TKN	mg/L	24.2			28.9														0.0	
20NOV89		NH3-N	mg/L				24.1															
		NO2-N	mg/L				0.0		1.3	1.7	2.0	2.2	2.4	2.4	2.2	2.1	2.2	1.4	1.4	0.7	1.4	0.8
		NO3-N	mg/L				0.1		14.3	15.2	16.8	17.5	19.5	21.0	21.8	23.2	23.7	25.9	26.0	27.2	26.0	26.6
		OP	P	17.9	18.2	18.3	18.2	17.5	17.6	18.2	17.5	17.4	17.6	17.8	17.5	17.6	17.6	17.6	17.7	18.0	17.6	17.9
		MLSS	mg/L				19		1600	1863	857	1170	1053	1300	1030	1037	1060	1340	1243	1303	3	1835
		MLVSS	mg/L				16		1353	1570	727	997	893	1093	873	877	897	1143	1063	1110	3	1585
		pH	pH Units				7.4		7.7	7.7				7.1							7.0	
		Alkalinity	mgCaCO3/L				212														34	
		ORP	mV																			
		SVI	mL/g																	190		
		P/VSS	%																	2.9		
5	10	COD	mg/L	344	313	211	195	94	40	36	36	35	35	31	31	31	31	40	31	34	36	30
		TKN	mg/L	31.2			31.8		17.2												9.9	
08DEC89		NH3-N	mg/L				23.2		14.3												8.1	
		NO2-N	mg/L				0.0		1.2	1.8	1.7	1.9	2.0	2.3	2.3	2.4	2.2	2.3	2.3	2.4	2.0	2.3
		NO3-N	mg/L				0.0		3.9	4.9	4.6	5.6	6.6	7.5	8.1	9.0	9.1	10.0	10.0	10.5	10.6	10.5
		OP	P	18.4	18.4	18.6	18.5	18.1	17.7	17.4		17.6	17.7	17.5	17.5	17.4	18.0	17.5	17.2	17.6	17.8	17.1
		MLSS	mg/L				34		1785	1740	1680	1865	1765	1430	1355	1460	1445	1455	1275	1810	2	2260
		MLVSS	mg/L				29		1540	1505	1460	1600	1515	1240	1175	1270	1255	1250	1095	1570	2	1925
		pH	pH Units				7.3		7.4												7.2	
		Alkalinity	mgCaCO3/L				175														80	
		ORP	mV																	+90		
		SVI	mL/g																	225		
		P/VSS	%																	2.6		

Table B-1 (Continued). Summary of Steady State Data: Conventional System (Reactor 3)

MCRT	Temp (C)	Parameter	Units	Inf''' Total	Inf'' Total	Inf' Total	Inf Total	Inf Sol	Sec1 Sol	Sec2 Sol	Sec3 Sol	Sec4 Sol	Sec5 Sol	Sec6 Sol	Sec7 Sol	Sec8 Sol	Sec9 Sol	Sec10 Sol	Sec11 Sol	Sec12 Sol	Eff Sol	RAS Sol
2.7	20	COD	mg/L	296	271	256	206	98	29	33	31	31	27	29	26	25	29	31	25	27	37	25
		TKN	mg/L				34.3		11.6	10.0	8.4			4.2							0.0	
10APR90		NH3-N	mg/L				26.0		11.0	10.0	8.3											
		NO2-N	mg/L				0.0		1.1	1.4	1.3	1.1	1.1	1.1	2.0	1.1	1.0	0.9	0.7	0.7	0.7	0.5
		NO3-N	mg/L				0.2		11.4	12.1	12.8	14.8	16.4	18.1	19.4	19.6	20.1	21.1	21.5	21.7	21.0	21.6
		OP	P	18.6	18.5	19.2	18.9	17.7	17.6	17.8	17.6	17.8	16.9	17.6	16.9	17.5	17.5	17.1	17.3	17.6	16.8	17.5
		MLSS	mg/L				41		920	1130	813	967	730	666	610	597	660	707	600	760	2	925
		MLVSS	mg/L				35		790	960	690	833	627	580	530	513	577	620	530	647	2	805
		pH	pH Units				7.0		7.3	7.3	7.3			7.1							7.1	
		Alkalinity	mgCaCO3/L				179														37	
		ORP	mV																			
		SVI	mL/g																	180		
		P/VSS	%																	3.1		
1.5	20	COD	mg/L	450	358	222	196	95	37	36	33	32	31	31	31	31	29	29	28	30	31	31
		TKN	mg/L				36.6		17.9	15.8	15.4			11.6							6.4	
17APR90		NH3-N	mg/L				30.0				12.0			10.2							5.6	
		NO2-N	mg/L				0.0		1.0	1.0	1.0	1.1	1.0	1.2	1.1	1.3	1.3	1.2	1.2	1.1	1.0	1.1
		NO3-N	mg/L				0.0		6.6	7.1	7.8	9.3	10.8	12.0	12.3	13.2	13.6	14.8	15.0	15.2	14.5	15.3
		OP	P	19.7	19.1	19.2	19.1	17.6	18.1	18.3	17.9	18.2	17.2	17.8	17.8	17.5	17.4	18.0	17.3	18.0	17.2	17.6
		MLSS	mg/L				39		462	524	560	654	474	406	444	428	428	510	344	466	10	450
		MLVSS	mg/L				32		392	462	490	572	420	368	402	392	382	472	314	424	9	403
		pH	pH Units				7.2		7.6	7.6	7.5			7.5			7.4				7.3	
		Alkalinity	mgCaCO3/L				200														77	
		ORP	mV																	-25		
		SVI	mL/g																			
		P/VSS	%																	3.9		

Appendix C

Summary of Raw Data

Table C-1. Raw Data: COD Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
1	20FEB89	7			146	124	64			29			25						36	28
	24FEB89	11				230	88			33			34							31
	01MAR89	16				231				30			33							16
	06MAR89	21				145	71			33			23			21			22	27
	08MAR89	23			363	282	120													
	09MAR89	24			273	241	120	31	28	24	15	22	18	14	22	14	19	23	20	22
	10MAR89	25			261	240	109													
2	15MAR89	30	236		204	184	72			32			28						28	28
	22MAR89	37			275	169	66			24			18						26	14
	28MAR89	43				300	124			25			18						24	25
	03APR89	49			130					13			8						1	6
	07APR89	53			277					22	22		>13			19			16	20
	12APR89	58	496	426	228	306	98			11			8						11	12
	17APR89	63	291	263	235	233	78			27			17						17	16
	26APR89	72	360	352	376	368	178			33	21		17			15			18	20
	02MAY89	78	265	231	227	218	84	25	20	19	12	16	11	12	11	11	18	15	14	19
	03MAY89	79	234		202	164	77													
	06MAY89	82				176	75													
	12MAY89	88		222	218	213				33			37							25
	20MAY89	96	182	149	175	116				37			25						25	25
	25MAY89	101	249			206				28			37						28	34
	01JUN89	108	284	270	223	197				31			23						23	23
3	07JUN89	114	223	280	188	185	85			70			34						54	27
	12JUN89	119	250	226	108	95	51			21			18	21					20	20
	16JUN89	123	267	205	190		100			33			26						31	23
	21JUN89	128	425	283	197	192	88			23			19						13	22
	26JUN89	133	290			68	27			17			12	17					14	17
	30JUN89	137	258	237	274	229	138			21			16	25					9	11
	02JUL89	139	219	191	140	118	60													
	03JUL89	140		207	146	142	60	17	17	12	8	8	8	16	8	7	8	8	8	12
	04JUL89	141	207	191	379	347	215													
4	12JUL89	149	229	208	250	227	119			32			30	31					27	34
	17JUL89	154	307	280	141	117	66			21			22	25					18	17
	21JUL89	158	263	259	190	178	69			17			12	13					18	14
	26JUL89	163	314	306	224	199	99			23			15	20		30			19	13
	31JUL89	168	232		73	65	36			6			8	14		13			12	8
	03AUG89	171	215	211	152					26			17	18		14			21	14
	07AUG89	175	245	216	75		47			15			20	19		17			19	17
	08AUG89	176	194	180	157	134	66	39	19	25	14	12	20	10	15	9	12	15	17	17
	09AUG89	177	230	203	136	118	58													
	10AUG89	178	225	209	136	123	64													

Table C-1 (Continued). Raw Data: COD Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
5	21AUG89	189	258	238	187					21			17						16	10
	25AUG89	193	567	482	229	193	105			25			18						15	15
	29AUG89	197	443	402	215	182	95	38	33	31	38		32	40					48	48
	01SEP89	200	403	320		270	146			38										22
	06SEP89	205	494	463	266	230	123	30		24			16						16	12
	11SEP89	210		365	114	107				15			11						11	15
	15SEP89	214	288	258	212	189	85	21	16	9			13						8	7
	20SEP89	219	393	351	217	201				31			37						34	30
	25SEP89	224	211		78	63				12			9						8	9
	27SEP89	226	632	587	102	81	40	15	19	12	16		16	10					20	20
	28SEP89	227	330	273	183	159	78													
	05OCT89	234	351	351	189	170				5			5						5	7
	12OCT89	241	455			166				18			12						12	12
6	18OCT89	247	308	275	211	184				12			11						10	15
	23OCT89	252	272	258	77	64				6			2						4	8
	25OCT89	254	284	259	185	171	75			9			8						18	
	27OCT89	256	363	327	193	160	52			15			4						9	15
	31OCT89	260	457		220	193	72													
	01NOV89	261	379	362	227	194	87	22	19	15	16	16	15	15	14	16	16	16	13	21
	02NOV89	262	458	422	272	223														
7	08NOV89	268	597	539	298	252				34			26						27	38
	09NOV89	269	326	290	288	253														
	13NOV89	273	300	273	120	91				13			8						11	23
	17NOV89	277		408	108	82				6			6						12	12
	20NOV89	280	142		100	77	29													
	21NOV89	281	223	205	205	170	92	31	26	24	25	23	22	23	20	25	24	23	27	27
8	29NOV89	289	338	309	213	183	183			27			22						27	34
	01DEC89	291	247	227	299	275				48			37						40	40
	05DEC89	295	267	233	226	239				15			11						15	4
	07DEC89	297	351	327	239	213	112	60	54	40	31	30	30	33	24	28	32	24	24	24
	08DEC89	298	344	313	211	195	94													
9	12DEC89	302	449	432	309					67			32						32	34
	14DEC89	304	534	528	294	292				82			41						27	25
	18DEC89	308		297	182	179				50			23						21	25
	21DEC89	311	356	327	321	297				77			42						34	30
10	27DEC89	317	201	188	135	110				34			18						18	19
	30DEC89	320	234	213	133	115				27			24						24	33
	03JAN90	324	145	139	65	57				25			25						29	12
	05JAN90	326	291	214	141	117				26			23						17	27

Table C-1 (Continued). Raw Data: COD Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
11	10JAN90	331	458	392	229	214				68			30						28	28
	13JAN90	334	346	425	328	328				86			50						30	37
	16JAN90	337	387	354	325	288				74			36						25	20
	20JAN90	341	387	322	442	393				116			59						39	37
	23JAN90	344	360	337	424	401	277													
	24JAN90	345		374		295	205	126	118	99	76	94	53	43	41	45	41		47	44
	26JAN90	347	559	477	278	275	174													
12	31JAN90	352	253	213	312	318				75			68						23	23
	05FEB90	357	287	271	175	129				35			26						32	29
	08FEB90	360	343	324	316	281				78			41						25	30
	12FEB90	364	337	306	141	124				46			23						31	39
	16FEB90	368	322	286	320	281				84			42						41	41
	20FEB90	372	520	461	286	258				71			33						30	29
	24FEB90	376	325	280	278	252				55			26						26	41
	27FEB90	379	428	380	277	251														
	01MAR90	381	361	326	269	239	130			26			16						22	
	06MAR90	386	275	250	97	75				18			19						23	26
	09MAR90	389	251	220	211	181				24			23						26	32
	13MAR90	393	216	182	342					57			20						19	22
	16MAR90	396	176	152	168	141				20			14						14	15
	20MAR90	400	409	374	205	156				19			19						18	21
	22MAR90	402	463	430	222	199				24			19						22	17
	26MAR90	406	240	226	79	70	27			10			19						16	15
	28MAR90	408	289	202	271	214	76	27	25	24	24	23	24	23	25	25	23	24	24	29
	29MAR90	409		454	224	201	92													
13	03APR90	414	212	190	208	184				18			14						14	17
	06APR90	417	252	221	214	197				30			27						35	51
	10APR90	421	296	271	256	206	98													
	11APR90	422		264	262	240	129	53	49	41	26	25	26	24	24	24	24	25	26	41
14	13APR90	424	301	278	406	378				87			34						29	30
	17APR90	428	450	358	222	196	95													
	18APR90	429	409	373	270	244														
	19APR90	430	293	270	220	203	100	57	55	43	37	33	30	30	29	29	30	32	29	33

Table C-1 (Continued). Raw Data: COD Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
1	20FEB89	7			146	124	64			29			46						37	25
	24FEB89	11				230	88			27			25							23
	01MAR89	16				231				18			18							13
	06MAR89	21				145	71			23			11			60			19	16
	08MAR89	23			282	181	120	38	33	23	15	31	15	13	13	15	14	15	20	15
	09MAR89	24			273	241	120													
	10MAR89	25			261	240	109													
2	15MAR89	30	236		204	184	72			36			20						26	24
	22MAR89	37			275	169	66			29			23						22	23
	28MAR89	43				300	124			29			24						21	16
	03APR89	49			130					16			8						9	3
	07APR89	53			277					21			16						13	13
	12APR89	58	496	426	228	306	98			21			16						11	33
	17APR89	63	291	263	235	233	78			22			24						21	15
	26APR89	72	360	352	376	368	178			29			17						17	18
	02MAY89	78	265	231	227	218	84													
	03MAY89	79	234		202	164	77	23	20	24	20	18	17	15	17	18	15	15	19	20
	06MAY89	82				176	75													
	12MAY89	88		222	218	213				33			33							25
	20MAY89	96	182	149	175	116				29			29						22	21
	25MAY89	101	249			206				41									32	28
	01JUN89	108	284	270	223	197				52			52						27	21
3	07JUN89	114	223	280	188	185	85			34									22	20
	12JUN89	119	250	226	108	95	51			23			21						19	21
	16JUN89	123	267	205	190		100			30			27						23	26
	21JUN89	128	425	283	197	192	88			26			17						16	13
	26JUN89	133	290			68	27			15			17						13	13
	30JUN89	137	258	237	274	229	138			17			12						10	8
	02JUL89	139	219	191	140	118	60	18	10	10	12	8	8	11	10	14	10	16	16	26
	03JUL89	140		207	146	142	60													
	04JUL89	141	207	191	379	347	215													
4	12JUL89	149	229	208	250	227	119			38			35						31	27
	17JUL89	154	307	280	141	117	66			22			22						21	18
	21JUL89	158	263	259	190	178	69			18			12						12	12
	26JUL89	163	314	306	224	199	99			24			20						18	15
	31JUL89	168	232		73	65	36			8			10						7	8
	03AUG89	171	215	211	152					25			18						18	12
	07AUG89	175	245	216	75		47			21			20						20	21
	08AUG89	176	194	180	157	134	66													
	09AUG89	177	230	203	136	118	58	27	22	33	17	17	19	18	18	19	17	17	17	19
	10AUG89	178	225	209	136	123	64													

Table C-1 (Continued). Raw Data: COD Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
5	21AUG89	189	258	238	187					30			17						17	13
	25AUG89	193	567	482	229	193	105			34			21						18	15
	29AUG89	197	443	402	215	182	95			40			30						38	29
	01SEP89	200	403	320		270	146			38										18
	06SEP89	205	494	463	266	230	123			21			18						11	11
	11SEP89	210		365	114	107				23			16						15	11
	15SEP89	214	288	258	212	189	85			14			10						8	9
	20SEP89	219	393	351	217	201				39			31						32	30
	25SEP89	224	211		78	63				15			13						16	9
	27SEP89	226	632	587	102	81	40													
	28SEP89	227	330	273	183	159	78													
	05OCT89	234	351	351	189	170				13									4	16
	12OCT89	241	455			166				19			12						11	28
6	18OCT89	247	308	275	211	184				20			12						14	9
	23OCT89	252	272	258	77	64				11			6						7	19
	25OCT89	254	284	259	185	171	75			13			9						9	20
	27OCT89	256	363	327	193	160	52													
	31OCT89	260	457		220	193	72													
	01NOV89	261	379	362	227	194	87													
	02NOV89	262	458	422	272	223		21	25	31			25	21					33	28
7	08NOV89	268	597	539	298	252				33			30						25	26
	09NOV89	269	326	290	288	253		22	14	12			4						9	16
	13NOV89	273	300	273	120	91				8			14						11	11
	17NOV89	277		408	108	82				9			8						0	6
	20NOV89	280	142		100	77	29													
	21NOV89	281	223	205	205	170	92													
8	29NOV89	289	338	309	213	183	183			19			16						16	15
	01DEC89	291	247	227	299	275				37			31						25	30
	05DEC89	295	267	233	226	239				12			0						4	0
	07DEC89	297	351	327	239	213	112													
	08DEC89	298	344	313	211	195	94													
9	12DEC89	302	449	432	309					54			24						17	22
	14DEC89	304	534	528	294	292				61			58						12	21
	18DEC89	308		297	182	179				27			11						17	11
	21DEC89	311	356	327	321	297				49			24						23	19
10	27DEC89	317	201	188	135	110				20			18						20	10
	30DEC89	320	234	213	133	115				21			19						18	16
	03JAN90	324	145	139	65	57				12			29						12	16
	05JAN90	326	291	214	141	117				13			13						13	12

Table C-1 (Continued). Raw Data: COD Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
11	10JAN90	331	458	392	229	214							21						33	29
	13JAN90	334	346	425	328	328				39			15						17	15
	16JAN90	337	387	354	325	288				16			11						7	13
	20JAN90	341	387	322	442	393				46			26						18	16
	23JAN90	344	360	337	424	401	277	109	98	52	25	22	21	16	16	24	24	18	21	21
	24JAN90	345		374		295	205													
	26JAN90	347	559	477	278	275	174													
12	31JAN90	352	253	213	312	318				18			12						18	16
	05FEB90	357	287	271	175	129				13			13						15	17
	08FEB90	360	343	324	316	281				15			14						12	17
	12FEB90	364	337	306	141	124				16			11						11	14
	16FEB90	368	322	286	320	281				20			16						15	15
	20FEB90	372	520	461	286	258				14			12						12	13
	24FEB90	376	325	280	278	252				11			11						22	11
	27FEB90	379	428	380	277	251														
	01MAR90	381	361	326	269	239	130			13			10						9	
	06MAR90	386	275	250	97	75				10			10						10	8
	09MAR90	389	251	220	211	181				23			9						9	9
	13MAR90	393	216	182	342					34			16						13	18
	16MAR90	396	176	152	168	141				14			10						10	10
	20MAR90	400	409	374	205	156				15			13						10	14
	22MAR90	402	463	430	222	199				17									14	14
	26MAR90	406	240	226	79	70	27	14	13	12	8		11	8						8
	28MAR90	408	289	202	271	214	76													
	29MAR90	409		454	224	201	92													
13	03APR90	414	212	190	208	184				8			6						9	7
	06APR90	417	252	221	214	197				18			17						16	11
	10APR90	421	296	271	256	206	98													
	11APR90	422	264	262	240	129	129													
14	13APR90	424	301	278	406	378				34			31						26	17
	17APR90	428	450	358	222	196	95													
	18APR90	429	409	373	270	244				17			12						14	20
	19APR90	430	293	270	220	203	100													

Table C-1 (Continued). Raw Data: COD Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
1	20FEB89	7			146	124	64			79			37						50	83
	24FEB89	11				230	88			42			42							58
	01MAR89	16				231				34			35							52
	06MAR89	21				145	71			31			39			35			33	43
	08MAR89	23			282	181	120													
	09MAR89	24			273	241	120													
	10MAR89	25			261	240	109	36	31	35	30	30	29	33	36	30	28	31	38	29
2	15MAR89	30	236		204	184	72			28			24						32	20
	22MAR89	37			275	169	66			25			23						21	25
	28MAR89	43				300	124			25			33						25	25
	03APR89	49			130					2									40	25
	07APR89	53			277					22			245						13	21
	12APR89	58	496	426	228	306	98			20			16						19	20
	17APR89	63	291	263	235	233	78			16			13						14	30
	26APR89	72	360	352	376	368	178			23			21						17	22
	02MAY89	78	265	231	227	218	84												19	
	03MAY89	79	234		202	164	77													
	06MAY89	82				176	75	21	15	17	18	24	19	15	22	19	19	22	20	15
	12MAY89	88		222	218	213														29
	20MAY89	96	182	149	175	116							23						23	23
	25MAY89	101	249			206							26						31	37
	01JUN89	108	284	270	223	197							23						25	23
3	07JUN89	114	223	280	188	185	85			21			22						21	21
	12JUN89	119	250	226	108	95	51	29		20			20						15	21
	16JUN89	123	267	205	190		100			32			26						22	28
	21JUN89	128	425	283	197	192	88			22			23						22	30
	26JUN89	133	290			68	27	39		31			29						22	34
	30JUN89	137	258	237	274	229	138	49		43			41						32	37
	02JUL89	139	219	191	140	118	60													
	03JUL89	140		207	146	142	60													
	04JUL89	141	207	191	379	347	215	52	52	41	46	42	44	39	36	37	37	37	37	35
4	12JUL89	149	229	208	250	227	119	55		54			55						47	45
	17JUL89	154	307	280	141	117	66	34		40			33						33	23
	21JUL89	158	263	259	190	178	69	28		21			24						24	26
	26JUL89	163	314	306	224	199	99	30		27			25						23	15
	31JUL89	168	232		73	65	36	26		18									13	17
	03AUG89	171	215	211	152			27		26			17						17	16
	07AUG89	175	245	216	75		47	25		22			19						26	21
	08AUG89	176	194	180	157	134	66													
	09AUG89	177	230	203	136	118	58													
	10AUG89	178	225	209	136	123	64	27	29	33	31	32	25	26	25	25	25	25	24	23

Table C-1 (Continued). Raw Data: COD Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
5	21AUG89	189	258	238	187														17	31
	25AUG89	193	567	482	229	193	105												28	25
	29AUG89	197	443	402	215	182	95	52		50										32
	01SEP89	200	403	320		270	146	42		34										38
	06SEP89	205	494	463	266	230	123	37	36											19
	11SEP89	210		365	114	107				19									17	21
	15SEP89	214	288	258	212	189	85	16	16											13
	20SEP89	219	393	351	217	201		36		34										55
	25SEP89	224	211		78	63		29	13	14			14						12	14
	27SEP89	226	632	587	102	81	40													
	28SEP89	227	330	273	183	159	78	19	19	19			16						14	19
	05OCT89	234	351	351	189	170							13							21
	12OCT89	241	455			166							19							11
6	18OCT89	247	308	275	211	184							18							17
	23OCT89	252	272	258	77	64		15		17										9
	25OCT89	254	284	259	185	171	75	28	24	24			24							20
	27OCT89	256	363	327	193	160	52	32	25	27			21							21
	31OCT89	260	457		220	193	72	32	32	29	28	32	28	32	32	27	32	25	29	39
	01NOV89	261	379	362	227	194	87													
	02NOV89	262	458	422	272	223														
7	08NOV89	268	597	539	298	252		48		50										38
	09NOV89	269	326	290	288	253														
	13NOV89	273	300	273	120	91		20	20				20							34
	17NOV89	277		408	108	82		18	19				19							18
	20NOV89	280	142		100	77	29	34	17	9	7	10	8	6	5	5	4	5	5	4
	21NOV89	281	223	205	205	170	92													
8	29NOV89	289	338	309	213	183	183	29												21
	01DEC89	291	247	227	299	275		57												39
	05DEC89	295	267	233	226	239		28	19											12
	07DEC89	297	351	327	239	213	112													
	08DEC89	298	344	313	211	195	94	40	36	36	35	35	31	31	31	31	40	31	34	36
9	12DEC89	302	449	432	309			45												22
	14DEC89	304	534	528	294	292		33												27
	18DEC89	308		297	182	179		23												19
	21DEC89	311	356	327	321	297		45					34							28
10	27DEC89	317	201	188	135	110		24												11
	30DEC89	320	234	213	133	115		35												20
	03JAN90	324	145	139	65	57		25												12
	05JAN90	326	291	214	141	117		20												17

Table C-1 (Continued). Raw Data: COD Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' TCOD mg/L	Inf'' TCOD mg/L	Inf' TCOD mg/L	Inf TCOD mg/L	Inf SCOD mg/L	Sec1 SCOD mg/L	Sec2 SCOD mg/L	Sec3 SCOD mg/L	Sec4 SCOD mg/L	Sec5 SCOD mg/L	Sec6 SCOD mg/L	Sec7 SCOD mg/L	Sec8 SCOD mg/L	Sec9 SCOD mg/L	Sec10 SCOD mg/L	Sec11 SCOD mg/L	Sec12 SCOD mg/L	Eff SCOD mg/L
11	10JAN90	331	458	392	229	214		24												21
	13JAN90	334	346	425	328	328		30												22
	16JAN90	337	387	354	325	288		28												18
	20JAN90	341	387	322	442	393		34												25
	23JAN90	344	360	337	424	401	277													
	24JAN90	345		374		295	205													
	26JAN90	347	559	477	278	275	174	30	28	32	28	26	28	28	28	27	25	30	26	31
12	31JAN90	352	253	213	312	318		21		21										15
	05FEB90	357	287	271	175	129		17		17										13
	08FEB90	360	343	324	316	281		29		26										21
	12FEB90	364	337	306	141	124		20		21										20
	16FEB90	368	322	286	320	281		51		57										47
	20FEB90	372	520	461	286	258		49		47										41
	24FEB90	376	325	280	278	252		41		43										41
	27FEB90	379	428	380	277	251														
	01MAR90	381	361	326	269	239	130	33		30										28
	06MAR90	386	275	250	97	75		22		20										19
	09MAR90	389	251	220	211	181		30		28										24
	13MAR90	393	216	182	342			28		27										20
	16MAR90	396	176	152	168	141		25		23										23
	20MAR90	400	409	374	205	156		31		28										
	22MAR90	402	463	430	222	199		29		27										35
	26MAR90	406	240	226	79	70	27	24		16										35
	28MAR90	408	289	202	271	214	76													
	29MAR90	409		454	224	201	92	31	33	33	25	29	25	24	25	24	25	25	24	35
13	03APR90	414	212	190	208	184		15		17										21
	06APR90	417	252	221	214	197		27		27										18
	10APR90	421	296	271	256	206	98	29	33	31	31	27	29	26	25	29	31	25	27	37
	11APR90	422	264	262	240	129	129													
14	13APR90	424	301	278	406	378		40		34										47
	17APR90	428	450	358	222	196	95	37	36	33	32	31	31	31	31	29	29	28	30	31
	18APR90	429	409	373	270	244														26
	19APR90	430	293	270	220	203	100													

Table C-2. Raw Data: TKN Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7		35.8													22.4
	24FEB89	11		33.3													24.0
	01MAR89	16		35.5													21.5
	06MAR89	21		33.0													18.9
	08MAR89	23		36.9													
	09MAR89	24		36.4													22.7
	10MAR89	25		35.8													
2	15MAR89	30		30.8													16.0
	22MAR89	37		40.8													4.8
	03APR89	49		24.7													0.5
	07APR89	53		37.4													1.0
	17APR89	63		34.7													0.4
	21APR89	67		39.7									1.3				0.0
	26APR89	72		43.0						8.2			2.0				0.3
	02MAY89	78		30.4	14.1	15.1	14.8	8.4	8.4	7.2	3.1	0.9	0.9	0.9	0.9	0.1	0.1
	03MAY89	79		22.8													
	06MAY89	82		29.3													
	12MAY89	88		23.6													0.3
	20MAY89	96		25.1													0.0
	25MAY89	101		31.9													1.0
	01JUN89	108		27.2													1.0
3	07JUN89	114		31.2													0.3
	12JUN89	119		27.0													0.0
	16JUN89	123		27.7													0.1
	21JUN89	128		25.7													0.0
	26JUN89	133		14.8							0.9						0.8
	30JUN89	137		31.3							2.9						0.4
	02JUL89	139		20.3													
	03JUL89	140		22.4			10.4			5.2	0.9		0.5				0.1
	04JUL89	141		25.6													
4	12JUL89	149		27.4							2.7						0.6
	17JUL89	154		13.3							0.9						0.6
	21JUL89	158		25.7							3.9						1.2
	26JUL89	163		30.1							6.0						1.2
	31JUL89	168		16.8							1.8						0.1
	03AUG89	171	28.9	27.5							3.3						0.4
	07AUG89	175		19.0							2.6						0.0
	08AUG89	176		24.5	12.9		10.8	6.5		7.0	3.8	1.0	0.8	0.6			0.2
	09AUG89	177		23.4													
	10AUG89	178		25.4													
5	29AUG89	197		38.8													0.0
	01SEP89	200	28.2	32.7													
	06SEP89	205		41.8													0.0
	11SEP89	210		27.2													0.0
	15SEP89	214	31.3	39.4													0.0
	20SEP89	219	27.3	33.4													0.0
	25SEP89	224	21.7	18.2													0.0
	27SEP89	226		22.3						4.9	2.2						0.3
	28SEP89	227	22.6	30.1													
	05OCT89	234	35.4	29.7													0.0
	06OCT89	235		58.5													0.2
	12OCT89	241	27.2														0.1
6	18OCT89	247	26.7	33.5													0.0
	23OCT89	252		19.1													0.0
	25OCT89	254		29.5													0.0
	27OCT89	256		27.9													0.0
	31OCT89	260	29.6	34.5													
	01NOV89	261		33.3							0.4	0.4	0.4				0.4
	02NOV89	262	30.6	33.6													
	03NOV89	263		35.9							4.2						0.7

Table C-2 (Continued). Raw Data: TKN Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
7	08NOV89	268		36.8													5.3
	09NOV89	269		37.4													
	13NOV89	273	24.7	23.5													1.4
	17NOV89	277	25.1	17.3													0.8
	20NOV89	280	24.2	28.9													
	21NOV89	281	24.6	34.3							10.5	9.9					6.2
8	29NOV89	289		31.8													15.6
	01DEC89	291		36.1													17.9
	05DEC89	295	31.8	35.6													19.8
	07DEC89	297	33.7	38.0							24.0						21.1
	08DEC89	298	31.2	31.8													
9	12DEC89	302		31.5													14.0
	14DEC89	304		28.2													10.4
	18DEC89	308		17.3													5.5
	21DEC89	311		29.4													11.5
10	03JAN90	324		12.7													0.0
	05JAN90	326		20.8													0.4
11	10JAN90	331		28.0													7.2
	13JAN90	334		36.6													14.0
	16JAN90	337	27.7	37.2													16.0
	20JAN90	341		32.9													12.3
	23JAN90	344	24.8	35.5													
	24JAN90	345	27.6	37.8						19.7	19.6	19.4					17.1
	26JAN90	347		32.3													
12	31JAN90	352		35.3													8.8
	05FEB90	357		13.8													1.1
	08FEB90	360		31.9													15.7
	13FEB90	365		29.6													16.2
	16FEB90	368		34.0													21.2
	20FEB90	372		14.8													8.9
	24FEB90	376		22.8													18.2
	01MAR90	381		30.8													6.4
	06MAR90	386		19.3													0.4
	09MAR90	389		32.0													0.6
	13MAR90	393		20.1													0.4
	16MAR90	396		25.7													0.0
	20MAR90	400		32.7													4.0
	22MAR90	402		35.2													7.3
	26MAR90	406		20.5													0.0
	28MAR90	408	26.7	30.0						6.3	2.9	1.9					0.0
	29MAR90	409	30.9	35.0													
13	03APR90	414		31.5													3.9
	06APR90	417	30.4														4.2
	10APR90	421		34.3													
	11APR90	422		31.5							6.8	5.1	5.1				1.6
14	13APR90	424		31.1													4.2
	16APR90	427															1.8
	17APR90	428		36.6													
	19APR90	430		36.6						22.5	21.0	19.5	19.9				16.2

Table C-2 (Continued). Raw Data: TKN Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7		35.8													21.9
	24FEB89	11		33.3													24.6
	01MAR89	16		35.5													19.9
	06MAR89	21		33.0													17.2
	08MAR89	23		36.9													22.4
	09MAR89	24		36.4													
	10MAR89	25		35.8													
2	15MAR89	30		30.8													15.8
	22MAR89	37		40.8													3.5
	03APR89	49		24.7													0.4
	07APR89	53		37.4													1.4
	17APR89	63		34.7													0.1
	21APR89	67		39.7													0.2
	26APR89	72		43.0													0.5
	02MAY89	78		30.4													
	03MAY89	79		22.8			11.2		5.4		2.2		0.9			0.9	0.6
	06MAY89	82		29.3													
	12MAY89	88		23.6													0.3
	20MAY89	96		25.1													0.3
	25MAY89	101		31.9													0.5
	01JUN89	108		27.2													1.3
3	07JUN89	114		31.2													0.6
	12JUN89	119		27.0													0.0
	16JUN89	123		27.7													0.5
	21JUN89	128		25.7													0.3
	26JUN89	133		14.8													0.8
	30JUN89	137		31.3													1.2
	02JUL89	139		20.3			8.4			3.8	1.2		0.3				0.0
	03JUL89	140		22.4													
	04JUL89	141		25.6													
4	12JUL89	149		27.4													0.8
	17JUL89	154		13.3													0.6
	21JUL89	158		25.7													0.7
	26JUL89	163		30.1													1.6
	31JUL89	168		16.8													0.0
	03AUG89	171	28.9	27.5													0.8
	07AUG89	175		19.0													0.0
	08AUG89	176		24.5													
	09AUG89	177		23.4			13.6			7.7	5.0	3.9	2.7				0.0
	10AUG89	178		25.4													
5	29AUG89	197		38.8													0.0
	01SEP89	200	28.2	32.7													
	06SEP89	205		41.8													0.0
	11SEP89	210		27.2													0.0
	15SEP89	214	31.3	39.4													0.0
	20SEP89	219	27.3	33.4													0.0
	25SEP89	224	21.7	18.2													0.0
	27SEP89	226		22.3													
	28SEP89	227	22.6	30.1													
	05OCT89	234	35.4	29.7													0.0
	06OCT89	235		58.5													
	12OCT89	241	27.2														0.2
6	18OCT89	247	26.7	33.5													0.0
	23OCT89	252		19.1													0.0
	25OCT89	254		29.5													0.0
	27OCT89	256		27.9													
	31OCT89	260	29.6	34.5													
	01NOV89	261		33.3													
	02NOV89	262	30.6	33.6													0.0
	03NOV89	263		35.9													

Table C-2 (Continued). Raw Data: TKN Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
7	08NOV89	268		36.8													0.3
	09NOV89	269		37.4													1.0
	13NOV89	273	24.7	23.5													0.4
	17NOV89	277	25.1	17.3													0.9
	20NOV89	280	24.2	28.9													
	21NOV89	281	24.6	34.3													
8	29NOV89	289		31.8													0.0
	01DEC89	291		36.1													3.3
	05DEC89	295	31.8	35.6													7.0
	07DEC89	297	33.7	38.0													
	08DEC89	298	31.2	31.8													
9	12DEC89	302		31.5													2.6
	14DEC89	304		28.2													1.8
	18DEC89	308		17.3													0.0
	21DEC89	311		29.4													5.0
10	03JAN90	324		12.7													0.0
	05JAN90	326		20.8													0.5
11	10JAN90	331		28.0													1.4
	13JAN90	334		36.6													1.6
	16JAN90	337	27.7	37.2													0.2
	20JAN90	341		32.9													0.0
	23JAN90	344	24.8	35.5						9.5	5.6	5.5					0.8
	24JAN90	345	27.6	37.8													
	26JAN90	347		32.3													
12	31JAN90	352		35.3													0.2
	05FEB90	357		13.8													0.9
	08FEB90	360		31.9													0.6
	13FEB90	365		29.6													0.9
	16FEB90	368		34.0													0.0
	20FEB90	372		14.8													0.8
	24FEB90	376		22.8													0.0
	01MAR90	381		30.8													0.0
	06MAR90	386		19.3													0.0
	09MAR90	389		32.0													0.1
	13MAR90	393		20.1													0.2
	16MAR90	396		25.7													0.0
	20MAR90	400		32.7													5.1
	22MAR90	402		35.2													0.0
	26MAR90	406		20.5													0.0
	28MAR90	408	26.7	30.0													
	29MAR90	409	30.9	35.0													
13	03APR90	414		31.5													0.0
	06APR90	417	30.4														0.0
	10APR90	421		34.3													
	11APR90	422		31.5													
14	13APR90	424		31.1													0.5
	17APR90	428		36.6													
	18APR90	429															0.0
	19APR90	430		36.6													

Table C-2 (Continued). Raw Data: TKN Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7		35.8													19.1
	24FEB89	11		33.3													16.0
	01MAR89	16		35.5													11.9
	06MAR89	21		33.0													0.6
	08MAR89	23		36.9													
	09MAR89	24		36.4													
	10MAR89	25		35.8													0.8
2	15MAR89	30		30.8													0.3
	22MAR89	37		40.8													0.0
	03APR89	49		24.7			0.0										0.0
	07APR89	53		37.4			7.4										1.3
	17APR89	63		34.7													0.0
	21APR89	67		39.7						2.2							0.6
	26APR89	72		43.0			5.1			0.0							0.0
	02MAY89	78		30.4													
	03MAY89	79		22.8													
	06MAY89	82		29.3	1.5	1.2	0.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	12MAY89	88		23.6													0.0
	20MAY89	96		25.1													0.3
	25MAY89	101		31.9													0.0
	01JUN89	108		27.2													0.0
3	07JUN89	114		31.2													0.0
	12JUN89	119		27.0													0.0
	16JUN89	123		27.7													0.1
	21JUN89	128		25.7													0.5
	26JUN89	133		14.8	4.9												0.0
	30JUN89	137		31.3	6.1												0.2
	02JUL89	139		20.3													
	03JUL89	140		22.4													
	04JUL89	141		25.6	6.2	4.9	4.1			1.6			1.4				0.6
4	12JUL89	149		27.4	9.1												0.0
	17JUL89	154		13.3	3.9												0.5
	21JUL89	158		25.7	7.4												0.0
	26JUL89	163		30.1	7.4												0.0
	31JUL89	168		16.8	1.6												0.0
	03AUG89	171	28.9	27.5	6.9												0.0
	07AUG89	175		19.0	5.2												0.0
	08AUG89	176		24.5													
	09AUG89	177		23.4													
	10AUG89	178		25.4	8.6	3.6	1.9	1.7		0.5			0.1				0.0
5	29AUG89	197		38.8													0.0
	01SEP89	200	28.2	32.7													
	06SEP89	205		41.8													0.0
	11SEP89	210		27.2													0.0
	15SEP89	214	31.3	39.4													0.0
	20SEP89	219	27.3	33.4													0.0
	25SEP89	224	21.7	18.2													0.0
	27SEP89	226		22.3													
	28SEP89	227	22.6	30.1	8.4	6.4	5.7										0.0
	05OCT89	234	35.4	29.7													0.0
	06OCT89	235		58.5													
	12OCT89	241	27.2														0.1
6	18OCT89	247	26.7	33.5													0.0
	23OCT89	252		19.1													0.0
	25OCT89	254		29.5													0.0
	27OCT89	256		27.9													0.0
	31OCT89	260	29.6	34.5	4.6	1.3	0.1										0.4
	01NOV89	261		33.3													
	02NOV89	262	30.6	33.6													
	03NOV89	263		35.9	11.6												

Table C-2 (Continued). Raw Data: TKN Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
7	08NOV89	268		36.8													0.1
	09NOV89	269		37.4													
	13NOV89	273	24.7	23.5													0.0
	17NOV89	277	25.1	17.3													0.0
	20NOV89	280	24.2	28.9	9.5	8.4											0.0
	21NOV89	281	24.6	34.3													
8	29NOV89	289		31.8													9.5
	01DEC89	291		36.1													13.7
	05DEC89	295	31.8	35.6													12.8
	07DEC89	297	33.7	38.0													
	08DEC89	298	31.2	31.8	17.2												9.9
9	12DEC89	302		31.5													3.1
	14DEC89	304		28.2													2.1
	18DEC89	308		17.3													0.0
	21DEC89	311		29.4													9.7
10	03JAN90	324		12.7													0.0
	05JAN90	326		20.8													0.0
11	10JAN90	331		28.0													0.0
	13JAN90	334		36.6													0.0
	16JAN90	337	27.7	37.2													0.0
	20JAN90	341		32.9													0.0
	23JAN90	344	24.8	35.5													
	24JAN90	345	27.6	37.8													
	26JAN90	347		32.3	8.9	7.1	5.4										0.8
12	31JAN90	352		35.3													0.5
	05FEB90	357		13.8													0.0
	08FEB90	360		31.9													0.0
	13FEB90	365		29.6													15.8
	16FEB90	368		34.0													1.1
	20FEB90	372		14.8													22.8
	24FEB90	376		22.8													22.8
	01MAR90	381		30.8													13.8
	06MAR90	386		19.3													2.5
	09MAR90	389		32.0													3.2
	13MAR90	393		20.1													0.7
	16MAR90	396		25.7													0.0
	20MAR90	400		32.7													8.4
	22MAR90	402		35.2													4.6
	26MAR90	406		20.5													0.0
	28MAR90	408	26.7	30.0													
	29MAR90	409	30.9	35.0	10.3	7.7	6.0			0.4							0.0
13	03APR90	414		31.5													0.0
	06APR90	417	30.4														0.0
	10APR90	421		34.3	11.6	10.0	8.4			4.2							0.0
	11APR90	422		31.5													
14	13APR90	424		31.1													0.7
	16APR90	427															0.1
	17APR90	428		36.6	17.9	15.8	15.4			11.6							6.4
	19APR90	430		36.6													

Table C-3. Raw Data: NH_3-N Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7		23.4			25.6			24.8						20.3	20.3
	24FEB89	11		23.8													19.8
	01MAR89	16		27.4													19.8
	06MAR89	21		19.5													16.9
	08MAR89	23		24.3													
	09MAR89	24		27.2	24.9	24.9	24.9	24.3	23.7	23.4	23.4	22.5	22.4	22.0	22.2	21.4	21.4
	10MAR89	25		28.2													
2	15MAR89	30		20.7													14.0
	22MAR89	37		26.6						10.3							3.8
	28MAR89	43		28.5													0.8
	03APR89	49		21.5													0.0
	26APR89	72		30.9						6.4			0.5				0.3
	02MAY89	78		22.0							1.9	0.2	0.0				0.0
	03MAY89	79		16.0													
3	07JUN89	114		23.4													
	02JUL89	139		14.8													
	03JUL89	140		15.9			7.3										
	04JUL89	141		17.4													
4	03AUG89	171		11.6													
	07AUG89	175															0.0
	08AUG89	176		17.8													0.0
	09AUG89	177		18.3													
	10AUG89	178		17.6													
5	29AUG89	197		26.8						5.9							
	06SEP89	205								7.8	3.3						
	27SEP89	226		16.2						2.5	0.1						
	28SEP89	227	13.9	22.6													
6	23OCT89	252		13.4													
	25OCT89	254		26.7													
	27OCT89	256		22.5													
7	20NOV89	280		24.1													
	21NOV89	281	20.1	27.2							10.1						5.9
8	07DEC89	297		28.4							21.2						19.4
	08DEC89	298		23.2													
11	23JAN90	344		25.7													
	24JAN90	345		27.0							18.6	18.2					16.2
	26JAN90	347		23.9													
12	28MAR90	408		27.5						4.9	2.9	1.1					0.0
	29MAR90	409		28.9													
13	10APR90	421		26.0													
	11APR90	422		23.8						6.0	5.0	4.1					1.6
14	17APR90	428		30.0													
	19APR90	430		29.8						19.9	18.8	15.1	17.0				15.4

Table C-3 (Continued). Raw Data: NH3-N Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7		23.4			26.4			25.6						21.1	21.2
	24FEB89	11		23.8			24.2			24.5							21.8
	01MAR89	16		27.4			24.5			22.7							19.8
	06MAR89	21		19.5			19.9			18.6							16.0
	08MAR89	23		24.3	22.9	22.9	22.8	21.8	21.8	22.4	20.3	19.6	19.7	19.2	17.9	18.0	18.0
	09MAR89	24		27.2													
	10MAR89	25		28.2													
2	15MAR89	30		20.7													14.3
	22MAR89	37		26.6													3.8
	28MAR89	43		28.5													0.0
	03APR89	49		21.5													0.0
	26APR89	72		30.9													0.3
	02MAY89	78		22.0													
	03MAY89	79		16.0							1.5		0.5				0.0
3	07JUN89	114		23.4													
	02JUL89	139		14.8													
	03JUL89	140		15.9													
	04JUL89	141		17.4													
4	03AUG89	171		11.6													
	08AUG89	176		17.8													
	09AUG89	177		18.3													
	10AUG89	178		17.6													
5	29AUG89	197		26.8													
	27SEP89	226		16.2													
	28SEP89	227	13.9	22.6													
6	23OCT89	252		13.4													
	25OCT89	254		26.7													
	27OCT89	256		22.5													
7	20NOV89	280		24.1													
	21NOV89	281	20.1	27.2													
8	07DEC89	297		28.4													
	08DEC89	298		23.2													
11	23JAN90	344		25.7							7.4	2.7					1.2
	24JAN90	345		27.0													
	26JAN90	347		23.9													
12	28MAR90	408		27.5													
	29MAR90	409		28.9													
13	10APR90	421		26.0													
	11APR90	422		23.8													
14	17APR90	428		30.0													0.0
	18APR90	429															0.0
	19APR90	430		29.8													

Table C-3. Raw Data: NH3-N Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' mg/L	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7		23.4			18.7			18.7						18.1	19.6
	24FEB89	11		23.8			18.6			17.5							14.3
	01MAR89	16		27.4			16.3			15.1							9.9
	06MAR89	21		19.5			4.7										
	08MAR89	23		24.3													
	09MAR89	24		27.2													
	10MAR89	25		28.2	15.6	7.5	6.7	4.7	4.2	3.3	1.8	1.9	1.3	1.2	0.6	0.6	0.9
2	15MAR89	30		20.7													0.0
	22MAR89	37		26.6													0.0
	28MAR89	43		28.5			2.3										0.0
	03APR89	49		21.5			0.3										0.0
	26APR89	72		30.9			4.2										0.2
	02MAY89	78		22.0													
	03MAY89	79		16.0													
	06MAY89	82				0.0											
3	07JUN89	114		23.4													
	02JUL89	139		14.8													
	03JUL89	140		15.9													
	04JUL89	141		17.4													0.0
4	03AUG89	171		11.6													
	07AUG89	175															0.0
	08AUG89	176		17.8													
	09AUG89	177		18.3													
	10AUG89	178		17.6													
5	29AUG89	197		26.8													
	06SEP89	205			9.3	6.9											
	27SEP89	226		16.2													
	28SEP89	227	13.9	22.6	7.8	5.8	5.0										
6	23OCT89	252		13.4													
	25OCT89	254		26.7													
	27OCT89	256		22.5													
7	20NOV89	280		24.1													
	21NOV89	281	20.1	27.2	9.1												
8	07DEC89	297		28.4													
	08DEC89	298		23.2	14.3												8.1
11	23JAN90	344		25.7													
	24JAN90	345		27.0													
	26JAN90	347		23.9	9.7	7.7	6.6										0.0
12	28MAR90	408		27.5													
	29MAR90	409		28.9	7.4	6.4	5.2			0.2							0.0
13	10APR90	421		26.0	11.0	10.0	8.3										0.0
	11APR90	422		23.8													
14	17APR90	428		30.0			12.0			10.2							5.6
	19APR90	430		29.8													

Table C-4. Raw Data: NO2-N Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
1	20FEB89	7	0.0			0.0			0.0						0.0	0.1	
	24FEB89	11					0.0		0.0							0.3	
	01MAR89	16	0.0			0.0	0.4		0.0							0.4	
	06MAR89	21	0.0			0.0	0.2		0.0			0.0			0.5	0.5	
	09MAR89	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2	15MAR89	30														0.7	
	22MAR89	37														3.0	
	28MAR89	43	0.1						0.1						0.2	1.9	
	03APR89	49														0.0	
	07APR89	53					0.0		0.0			0.0				0.1	
	17APR89	63	0.0													0.0	
	21APR89	67	0.0				0.0		0.0			0.0				0.0	
	26APR89	72	0.0				0.0		0.0			0.0				0.0	
	02MAY89	78	0.0	0.1	0.0	0.1	0.0	0.3	0.4	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.3
	12MAY89	88	0.0													0.0	
	20MAY89	96	0.0													0.0	
	25MAY89	101	0.0													0.2	
	01JUN89	108	0.0													0.4	
3	07JUN89	114	0.0													0.0	
	12JUN89	119	0.0							0.4						0.0	
	16JUN89	123	0.0						0.0							0.0	
	21JUN89	128	0.0													0.0	
	26JUN89	133	0.0													0.0	
	30JUN89	137	0.0							0.0						0.0	
	03JUL89	140	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0
4	12JUL89	149								0.5						0.2	
	17JUL89	154	0.2							0.1						0.0	
	21JUL89	158	0.1							0.3						0.1	
	26JUL89	163	0.0						0.1	0.3		0.3				0.6	
	31JUL89	168	0.0						0.8	0.2		0.3				0.1	
	03AUG89	171							0.1	0.2		0.2				0.1	
	07AUG89	175	0.0							0.1		0.2				0.1	
	08AUG89	176	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.0	0.1	0.1
	15AUG89	183														0.3	
5	29AUG89	197	0.1						0.2	0.1	0.3	0.3				0.0	
	01SEP89	200	0.1						0.1	0.0		0.0				0.0	
	06SEP89	205	0.0			0.1	0.2	0.2	0.2	0.4	0.5	0.4	0.1	0.1	0.1	0.0	0.1
	11SEP89	210														0.0	
	15SEP89	214	0.1			0.1	0.1	0.0	0.1	0.5	0.0	0.3			0.0	0.0	0.3
	20SEP89	219	0.0													0.0	
	25SEP89	224	0.0				0.0		0.0						0.0	0.0	0.0
	27SEP89	226	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	04OCT89	233				0.0	0.1	0.1							0.0		0.2
	05OCT89	234	0.0			0.0			0.2							0.0	
	06OCT89	235	0.0			0.0	0.2	0.2							0.0	0.4	0.0
	12OCT89	241	0.0													0.1	
6	18OCT89	247	0.2						0.2						0.0	0.0	
	23OCT89	252	0.0						0.2	0.0		0.0				0.0	
	25OCT89	254	0.0			0.0	0.0	0.0	0.1	0.3	0.3	0.2				0.1	0.1
	27OCT89	256				0.0	0.0	0.0	0.0	0.2	0.2	0.1			0.0	0.1	0.0
	01NOV89	261	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1
	03NOV89	263														0.1	
7	08NOV89	268	0.0						0.1							1.4	
	13NOV89	273	0.0			0.0	0.2		0.1	0.7	1.0	0.9			1.0	1.4	
	17NOV89	277	0.0			0.0	0.1		0.1	0.3		0.6			0.3	0.6	
	21NOV89	281	0.0	0.0	0.0	0.3	0.6	0.5	0.6	1.3	1.5	1.9	2.3	2.5	2.7	2.5	2.4
8	29NOV89	289	0.1			0.1			0.2						0.6	0.5	
	01DEC89	291	0.2			0.1			0.1						0.7	0.5	
	05DEC89	295	0.0			0.0			0.1	0.3	0.3				0.7	0.4	
	07DEC89	297	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.2	0.3	0.4	0.5	0.6	0.5	0.7

Table C-4 (Continued). Raw Data: NO2-N Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
9	12DEC89	302				0.0			0.0							0.3	
	14DEC89	304	0.0			0.0			0.0							0.2	
	18DEC89	308				0.0			0.0						0.3	0.3	
	21DEC89	311				0.0			0.0							0.4	
10	03JAN90	324	0.2			0.4			0.3							0.3	
	05JAN90	326	0.3			0.6			0.5						0.3	0.3	
11	10JAN90	331	0.0			0.0			0.0							0.1	
	13JAN90	334	0.0			0.0			0.0						0.1	0.1	
	16JAN90	337	0.0													0.2	
	20JAN90	341	0.0			0.0			0.0						0.2	0.2	
	24JAN90	345	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
12	31JAN90	352	0.0			0.0									0.8	0.6	
	05FEB90	357	0.0			0.0			0.1						0.3	0.3	
	08FEB90	360	0.0													0.2	
	12FEB90	364										0.0				0.1	
	16FEB90	368	0.0			0.0			0.0						0.1	0.1	
	20FEB90	372	0.0												0.4	0.2	
	24FEB90	376	0.0												0.7	0.6	
	27FEB90	379													2.2		
	01MAR90	381	0.0			0.0			0.2						4.3	3.8	
	06MAR90	386	0.0			0.6			2.1						5.8	5.7	
	09MAR90	389	0.0			0.3			3.0						7.1	7.3	
	13MAR90	393	0.0			0.1			0.0						0.0	0.0	
	16MAR90	396														0.2	
	20MAR90	400	0.0			0.0			0.5						0.9	0.9	
	22MAR90	402	0.0			0.1			0.2								
	26MAR90	406	0.0			0.3			0.4						0.1	0.2	
	28MAR90	408	0.0	0.1	0.1	0.2	0.3	0.2	0.3	0.5	0.5	0.6	0.2	0.2	0.1	0.4	0.1
13	03APR90	414	0.0			0.0			0.3						0.9	0.8	
	06APR90	417	0.0			0.3			0.4						0.8	0.9	
	11APR90	422	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.7	1.1	1.1	1.1	1.1	1.1	1.0	1.2
14	13APR90	424	0.0			0.0			0.0						0.5	0.6	
	16APR90	427														0.9	
	19APR90	430	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.6	0.7	0.8	0.9	0.9	0.9

Table C-4 (Continued). Raw Data: NO2-N Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
1	20FEB89	7	0.0			0.0			0.0						0.1	0.0	
	24FEB89	11				0.0	0.1		0.2							0.2	
	01MAR89	16	0.0			0.0	0.1		0.0							0.6	
	06MAR89	21	0.0			0.0	0.0		0.0						0.0	0.7	
	08MAR89	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	
	09MAR89	24	0.0														
	10MAR89	25	0.0														
2	28MAR89	43	0.1						0.0						0.2	1.4	
	03APR89	49														0.0	
	03MAY89	79	0.0	0.0			0.1	0.1		0.0		0.4			0.1	0.0	0.0
	12MAY89	88	0.0													0.1	
	20MAY89	96	0.0													0.0	
	25MAY89	101	0.0													0.0	
	01JUN89	108	0.0													0.0	
3	07JUN89	114	0.0													0.0	
	12JUN89	119	0.0													0.0	
	16JUN89	123	0.0													0.0	
	21JUN89	128	0.0													0.0	
	26JUN89	133	0.0													0.0	
	30JUN89	137	0.0													0.0	
	02JUL89	139	0.0													0.0	0.0
4	17JUL89	154	0.2													0.0	
	21JUL89	158	0.1													0.1	
	26JUL89	163	0.0													0.7	
	31JUL89	168	0.0													0.0	
	03AUG89	171														0.2	
	07AUG89	175	0.0													0.1	
	09AUG89	177	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.0	0.1	0.0
	15AUG89	183														0.5	
5	29AUG89	197	0.1													0.0	
	01SEP89	200	0.1													0.0	
	06SEP89	205	0.0													0.3	
	11SEP89	210														0.0	
	15SEP89	214	0.1													0.1	
	20SEP89	219	0.0													0.0	
	25SEP89	224	0.0													0.0	
	05OCT89	234	0.0			0.0			0.1							0.1	
	12OCT89	241	0.0			0.0										0.0	
6	18OCT89	247	0.2													0.0	
	23OCT89	252	0.0													0.0	
	25OCT89	254	0.0													0.1	
	02NOV89	262	0.0	0.0		0.0	0.0		0.0	0.0					0.0	0.2	0.0
7	08NOV89	268	0.0													0.1	
	09NOV89	269	0.0	0.0		0.0	0.0	0.1	0.0	0.1					0.0	0.2	0.0
	13NOV89	273	0.0													0.7	
	17NOV89	277	0.0													0.0	
8	29NOV89	289	0.1													0.1	
	01DEC89	291	0.2													0.2	
	05DEC89	295	0.0													0.3	
9	12DEC89	302														0.1	
	14DEC89	304	0.0													0.2	
	18DEC89	308														0.0	
	21DEC89	311				0.0										0.6	
10	03JAN90	324	0.2			0.1			0.0							0.0	
	05JAN90	326	0.3			0.1			0.0						0.0	0.0	
11	10JAN90	331	0.0			0.0			0.0							0.4	
	13JAN90	334	0.0			0.0			0.0						0.4	0.4	
	16JAN90	337	0.0													0.6	
	20JAN90	341	0.0			0.0			0.0						0.5	0.5	
	23JAN90	344	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.8	0.9	0.8	0.7	0.7

Table C-4 (Continued). Raw Data: NO2-N Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
12	31JAN90	352	0.0			0.0									0.0	0.1	
	05FEB90	357	0.0			0.0			0.0						0.0	0.0	
	08FEB90	360	0.0			0.0			0.0						0.0	0.1	
	12FEB90	364													0.0	0.1	
	16FEB90	368	0.0			0.0			0.0						0.1	0.1	
	20FEB90	372	0.0			0.0			0.1						0.0	0.1	
	24FEB90	376	0.0			0.1			0.1						0.0	0.1	
	01MAR90	381	0.0			0.0			0.3						0.0	0.1	
	06MAR90	386	0.0						0.0						0.0	0.0	
	09MAR90	389	0.0			0.1			0.2						0.2	0.1	
	13MAR90	393	0.0			0.1			0.0						0.0	0.0	
	16MAR90	396														0.1	
	20MAR90	400	0.0			0.3			0.7						0.3	0.2	
	22MAR90	402	0.0			0.0			0.7						0.0	0.2	
	26MAR90	406	0.0			0.3	0.1		0.4	0.3	0.2					0.0	
13	03APR90	414	0.0			0.0			0.2						0.0	0.0	
	06APR90	417	0.0			0.0			0.3						0.0	0.0	
14	13APR90	424	0.0			0.0			0.0						0.0	0.0	

Table C-4 (Continued). Raw Data: NO2-N Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
1	20FEB89	7	0.0			3.2			4.2						4.9	5.5	
	24FEB89	11				3.2			4.2								
	01MAR89	16	0.0			0.4			2.8							9.5	
	06MAR89	21	0.0			5.7			7.1			7.1			7.0	6.8	
	10MAR89	25	0.0	3.6	4.9	4.2	4.0	4.0	2.0	2.4	0.8	1.0	0.9	0.5	0.5	0.4	
2	28MAR89	43	0.1			2.0										0.0	
	03APR89	49				0.2										0.0	
	21APR89	67	0.0						1.1								
	26APR89	72	0.0			2.8											
	06MAY89	82	0.0	2.5	3.0	1.4	1.5	1.3	1.1	0.9	0.6	0.3	0.3	0.4	0.4	0.0	0.2
	12MAY89	88	0.0													0.0	
	20MAY89	96	0.0													0.0	
	25MAY89	101	0.0													0.0	
	01JUN89	108	0.0													0.0	
3	07JUN89	114	0.0													0.0	
	12JUN89	119	0.0			3.2										0.0	
	16JUN89	123	0.0													0.0	
	21JUN89	128	0.0													0.0	
	26JUN89	133	0.0													0.2	
	30JUN89	137	0.0	0.2												0.3	
	04JUL89	141	0.0	1.2	1.3	1.3	1.2	1.1	0.9	0.6	0.6	0.4	0.4	0.4	0.5	0.2	0.4
4	17JUL89	154	0.2	0.5												0.1	
	21JUL89	158	0.1	0.8												0.2	
	26JUL89	163	0.0	1.5												0.1	
	31JUL89	168	0.0	2.1		1.3										0.3	
	03AUG89	171		2.1		1.5										0.1	
	07AUG89	175	0.0	1.3		1.8										0.1	
	10AUG89	178	0.0	1.7	1.9	1.8	1.7	0.9	0.4	0.3	0.3	0.3	0.2	0.1	0.2	0.0	0.1
	15AUG89	183														0.0	
5	29AUG89	197	0.1	0.3		0.3										0.1	
	01SEP89	200	0.1	2.4		1.8										0.0	
	06SEP89	205	0.0	0.8	0.9	0.5	0.7	0.5	0.5						0.3	0.0	
	11SEP89	210														0.0	
	15SEP89	214	0.1	1.1	0.6	0.7			0.8						1.1	0.0	0.6
	20SEP89	219	0.0			1.2										0.0	
	25SEP89	224	0.0	0.3	0.1	0.0			0.0							0.0	0.0
	28SEP89	227	0.0	1.6	1.6	1.7	1.0	0.8	0.6	0.4	0.3	0.2	0.1	0.1	0.1	0.0	0.2
	05OCT89	234	0.0						0.5							1.0	
	12OCT89	241	0.0						0.8							0.0	
6	18OCT89	247	0.2						0.8						0.3	0.0	
	23OCT89	252	0.0	0.9		0.9			0.2							0.0	
	25OCT89	254		1.4		1.2			1.2						0.3	0.2	0.4
	27OCT89	256		1.5	1.5	1.6			0.9							0.3	0.3
	31OCT89	260	0.0	1.4	2.0	1.9	2.1	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4
	03NOV89	263		1.1	1.4	1.7										0.4	
7	08NOV89	268	0.0	2.1													
	13NOV89	273	0.0	1.3	1.6	1.7			1.5						0.2	0.3	
	17NOV89	277	0.0	1.2	1.3	1.3			0.6							0.1	0.1
	20NOV89	280	0.0	1.3	1.7	2.0	2.2	2.4	2.4	2.2	2.1	2.2	1.4	1.4	0.7	1.4	0.8
8	29NOV89	289	0.1	0.7		0.8									0.7	0.6	
	01DEC89	291	0.2	1.6	1.5				1.5			1.6			1.5	1.2	
	05DEC89	295	0.0	0.9	1.3				1.5			1.5			1.8	1.5	
	08DEC89	298	0.0	1.2	1.8	1.7	1.9	2.0	2.3	2.3	2.4	2.2	2.3	2.3	2.4	2.0	2.3
9	12DEC89	302		0.4					3.0							2.4	
	14DEC89	304	0.0	0.4					2.2							1.8	
	18DEC89	308		1.5					1.4							0.6	
	21DEC89	311		0.1					0.7							0.9	
10	03JAN90	324	0.2	0.3					0.3							0.2	
	05JAN90	326	0.3	0.7					0.5							0.4	
11	10JAN90	331	0.0	0.8					0.5							0.3	
	13JAN90	334	0.0	1.4					1.0						1.0	0.4	
	16JAN90	337	0.0						0.8							0.5	
	20JAN90	341	0.0	1.3					1.2						0.7	0.3	
	26JAN90	347	0.0	0.8	0.6	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.1

Table C-4 (Continued). Raw Data: NO2-N Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
12	31JAN90	352	0.0	1.8		0.9										0.3	
	05FEB90	357	0.0	0.3		0.0			0.0						0.0	0.0	
	08FEB90	360	0.0	1.8		0.8										0.9	
	12FEB90	364														0.1	
	16FEB90	368	0.0	0.3		0.4										1.4	
	20FEB90	372	0.0						0.8							1.2	
	24FEB90	376	0.0	0.7		0.9			1.4							1.8	
	27FEB90	379													2.6		
	01MAR90	381	0.0	1.1		1.7										2.7	
	06MAR90	386	0.0	2.2		2.6			2.8						3.3	3.2	
	09MAR90	389	0.0	3.8		4.1			4.8						5.1	5.2	
	13MAR90	393	0.0	0.4		0.4			0.2						0.2	0.2	
	16MAR90	396														0.3	
	20MAR90	400	0.0	0.8		0.9			0.9						0.6	0.9	
	22MAR90	402	0.0	1.4		1.5			1.2						1.3	1.2	
	26MAR90	406	0.0	1.0		1.0			0.2						0.1	0.0	
	29MAR90	409	0.0	1.4	1.5	1.4	1.3	1.0	0.7	0.6	0.4	0.3	0.1	0.1	0.2	0.1	0.0
13	03APR90	414	0.0	1.0		1.1			0.9						0.3	0.2	
	06APR90	417	0.0	1.7		1.3			1.0						0.4	0.2	
	10APR90	421	0.0	1.1	1.4	1.3	1.1	1.1	1.1	2.0	1.1	1.0	0.9	0.7	0.7	0.7	0.5
14	13APR90	424	0.0	2.6		1.3			1.1						0.6	0.6	
	16APR90	427														0.3	
	17APR90	428	0.0	1.0	1.0	1.0	1.1	1.0	1.2	1.1	1.3	1.3	1.2	1.2	1.1	1.0	1.1

Table C-5. Raw Data: NO3-N, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
1	20FEB89	7	0.1			0.0			0.1						0.0	0.1	
	24FEB89	11					0.1		0.0							0.1	
	01MAR89	16	0.4			0.1	0.0		0.1							0.3	
	06MAR89	21	0.0			0.0	0.3		0.0			0.0			0.3	0.3	
	09MAR89	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	
2	15MAR89	30	0.0													0.3	
	22MAR89	37	0.1													2.3	
	28MAR89	43	0.3						0.1						5.3	7.1	
	03APR89	49														8.1	
	07APR89	53					0.4		0.1			0.1				5.2	
	17APR89	63	0.6													11.7	
	21APR89	67	0.3				0.2		0.2			5.8			8.4	11.1	
	26APR89	72	0.2				0.2		0.1			5.1				11.2	3.0
	02MAY89	78	0.3	0.0	0.1	0.0	0.1	0.1	0.3	3.4	5.9	5.7	8.1	8.3	9.4	9.7	9.1
	12MAY89	88	0.1													7.4	
	20MAY89	96	0.4													9.9	
	25MAY89	101	0.2													9.7	
	01JUN89	108	0.3													4.1	
3	07JUN89	114	0.1													11.1	
	12JUN89	119	0.1							6.8						9.0	
	16JUN89	123	0.1						1.3							8.1	
	21JUN89	128	0.1													6.3	
	26JUN89	133	0.1													4.9	
	30JUN89	137	0.0							1.6						8.7	
	03JUL89	140	0.0	0.0	0.0	0.1	1.0	1.2	1.0	4.5	4.8	7.0	6.6	7.5	7.8	7.3	8.4
4	12JUL89	149	0.3							4.2						8.9	
	17JUL89	154	0.0							1.4						2.7	
	21JUL89	158	0.1							2.4						7.1	
	26JUL89	163	0.0						0.9	2.5		3.5				8.4	
	31JUL89	168	0.1						2.3	4.7		6.4				7.2	
	03AUG89	171							3.0	6.2		8.8				11.7	
	07AUG89	175	0.1							6.1		8.1				9.7	
	08AUG89	176	0.0	0.1	0.1	0.8	2.8	2.5	2.4	4.3	6.1	8.3	8.9	9.3	9.6	9.5	10.2
	15AUG89	183														10.4	
5	29AUG89	197	0.0						1.5	2.7	4.0	5.0				11.8	
	01SEP89	200	0.0						0.2	0.7		1.4				5.7	
	06SEP89	205	0.1			0.0	0.3	0.2	0.4	1.7	0.5	4.2	4.6	4.8	5.4	10.7	1.1
	11SEP89	210														8.8	
	15SEP89	214	0.1			0.2	0.8	0.9	1.3	6.9	9.3	10.1			12.2	12.3	8.7
	20SEP89	219	0.0													9.7	
	25SEP89	224	0.3				2.7		4.2						9.3	8.8	8.1
	04OCT89	233				0.0	0.3	0.1							7.2		5.2
	05OCT89	234	0.0			0.2			2.0							10.0	
	06OCT89	235	0.0			0.4	3.6	3.5							18.4	17.2	16.7
	12OCT89	241	0.1													9.9	
6	18OCT89	247	0.1						2.8						8.9	10.2	
	23OCT89	252	0.0						5.1	7.0		7.6				7.0	
	25OCT89	254	0.0			0.3	2.3	2.7	4.1	7.3	8.1	8.5				11.1	11.0
	27OCT89	256				0.3	2.1	2.0	2.3	6.9	8.3	9.3			10.5	9.9	
	01NOV89	261	0.0	0.1	0.0	0.2	1.5	1.3	1.2	4.5	6.8	7.3	9.2	9.8	9.7	10.0	9.8
	03NOV89	263														6.5	
7	08NOV89	268	0.1						0.8							4.0	
	13NOV89	273	0.0			0.1	1.2		1.0	2.9	4.2				5.5	5.3	
	17NOV89	277	0.0			0.1	0.5		0.6	1.0	1.6	2.0			2.9	3.1	
	21NOV89	281	0.1	0.1	0.1	0.5	1.8	1.6	1.7	3.0	3.4	4.3	5.5	5.9	6.1	6.3	6.2
8	29NOV89	289	0.1			0.1			0.8						2.0	2.4	
	01DEC89	291	0.2			0.0			0.1						1.5	1.7	
	05DEC89	295	0.1			0.0			0.1	0.4	0.5				1.1	1.3	
	07DEC89	297	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.2
9	12DEC89	302				0.0			0.1							1.2	
	14DEC89	304	0.0			0.1			0.1							0.6	
	18DEC89	308				0.0			0.1						1.1	1.0	
	21DEC89	311				0.0			0.0							0.6	

Table C-5 (Continued). Raw Data: NO3-N, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
10	03JAN90	324	0.2			4.2			6.9							9.0	
	05JAN90	326	0.3			1.4			4.3						8.9	8.2	
11	10JAN90	331	0.0			0.1			0.1							1.9	
	13JAN90	334	0.0			0.0			0.0						0.8	1.1	
	16JAN90	337	0.1													1.1	
	20JAN90	341	0.0			0.0			0.0						0.3	0.6	
	24JAN90	345	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.5	0.7	0.4
12	31JAN90	352	0.1			0.1									2.1	1.8	
	05FEB90	357	0.0			0.1			0.3						2.1	1.9	
	08FEB90	360	0.2													0.2	
	12FEB90	364	0.0												0.1	0.1	
	16FEB90	368	0.0			0.0			0.0						0.1	0.0	
	20FEB90	372	0.0												0.2	0.0	
	24FEB90	376	0.0												0.3	0.1	
	27FEB90	379													0.2		
	01MAR90	381	0.0			0.0			0.0						0.3	0.2	
	06MAR90	386	0.0			0.1			0.7						1.6	1.7	
	09MAR90	389	0.0			0.1			1.1						7.3	3.5	
	13MAR90	393	0.0			0.2			0.2						0.9	1.3	
	16MAR90	396														6.9	
	20MAR90	400	0.1			0.5			2.3						6.0	5.6	
	22MAR90	402	0.1			0.2			0.9								
	26MAR90	406	0.0			2.3			5.9						9.5	9.4	
	28MAR90	408	0.1	0.4	0.1	0.5	3.2	3.3	4.3	7.4	8.7	9.1	10.8	10.9	11.5	11.0	11.4
13	03APR90	414	0.0			0.2			2.9						6.7	6.8	
	06APR90	417	0.1			0.2			2.3						7.0	6.5	
	11APR90	422	0.0	0.1	0.0	0.1	0.5	0.4	0.8	1.6	2.3	2.8	4.2	4.5	5.0	5.1	4.6
14	13APR90	424	0.0			0.1			0.1						1.6	2.0	
	16APR90	427														5.7	
	19APR90	430	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	1.1	1.3	1.4	1.4	1.1

Table C-5 (Continued). Raw Data: NO3-N, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
1	20FEB89	7	0.1			0.0			0.0						0.2	0.1	
	24FEB89	11				0.0	0.0		0.1							0.2	
	01MAR89	16	0.4			0.1	0.4		0.1							0.7	
	06MAR89	21	0.0			0.0	0.0		0.0			0.0			0.0	0.5	
	08MAR89	23	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	
2	15MAR89	30	0.0													0.3	
	22MAR89	37	0.1													3.0	
	28MAR89	43	0.3						0.1						5.5	7.4	
	03APR89	49														8.1	
	07APR89	53														3.0	
	17APR89	63	0.6													11.2	
	21APR89	67	0.3													11.4	
	26APR89	72	0.2													9.4	
	03MAY89	79	0.0	0.0			0.1	0.1		0.9		3.6			8.3	7.2	9.4
	12MAY89	88	0.1													7.6	
	20MAY89	96	0.4													8.9	
	25MAY89	101	0.2													9.3	
	01JUN89	108	0.3													3.1	
3	07JUN89	114	0.1													9.8	
	12JUN89	119	0.1													8.7	
	16JUN89	123	0.1													7.5	
	21JUN89	128	0.1													6.4	
	26JUN89	133	0.1													4.2	
	30JUN89	137	0.0													7.9	
	02JUL89	139	0.0	0.0	0.0	0.1	1.2	1.9	1.8	4.2	6.1	5.0	6.1	6.3	6.3	6.1	7.0
4	12JUL89	149	0.3													8.9	
	17JUL89	154	0.0													2.8	
	21JUL89	158	0.1													6.8	
	26JUL89	163	0.0													7.0	
	31JUL89	168	0.1													7.4	
	03AUG89	171														11.5	
	07AUG89	175	0.1													9.9	
	09AUG89	177	0.0	0.2	0.1	0.5	2.8	2.5	2.2	4.4	5.4	6.4	8.2	8.4	9.2	9.8	8.7
	15AUG89	183														10.1	
5	29AUG89	197	0.0													11.7	
	01SEP89	200	0.0													5.7	
	06SEP89	205	0.1													8.8	
	11SEP89	210														7.8	
	15SEP89	214	0.1													11.9	
	20SEP89	219	0.0													8.8	
	25SEP89	224	0.3													7.4	
	05OCT89	234	0.0			0.1			2.9							8.6	
	12OCT89	241	0.1			0.3										9.5	
6	18OCT89	247	0.1													8.9	
	23OCT89	252	0.0													5.2	
	25OCT89	254	0.0													7.7	
	02NOV89	262	0.0	0.0		0.0	0.1		0.1	1.2					3.1	8.7	1.4
7	08NOV89	268	0.1													7.2	
	09NOV89	269	0.0	0.0		0.0	0.3	0.1	0.2	1.5					6.0	9.2	2.4
	13NOV89	273	0.0													6.8	
	17NOV89	277	0.0													3.0	
8	29NOV89	289	0.1													12.0	
	01DEC89	291	0.2													9.3	
	05DEC89	295	0.1													6.5	
9	12DEC89	302														2.8	
	14DEC89	304	0.0													2.4	
	18DEC89	308														2.0	
	21DEC89	311				0.0										1.3	
10	03JAN90	324	0.2			0.9			2.8							6.7	
	05JAN90	326	0.3			0.3			2.6						8.8	8.3	
11	16JAN90	337	0.1													5.3	
	20JAN90	341	0.0			0.0			0.1						2.1	2.7	
	23JAN90	344	0.0	7.0	8.4	9.1	10.6	12.1	13.7	14.1	15.2	15.7	16.4	16.6	16.7	15.5	15.8

Table C-5 (Continued). Raw Data: NO3-N, Test BNR System (Reactor 2)

12	31JAN90	352	0.1	0.1					5.1	3.0
	05FEB90	357	0.0	0.1		0.6			2.8	0.9
	08FEB90	360	0.2	0.1		0.4			5.4	3.2
	12FEB90	364	0.0						1.4	0.8
	16FEB90	368	0.0	0.0		0.1			4.9	4.2
	20FEB90	372	0.0	0.1		0.4			5.5	3.8
	24FEB90	376	0.0	0.2		0.5			8.0	6.4
	01MAR90	381	0.0	0.3		1.8			8.5	5.2
	06MAR90	386	0.0	0.4		1.9			7.0	6.9
	09MAR90	389	0.0	0.4		2.0			10.2	10.5
	13MAR90	393	0.0	0.0		0.2			2.1	2.5
	16MAR90	396								8.1
	20MAR90	400	0.1	0.5		4.8			12.2	11.8
	22MAR90	402	0.1	0.2		2.3			8.2	10.1
	26MAR90	406	0.0	0.5	2.2	3.6	8.4	9.0		9.8
13	03APR90	414	0.0	0.5		4.7			11.4	11.4
	06APR90	417	0.1	0.3		2.6			9.8	9.1
14	13APR90	424	0.0	0.1		0.2			3.1	3.9

Table C-5 (Continued). Raw Data: NO3-N, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
1	20FEB89	7	0.1			0.4			0.5						0.6	0.9	
	24FEB89	11				0.4			0.5								
	01MAR89	16	0.4			0.0			0.6							2.2	
	06MAR89	21	0.0			8.7			11.5			13.0			11.9	13.5	
	10MAR89	25	0.1	7.3	10.3	12.2	15.4	16.0	21.1	21.4	24.3	24.7	26.4	26.9	27.2	27.4	
2	28MAR89	43	0.3			16.7										26.0	
	03APR89	49				18.3										22.6	
	07APR89	53														23.3	
	17APR89	63	0.6													28.6	
	21APR89	67	0.3						23.9							28.5	
	26APR89	72	0.2			13.0										31.0	
	06MAY89	82	0.0	12.4	14.8	19.4	19.3	20.0	21.6	22.3	23.0	23.6	23.8	23.4	23.5	24.1	22.2
	12MAY89	88	0.1													16.1	
	20MAY89	96	0.4													19.7	
	25MAY89	101	0.2													20.0	
	01JUN89	108	0.3													21.3	
3	07JUN89	114	0.1													26.0	
	12JUN89	119	0.1			12.0										21.1	
	16JUN89	123	0.1													21.1	
	21JUN89	128	0.1													19.2	
	26JUN89	133	0.1													14.7	
	30JUN89	137	0.0	2.2												20.0	
	04JUL89	141	0.0	5.4	6.7	8.0	9.6	10.6	11.1	11.5	11.7	12.2	12.1	12.2	12.1	13.6	12.1
4	17JUL89	154	0.0	4.3												9.5	
	21JUL89	158	0.1	6.3												17.0	
	26JUL89	163	0.0	8.5												21.2	
	31JUL89	168	0.1	8.2		12.4										14.8	
	03AUG89	171		8.4		12.9										21.3	
	07AUG89	175	0.1	7.3		11.7										20.5	
	10AUG89	178	0.1	8.4	11.9	12.9	14.3	17.4	18.2	18.4	18.5	18.5	18.8	18.9	18.8	18.8	18.8
	15AUG89	183														19.8	
5	29AUG89	197	0.0	13.8		16.4										30.9	
	01SEP89	200	0.0	7.3		14.0										22.7	
	06SEP89	205	0.1	8.5	11.5	15.0	18.9	20.1	19.7						20.3	27.4	
	11SEP89	210														24.2	
	15SEP89	214	0.1	18.4	24.2	24.7			25.1						26.1	29.9	27.8
	20SEP89	219	0.0			19.3										24.6	
	25SEP89	224	0.3	16.3	17.7	17.9			18.8			19.1				18.8	19.2
	05OCT89	234	0.0						22.4							22.5	
	12OCT89	241	0.1						26.1							26.9	
6	18OCT89	247	0.1						24.8						25.9	27.8	
	23OCT89	252	0.0	10.0		12.5			15.6							16.2	
	25OCT89	254	0.0	13.5		17.3			19.8						26.1	25.5	26.4
	27OCT89	256		10.0	13.5	14.3			20.6							23.2	23.4
	31OCT89	260	0.0	5.2	7.8	9.0	10.1	12.5	13.6	14.7	16.0	16.7	18.2	18.5	20.1	18.6	18.4
	03NOV89	263		8.3	8.8	8.2										20.3	
7	08NOV89	268	0.1	6.1													
	13NOV89	273	0.0	11.5	14.2	16.9			19.4						22.6	21.5	
	17NOV89	277	0.0	7.4	9.2	10.5			13.5							14.2	14.0
	20NOV89	280	0.1	14.3	15.2	16.8	17.5	19.5	21.0	21.8	23.2	23.7	25.9	26.0	27.2	26.0	26.6
8	29NOV89	289	0.1	4.0		6.9									8.7	9.0	
	01DEC89	291	0.2	3.7	4.0				6.4			7.9			8.9	9.0	
	05DEC89	295	0.1	3.9	4.8				7.9			9.7			10.2	10.9	
	08DEC89	298	0.0	3.9	4.9	4.6	5.6	6.6	7.5	8.1	9.0	9.1	10.0	10.0	10.5	10.6	10.5
9	12DEC89	302		0.5					6.1							9.9	
	14DEC89	304	0.0	0.5					3.6							6.4	
	18DEC89	308		5.2					5.4							7.2	
	21DEC89	311		0.1					0.5							2.1	
10	03JAN90	324	0.2	8.0					11.1							11.5	
	05JAN90	326	0.3	7.7					1.0							13.1	

Table C-5 (Continued). Raw Data: NO3-N, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L	RAS mg/L
11	10JAN90	331	0.0	6.0					10.9							10.1	
	13JAN90	334	0.0	3.5					9.6						12.6	14.5	
	16JAN90	337	0.1						17.2							19.5	
	20JAN90	341	0.0	2.2					9.2						9.3	8.3	
	26JAN90	347	0.2	7.0	8.4	9.1	10.6	12.1	13.7	14.1	15.2	15.7	16.4	16.6	16.7	15.5	15.8
12	31JAN90	352	0.1	6.9		13.7										14.7	
	05FEB90	357	0.0	6.4		8.6			9.0						9.3	8.3	
	08FEB90	360	0.2	6.1		9.2										14.2	
	12FEB90	364	0.0													7.5	
	16FEB90	368	0.0	0.3		0.5										2.0	
	20FEB90	372	0.0						0.9							1.5	
	24FEB90	376	0.0	0.6		0.8			1.4							1.9	
	27FEB90	379													2.8		
	01MAR90	381	0.0	0.8		1.3										3.0	
	06MAR90	386	0.0	4.3		5.6			7.7						8.9	8.5	
	09MAR90	389	0.0	5.4		7.0			9.4						13.3	13.3	
	13MAR90	393	0.0	1.8		1.9			2.8						3.5	3.7	
	16MAR90	396														8.8	
	20MAR90	400	0.1	5.5		5.0			7.4						9.1	8.9	
	22MAR90	402	0.1	6.0		8.4			12.1						14.6	14.3	
	26MAR90	406	0.0	12.5		16.4			19.1						20.2	20.8	
	29MAR90	409	0.3	11.1	13.4	14.7	17.4	18.6	19.8	21.1	21.7	21.7	21.9	22.2	21.9	21.4	21.5
13	03APR90	414	0.0	12.7		15.3			19.5						20.2	20.5	
	06APR90	417	0.1	11.6		14.2			20.0						22.1	22.5	
	10APR90	421	0.2	11.4	12.1	12.8	14.8	16.4	18.1	19.4	19.6	20.1	21.1	21.5	21.7	21.0	21.6
14	13APR90	424	0.0	2.2		4.4			8.6						11.6	12.5	
	16APR90	427														13.5	
	17APR90	428	0.0	6.6	7.1	7.8	9.3	10.8	12.0	12.3	13.2	13.6	14.8	15.0	15.2	14.5	15.3

Table C-6. Raw Data: TSS Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7	30			2555			3590						3620	33
	24FEB89	11	34			2840			4120						4030	9
	01MAR89	16	48			3800			4680						4840	8
	06MAR89	21	25			4130			4930						4720	10
	09MAR89	24	50	2610	2710	3950	4680	4690	4650	4610	4710	4500	4540	4610	4610	0
2	15MAR89	30	45			3720			5040						4910	3
	22MAR89	37	40			2940			3880						4100	6
	28MAR89	43	58			3850			4960						4630	58
	30MAR89	45													4700	220
	31MAR89	46													4920	51
	03APR89	49				4340			5330						4990	33
	07APR89	53				3690			4630						4390	5
	12APR89	58	56			3230			4330						3780	2
	17APR89	63	24			2890			4780						4410	17
	21APR89	67	50			3600	4810		4380						4250	3
	26APR89	72	61			2390	4630		4380			4640			4400	5
	02MAY89	78	46	2290	2370	2400	6190	4880	4620	4690	4670	5120	4970	4570	4410	11
	09MAY89	85	32			2220			5220						4510	15
	20MAY89	96	22			1530			3080						3680	8
	25MAY89	101				2200			3820						4070	5
	01JUN89	108	34			2590			4150						4310	16
3	07JUN89	114	37			2320			3780						4160	9
	12JUN89	119	19			1915			3425						3850	7
	16JUN89	123	75			1980			3330						3385	5
	21JUN89	128	51			2045			3395						3540	9
	26JUN89	133	20			2250			3735	3300					3605	9
	30JUN89	137	9			2165			3290	3060					3600	14
	03JUL89	140	26	1860	2040	2230	3490	3405	3705	3520	3495	3685	3610	3490	3630	16
4	12JUL89	149	35			2280			3275	3315					3565	13
	17JUL89	154	28			2560			3490	3595					4125	13
	21JUL89	158	36			2600			3615	3540					4095	14
	26JUL89	163	45			2690			3840	3720		3850			4370	10
	31JUL89	168	15			2700			4075	3660		3750			4200	5
	03AUG89	171				2440			3740	3530		3680			4060	9
	07AUG89	175	17			2435			3515	3225		3495			3795	7
	08AUG89	176	25	2080	2003	2315	3430	3205	3365	3280	3250	3260	3560	3610	3785	10
5	21AUG89	189				2165			3170						3205	8
	25AUG89	193	36			2705			3855						4075	11
	29AUG89	197	49	2510	2530	2935	4305	4235	4100	4000	3965	4285	4735	4455	4295	16
	01SEP89	200	49			2955			4445	4345		4385			4640	38
	06SEP89	205	33	2440		2865	4840	4535	4665	4570	4660	4535	5035	4810	4855	16
	11SEP89	210				4510			4470						4435	7
	15SEP89	214	40			3220	4500	4460	4450						4900	9
	20SEP89	219	35			2655			4310						4580	26
	25SEP89	224				2185	3410		3545						3685	28
	27SEP89	226	21	2090	2170	2543	3765	3680	3815	3685	3765	3705	3855	3945	4065	11
	05OCT89	234				2205	3605	3590	3645						3675	17
	12OCT89	241	31			2520			3960						3935	13
6	18OCT89	247				2333			3267						3292	14
	23OCT89	252				1513			2207						2237	4
	25OCT89	254	31			1470			2250						2263	6
	27OCT89	256	35			1513	2060	2063	2483	2113	2150	2140			2363	4
	01NOV89	261	38	1257	1367	1593	2430	2193	2613	2403	2103	2213	2320	2320	2113	9
7	08NOV89	268				1360			2270						2235	11
	13NOV89	273				1460	2265		2505	2180	2125	2270			2495	13
	17NOV89	277				1625	2310		2695	2525	2345	2230			2755	19
	21NOV89	281	29	840	910	1220	1510	1515	1670	1590	1580	1560	1745	1625	1375	8

Table C-6 (Continued). Raw Data: TSS Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
8	29NOV89	289				763			1185						1290	13
	01DEC89	291	51			920			1410						1325	15
	05DEC89	295				955			1455	1330	1680				1595	12
	07DEC89	297	41	785	900	1065	1525	1290	1465	1385	1585	1440	1610	1680	1845	7
9	12DEC89	302				1150			1630						1790	11
	14DEC89	304	36			1115			1535						1845	107
	18DEC89	308													1675	
	21DEC89	311				1020			1570						1780	81
10	27DEC89	317				930			1520						1920	17
	30DEC89	320				930			1450						2020	12
	03JAN90	324				707			993						1375	8
	05JAN90	326	35			590			840						997	5
11	10JAN90	331	26			975			1430						1910	11
	13JAN90	334				1125			1770						2115	25
	16JAN90	337				1205			1580						2050	13
	20JAN90	341				1635			2440						2600	20
	24JAN90	345	39	1045	1415	1360	1760	1750	2060	2170	2860	2120	2630	2655	2270	10
12	31JAN90	352				940			1375						1755	7
	05FEB90	357	17			540			780						990	21
	08FEB90	360				840			1155						1290	42
	12FEB90	364				585			835						900	35
	16FEB90	368				1015			1540						1915	17
	20FEB90	372				815			1160						1375	13
	24FEB90	376	35			845			1175						1470	48
	27FEB90	379													2040	
	01MAR90	381	51			1400			2175						2515	11
	06MAR90	386				845			1495						1730	12
	09MAR90	389				1115			1860						2040	12
	13MAR90	393				765			1400						1650	8
	16MAR90	396				860			1460						1500	9
	20MAR90	400	31			540			1315						975	16
	22MAR90	402				695			1935						1450	15
	26MAR90	406	25			1010			1825						1625	13
	28MAR90	408	75	805	925	930	1485	1410	1830	1500	1500	1450	1645	1445	1575	14
13	03APR90	414				453			860						917	21
	06APR90	417	38			590			1033						1223	7
	11APR90	422	46	540	567	530	897	830	910	937	1027	1043	1053	963	1070	5
14	13APR90	424				473			733						747	10
	16APR90	427													510	19
	19APR90	430	41	302	292	318	423	400	515	500	540	535	595	590	618	11

Table C-6 (Continued). Raw Data: TSS Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7	30			2965			3930						3970	17
	24FEB89	11	34			2540			4260						4110	9
	01MAR89	16	48			3200			4830						4910	3
	06MAR89	21	25			3120			5010						5000	10
	08MAR89	23	50	2610	2800	3440	4960	4880	4970	4690	4750	4810	4780	4900	4680	3
2	15MAR89	30	45			2840			5030						5000	6
	22MAR89	37	40			2620			3860						4390	4
	28MAR89	43	58			2870			5150						4550	21
	30MAR89	45													4860	31
	31MAR89	46													5050	48
	03APR89	49				3170			4910						4860	99
	07APR89	53				2960			4280						4160	high
	12APR89	58	56			1560			6070						2610	13
	13APR89	59				3050			5420						4760	
	17APR89	63	24			2840			4900						4790	4
	21APR89	67	50			2420			4470						4330	8
	26APR89	72	61			2620			4410						4340	1
	03MAY89	79	48	2530	2510	2520	4950	4470	5340	4850	5190	4640	4980	5110	4960	6
	09MAY89	85	32			2400			4320						4540	10
	20MAY89	96	22			2320			3580						4140	7
	25MAY89	101				2370			3970						4330	7
	01JUN89	108	34			2500			4120						4210	7
3	07JUN89	114	37			2060			3780						3720	7
	12JUN89	119	19			2075			3500						3905	3
	16JUN89	123	75			2360			3420						3485	4
	21JUN89	128	51			1595			3010						3205	13
	26JUN89	133	20			2210			3535						3560	5
	30JUN89	137	9			1950			3195						3685	7
	02JUL89	139	19	2245	2210	2420	3525	3230	3385	3500	3585	3640	3760	3895	3770	6
4	12JUL89	149	35			2210			3430						3660	6
	17JUL89	154	28			2300			3535						3980	8
	21JUL89	158	36			2305			3620						4125	4
	26JUL89	163	45			2485			3755						4330	5
	31JUL89	168	15			2355			3690						3940	3
	03AUG89	171				2370			3555						3950	4
	07AUG89	175	17			2165			3360						3540	6
	09AUG89	177	30	2120	2025	2130	3250	2955	2815	3035	3165	3115	3410	3465	3525	6
5	21AUG89	189				1915			3075						3055	5
	25AUG89	193	36			2320			3535						3795	2
	29AUG89	197	49			2440			3900						3950	1
	01SEP89	200	49			2605			4155						4300	3
	06SEP89	205	33			2655			4270						4530	6
	11SEP89	210				2820			4510						4470	4
	15SEP89	214	40			2740			4260						4290	2
	20SEP89	219	35			2565			4720						4440	17
	25SEP89	224				2410			4540						3960	8
	05OCT89	234				2430			3630						3665	5
	12OCT89	241	31			2150			3525						4130	2
6	18OCT89	247				2305			3965						5605	2
	23OCT89	252				1847			3585						5150	1
	25OCT89	254	31			2225			3660						5050	1
	02NOV89	262	41	2100	2247	2565	4165	4150	4125	3955	4150	4440	4560	5550	5230	6
7	08NOV89	268				2400			4900						4725	35
	09NOV89	269		2680		3030		5315							3640	11
	13NOV89	273				2320			4790						4045	13
	17NOV89	277				3100			5340						4640	70

Table C-6 (Continued). Raw Data: TSS Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
8	24NOV89	284				1940			3870						3740	3
	29NOV89	289				2355			3500						3485	1
	01DEC89	291	51			1860			3310						3240	7
	05DEC89	295				2170			3180						3070	6
9	12DEC89	302				1890			3410						3105	2
	14DEC89	304	36			1605			2830						2675	155
	21DEC89	311				2230			4670						3980	3
10	27DEC89	317				2540			4480						5340	2
	30DEC89	320				2810			4870						4800	2
	03JAN90	324				2580			4390						4460	2
	05JAN90	326	35			2540			3780						3765	4
11	10JAN90	331	26			2510			3970						4410	2
	13JAN90	334				2675			4635						4890	1
	16JAN90	337				3150			4960						5340	1
	20JAN90	341				3625			5660						5980	3
	23JAN90	344	55	2425	2480	3240	5240	5020	5330	5270	5860	5670	5770	5760	5960	1
12	31JAN90	352				2790			5190						5530	2
	05FEB90	357	17			2735			4605						4685	636
	08FEB90	360				2950			4785						4570	high
	12FEB90	364				2145			4575						4210	348
	16FEB90	368				2395			4025						4375	high
	20FEB90	372				2605			4335						4145	19
	24FEB90	376	35			2575			4292						4358	6
	27FEB90	379													4420	
	01MAR90	381	51			1315			4417						4430	
	06MAR90	386				2875			4245						3960	4
	09MAR90	389				2735			4100						4235	7
	13MAR90	393				2185			3990						3990	10
	16MAR90	396				2580			4135						4055	10
	20MAR90	400	31			2340			3800						3833	42
	22MAR90	402				2770			4590						4715	27
	26MAR90	406	25	2615	2810	3360	5460	5430	5295	5290	5325	5590	5640	5670	5650	18
13	03APR90	414				3440			4875						5055	13
	06APR90	417	38			3285			4685						4945	12
14	13APR90	424				2330			4350						4575	17
	17APR90	428	39													
	18APR90	429				2765			4715						4310	36

Table C-6 (Continued). Raw Data: TSS Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7	30			1535			1590						1600	25
	24FEB89	11	34			1950			2040						2300	20
	01MAR89	16	48			2910			2680						2750	18
	06MAR89	21	25			2610			2480						2540	13
	10MAR89	25	44	2680	3060	2810	2660	2760	2910	2560	2610	2540	2640	2480	2630	10
2	15MAR89	30	45			3200			2610						2510	23
	22MAR89	37	40			2130			2070						2150	16
	28MAR89	43	58			2610			2540						2450	17
	30MAR89	45													2720	9
	31MAR89	46													2750	22
	03APR89	49				2860			2540						2650	15
	07APR89	53				3060			3470						2930	27
	12APR89	58	56			3060			3220						2610	17
	17APR89	63	24			2990			2600						2990	8
	21APR89	67	50			3010			2890						2850	4
	26APR89	72	61			2980			3060						3090	12
	06MAY89	82	31	2445	2590	2540	2680	3030	2495	2475	2520	2755	2655	2460	2460	18
	09MAY89	85	32						2360						2270	9
	20MAY89	96	22						2060						2360	11
	25MAY89	101							2400						2810	3
	01JUN89	108	34						2100						2630	7
3	07JUN89	114	37			2690			2710						2540	19
	12JUN89	119	19			2395			2210						2450	13
	16JUN89	123	75			2810			2040						2290	11
	21JUN89	128	51			1820			1770						1885	11
	26JUN89	133	20	1920		1655			1180						1230	28
	30JUN89	137	9	1675		1535			1325						1460	37
	04JUL89	141	59	1515	1630	1455	1625	1625	1810	1655	1790	1660	1950	1810	1675	23
4	12JUL89	149	35	1520		1995			1815						1850	3
	17JUL89	154	28	2225		2225			2035						2195	7
	21JUL89	158	36	2575		2630			2485						2430	8
	26JUL89	163	45	2745		2930			2595						2675	12
	31JUL89	168	15	2600		2845			2515						2635	9
	03AUG89	171		2630		3115			2570						2615	6
	07AUG89	175	17	2570		2755			2470						2695	5
	10AUG89	178	30	2255	2825	3265	2975	2770	2670	2505	2440	2430	2520	2370	2330	2
5	21AUG89	189													1705	43
	25AUG89	193	36												2785	3
	29AUG89	197	49	2640		2540			2395						2640	6
	01SEP89	200	49	2740		2495									2820	7
	06SEP89	205	33	2455	2700	2600	2605	2525	2665						2715	17
	11SEP89	210				3410									3090	19
	15SEP89	214	40	2420	2470	2450			2425						2515	10
	20SEP89	219	35	3275		3070									2360	13
	25SEP89	224		1820	1800	1965	1955	1685	2065						1975	19
	28SEP89	227	39	2095	2175	2000	1830	1590	1830	1625	1830	1840	2155	1970	1755	17
	05OCT89	234							1440						1655	7
	12OCT89	241	31						2050						2260	17
6	18OCT89	247							1783						2020	17
	23OCT89	252		1480					1197						1363	6
	25OCT89	254	31	1443					1293						1690	6
	27OCT89	256	35	1307	1023	1167			1157						1585	10
	31OCT89	260	40	1103	1177	817	1120	1097	890	730	763	720	803	917	1157	3
7	08NOV89	268		1617		2557			1227						2226	18
	13NOV89	273		1400	1345				1580						2000	8
	17NOV89	277		1630	1940				1695						1855	6
	20NOV89	280	19	1600	1863	857	1170	1053	1300	1030	1037	1060	1340	1243	1303	3

Table C-6 (Continued). Raw Data: TSS Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
8	29NOV89	289		1120					720						1155	4
	01DEC89	291	51	1565	1405				1075			1145			1465	7
	05DEC89	295		2175	1985				1500			1245			2085	2
	08DEC89	298	34	1785	1740	1680	1865	1765	1430	1355	1460	1445	1455	1275	1810	2
9	12DEC89	302		2350					1695						2490	3
	14DEC89	304	36	2395					1690						1895	2
	18DEC89	308													1690	
	21DEC89	311		2320					1580						2010	5
10	27DEC89	317		1580					1500						1510	2
	30DEC89	320		2310					1400						1540	2
	03JAN90	324		960					1050						1097	2
	05JAN90	326	35	693					893						897	3
11	10JAN90	331	26	1735					1415						1995	2
	13JAN90	334		1850					1535						2055	2
	16JAN90	337		2445					1780						1945	3
	20JAN90	341		2135					1880						2130	4
	26JAN90	347	37	1810	1935	2000	1895	1790	1825	1920	1890	1900	1770	1845	2105	3
12	31JAN90	352		1595		1190			1040						1345	145
	05FEB90	357	17	1500		1200			735						1150	99
	08FEB90	360		1320		1565			1280						1740	6
	12FEB90	364				1530			1175						1380	7
	16FEB90	368		1010		1040			1080						1315	13
	20FEB90	372		1300		3550			1220						820	20
	24FEB90	376	35	1190		1465			1220						1115	27
	27FEB90	379													945	
	01MAR90	381	51	1435		905			925						940	24
	06MAR90	386		910		710			470						405	27
	09MAR90	389		940		790			885						860	48
	13MAR90	393		1275		1035			1265						1400	14
	16MAR90	396		1230		1170			1015						1145	17
	20MAR90	400	31	555		770			470						420	63
	22MAR90	402		1625		1550			985						1595	14
	26MAR90	406	25	1905		1670			1205						1505	9
	29MAR90	409	33	1360	1725	1535	1635	1470	1315	1320	1305	1270	1435	1800	1615	19
13	03APR90	414		1144		1123			933						950	12
	06APR90	417	38	923		1073			830						930	4
	10APR90	421	41	920	1130	813	967	730	666	610	597	660	707	600	760	2
14	13APR90	424		697		697			617						690	5
	16APR90	427													590	5
	17APR90	428	39	462	524	560	654	474	406	444	428	428	510	344	466	10

Table C-7. Raw Data: VSS Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7	25			1900			2700						2640	28
	24FEB89	11	27			2100			3040						2980	6
	01MAR89	16	41			2900			3530						3590	8
	06MAR89	21	22			3060			3650						3450	10
	09MAR89	24	42	1970	2060	2950	3450	3470	3410	3370	3420	3290	3320	3360	3360	1
2	15MAR89	30	38			2710			3570						3470	2
	22MAR89	37	33			2210			2820						2940	6
	28MAR89	43	51			2770			3490						3250	44
	30MAR89	45													3250	170
	31MAR89	46													3340	41
	03APR89	49				3000			3620						3410	26
	07APR89	53				2580			3160						2960	4
	12APR89	58	78			2490			3130						2760	2
	13APR89	59														
	17APR89	63	29			2080			3440						3130	12
	21APR89	67	44			2730	3580		3380						3240	4
	26APR89	72	52			1880	3480		3290			3480			3270	4
	02MAY89	78	35	1720	1810	1810	4510	3600	3380	3420	3410	3720	3610	3340	3240	7
	09MAY89	85	20			1610			3690						3170	9
	20MAY89	96	21			1180			2310						2770	7
	25MAY89	101				1680			2880						3020	5
	01JUN89	108	29			1990			3090						3150	12
3	07JUN89	114	29			1710			2740						2960	7
	12JUN89	119	17			1330			2475						2740	5
	16JUN89	123	67			1525			2490						2530	5
	21JUN89	128	41			1595			2515						2595	7
	26JUN89	133	19			1540			2535	2175					2290	2
	30JUN89	137	12			1710			2495	2325					2655	12
	03JUL89	140	29	1475	1615	1735	2590	2540	2705	2590	2595	2705	2655	2610	2660	14
4	12JUL89	149	34			1815			2560	2570					2765	11
	17JUL89	154	21			2005			2715	2800					3165	10
	21JUL89	158	30			2020			2795	2730					3090	10
	26JUL89	163	35			2115			2965	2875		2965			3320	7
	31JUL89	168	10			2030			3040	2715		2760			3110	4
	03AUG89	171				1835			2760	2600		2690			2980	7
	07AUG89	175	13			1820			2615	2390		2580			2780	5
	08AUG89	176	19	1597	1507	1740	2525	2410	2465	2425	2355	2400	2625	2670	2755	7
5	21AUG89	189				1650			2355						2370	5
	25AUG89	193	30			2040			2840						2940	9
	29AUG89	197	43	1880	1895	2200	3130	3075	2965	2835	2805	2975	3110	3085	3025	11
	01SEP89	200	37			2145			3090	3050		3015			3180	29
	06SEP89	205	28	1820		2070	3385	3155	3160	3155	3170	3080	3345	3260	3320	10
	11SEP89	210				1950			3080						3140	4
	15SEP89	214	37			2300	3150	3105	3095						3315	7
	20SEP89	219	29			1975			3110						3270	18
	25SEP89	224				1515	2350		2460						2540	21
	27SEP89	226	16	1487	1550	1797	2630	2565	2660	2550	2640	2550	2645	2720	2830	8
	05OCT89	234				1605	2625	2610	2490						2595	13
	12OCT89	241	32			1880			2890						2850	11
6	18OCT89	247				1687			2270						2307	9
	23OCT89	252				1083			1557						1570	3
	25OCT89	254	27			1083			1600						1597	5
	27OCT89	256	31			1103	1490	1477	1753	1493	1513	1520			1673	4
	01NOV89	261	31	923	990	1107	1637	1477	1737	1570	1387	1457	1517	1537	1400	6
7	08NOV89	268				1105			1765						1700	8
	13NOV89	273				1075	1630		1810	1570	1515	1630			1765	10
	17NOV89	277				1230	1705		1950	1805	1720	1605			1985	11

Table C-7 (Continued). Raw Data: VSS Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
8	29NOV89	289				630			970						1043	11
	01DEC89	291	42			745			1175						1090	13
	05DEC89	295				825			1230	1250	1460				1370	11
	07DEC89	297	34	685	770	915	1300	1105	1250	1200	1335	1220	1380	1420	1555	7
9	12DEC89	302				1010			1395						1525	10
	14DEC89	304	26			970			1315						1570	93
	18DEC89	308				820			1165						1435	75
	21DEC89	311				850			1320						1495	68
10	27DEC89	317				780			1250						1500	13
	30DEC89	320				750			1140						1630	10
	03JAN90	324				560			803						1100	7
	05JAN90	326	20			477			680						820	4
11	10JAN90	331	19			850			1215						1615	9
	13JAN90	334				970			1530						1825	21
	16JAN90	337				980			1355						1735	12
	20JAN90	341				1350			1950						2145	13
	24JAN90	345	33	905	1210	1160	1480	1460	1710	1810	2460	1800	2240	2260	1925	9
12	31JAN90	352				795			1170						1485	6
	05FEB90	357	15			455			650						810	18
	08FEB90	360				650			920						1040	35
	12FEB90	364				480			685						730	31
	16FEB90	368				890			1380						1640	16
	20FEB90	372				690			965						1125	11
	24FEB90	376	33			685			910						1090	39
	27FEB90	379													1330	
	01MAR90	381	43			890			1415						1580	8
	06MAR90	386				540			900						1040	8
	09MAR90	389				775			1205						1285	8
	13MAR90	393				630			1030						1135	5
	16MAR90	396				600			1025						1030	6
	20MAR90	400	24			395			960						690	12
	22MAR90	402				535			1480						1040	12
	26MAR90	406	24			735			1260						1130	12
	28MAR90	408	69	565	675	665	1020	945	1240	990	995	955	1110	970	1065	10
13	03APR90	414				343			597						633	15
	06APR90	417	29			443			750						873	7
	11APR90	422	39	433	450	420	673	633	723	700	760	770	763	710	790	5
14	13APR90	424				413			633						613	10
	16APR90	427													385	16
	19APR90	430	34	250	240	258	340	318	415	405	435	423	468	463	484	8

Table C-7 (Continued). Raw Data: VSS Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7	25			2200			2890						2890	13
	24FEB89	11	27			1950			3180						2820	6
	01MAR89	16	41			2420			3620						3600	4
	06MAR89	21	22			2380			3690						3590	9
	08MAR89	23	42	1960	2120	2530	3630	3590	3690	3460	3430	3470	3460	3550	3390	4
2	15MAR89	30	38			1980			3480						3550	5
	22MAR89	37	33			2000			2830						3110	5
	28MAR89	43	51			2120			3620						3160	17
	30MAR89	45													3210	24
	31MAR89	46													3390	38
	03APR89	49				2220			3360						3290	70
	07APR89	53				2100			3040						2800	814
	12APR89	58	78			1260			4430						1990	11
	13APR89	59				2180			3840						3300	2
	17APR89	63	29			2090			3560						3450	4
	21APR89	67	44			1870			3460						3290	8
	26APR89	72	52			2020			3300						3250	2
	03MAY89	79	41	1950	1900	1900	3610	3260	3900	3530	3760	3380	3620	3710	3610	5730
	09MAY89	85	20			1680			3030						3190	6
	20MAY89	96	21			1780			2690						3080	6
	25MAY89	101				1810			2990						3230	5
	01JUN89	108	29			1920			3070						3120	6
3	07JUN89	114	29			1570			2810						2730	5
	12JUN89	119	17			1550			2535						2825	2
	16JUN89	123	67			1830			2580						2630	4
	21JUN89	128	41			1260			2250						2385	11
	26JUN89	133	19			1565			2360						2420	2
	30JUN89	137	12			1600			2450						2735	8
	02JUL89	139	14	1710	1645	1785	2550	2335	2440	2500	2560	2625	2725	2805	2715	5
4	12JUL89	149	34			1790			2695						2885	4
	17JUL89	154	21			1910			2825						3135	6
	21JUL89	158	30			1850			2840						3190	4
	26JUL89	163	35			1950			2945						3370	4
	31JUL89	168	10			1800			2805						2950	2
	03AUG89	171				1810			2670						2930	3
	07AUG89	175	13			1640			2510						2660	4
	09AUG89	177	22	1655	1535	1600	2410	2220	2115	2250	2360	2300	2520	2545	2605	4
5	21AUG89	189				1475			2310						2280	3
	25AUG89	193	30			1785			2650						2770	2
	29AUG89	197	43			1825			2825						2785	1
	01SEP89	200	37			1915			2960						3030	3
	06SEP89	205	28			1950			2965						3070	4
	11SEP89	210				2015			3070						3045	3
	15SEP89	214	37			2005			2995						2925	2
	20SEP89	219	29			1875			3360						3190	11
	25SEP89	224				1685			3140						2780	8
	05OCT89	234				1710			2485						2510	4
	12OCT89	241	32			1510			2405						2825	2
6	18OCT89	247				1605			2620						3795	1
	23OCT89	252				1227			2360						3535	0
	25OCT89	254	27			1525			2455						3385	1
	02NOV89	262	36	1463	1523	1745	2770	2695	2660	2480	2690	2920	2880	3635	3455	5
7	08NOV89	268				1745			3430						3270	25
	09NOV89	269		1805		1700		3800							2985	9
	13NOV89	273				1645			3290						2755	10
	17NOV89	277				2240			3750						3240	52

Table C-7 (Continued). Raw Data: VSS Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
8	24NOV89	284				1390			2720						2640	3
	29NOV89	289				1770			2640						2540	2
	01DEC89	291	42			1380			2470						2470	7
	05DEC89	295				1520			2420						2400	5
9	12DEC89	302				1620			2830						2490	2
	14DEC89	304	26			1365			2390						2170	129
	18DEC89	308				1880			3530						3140	2
	21DEC89	311				2335			3720						3140	1
10	27DEC89	317				1880			3200						3830	2
	30DEC89	320				2080			3500						3460	1
	03JAN90	324				1850			3120						3170	2
	05JAN90	326	20			1910			2795						2815	3
11	10JAN90	331	19			2010			3060						3335	2
	13JAN90	334				2145			3570						3700	1
	16JAN90	337				2400			3595						3810	1
	20JAN90	341				2610			3930						4000	1
	23JAN90	344	50	1825	1875	2355	3760	3550	3790	3680	4040	3890	3930	3950	4100	1
12	31JAN90	352				1965			3400						3565	1
	05FEB90	357	15			1810			2880						2850	426
	08FEB90	360				1930			2930						2740	high
	12FEB90	364				1400			2815						2505	237
	16FEB90	368				1705			2683						2775	high
	20FEB90	372				1705			2655						2485	13
	24FEB90	376	33			1715			2658						2675	4
	27FEB90	379													2520	
	01MAR90	381	43			835			2625						2620	
	06MAR90	386				1745			2585						2395	3
	09MAR90	389				1835			2605						2630	5
	13MAR90	393				1555			2605						2850	8
	16MAR90	396				1730			2650						2625	7
	20MAR90	400	24			1510			2383						2375	30
	22MAR90	402				1735			2840						2880	20
	26MAR90	406	24	1490	1600	1890	3095	3180	2930	2965	2990	3160	3230	3260	3240	13
13	03APR90	414				2040			2835						2955	8
	06APR90	417	29			2030			2825						2985	8
14	13APR90	424				1625			2805						2910	12
	18APR90	429				1800			2990						2710	26

Table C-7 (Continued). Raw Data: VSS Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
1	20FEB89	7	25			1305			1350						1360	20
	24FEB89	11	27			1640			1710						1930	14
	01MAR89	16	41			2490			2310						2410	16
	06MAR89	21	22			2250			2140						2220	12
	10MAR89	25	38	2270	2590	2360	2280	2360	2490	2190	2240	2140	2240	2160	2290	9
2	15MAR89	30	38			2690			2230						2140	19
	22MAR89	37	33			1820			1800						1860	11
	28MAR89	43	51			2210			2150						2090	14
	30MAR89	45													2200	7
	31MAR89	46													2300	17
	03APR89	49				2450			2210						2270	15
	07APR89	53				2620			2930						2460	19
	12APR89	58	78			2830			2900						2440	22
	17APR89	63	29			2390			2320						2520	7
	21APR89	67	44			2650			2550						2500	6
	26APR89	72	52			2570			2680						2640	11
	06MAY89	82	31	2045	2170	2115	2250	2505	2080	2070	2105	2310	2215	2085	2115	16
	09MAY89	85	20						1870						1760	7
	20MAY89	96	21						1665						1890	10
	25MAY89	101							1950						2240	3
	01JUN89	108	29						1680						2130	5
3	07JUN89	114	29			2080			2100						1980	14
	12JUN89	119	17			1840			1690						1875	9
	16JUN89	123	67			2175			1630						1815	10
	21JUN89	128	41			1445			1370						1475	9
	26JUN89	133		1345		1135			880						825	15
	30JUN89	137	12	1390		1305			1145						1255	33
	02JUL89	139	14												1375	21
	04JUL89	141	58	1270	1430	1290	1260	1275	1430	1335	1375	1310	1505	1355	1340	14
4	12JUL89	149	34	1245		1645			1500						1520	3
	17JUL89	154	21	1795		1810			1680						1795	6
	21JUL89	158	30	2125		2150			2035						1980	6
	26JUL89	163	35	2280		2415			2135						2200	10
	31JUL89	168	10	2120		2335			2090						2175	6
	03AUG89	171		2110		2490			2075						2130	4
	07AUG89	175	13	2065		2210			2015						2200	4
	10AUG89	178	22	1830	2215	2580	2355	2215	2145	2015	1980	1960	1995	1925	1890	1
5	21AUG89	189													1405	35
	25AUG89	193	30												2305	2
	29AUG89	197	43	2225		2095			2020						2215	5
	01SEP89	200	37	2335		2115									2390	6
	06SEP89	205	28	2120	2315	2255	2245	2165	2265						2320	14
	11SEP89	210				3020									2710	16
	15SEP89	214	37	2090	2130	2100			2090						2185	9
	20SEP89	219	29	2770		2565									2025	11
	25SEP89	224		1490	1485	1635	1590	1490	1720						1605	15
	28SEP89	227	31	1780	1830	1685	1555	1330	1550	1365	1545	1560	1835	1665	1480	13
	05OCT89	234							1245						1425	6
	12OCT89	241	32						1800						1955	15
6	18OCT89	247							1497						1710	13
	23OCT89	252		1207					997						1150	5
	25OCT89	254	27	1213					1073						1397	5
	27OCT89	256	31	1097	867	977			990						1330	9
	31OCT89	260	36	973	1030	727	1015	960	780	647	680	663	720	827	1020	3
7	08NOV89	268		1593		2017			1027						1963	17
	13NOV89	273		1255	1185				1390						1765	7
	17NOV89	277		1435	1710				1470						1620	5
	20NOV89	280	16	1353	1570	727	997	893	1093	873	877	897	1143	1063	1110	3

Table C-7 (Continued). Raw Data: USS Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf mg/L	Sec1 mg/L	Sec2 mg/L	Sec3 mg/L	Sec4 mg/L	Sec5 mg/L	Sec6 mg/L	Sec7 mg/L	Sec8 mg/L	Sec9 mg/L	Sec10 mg/L	Sec11 mg/L	Sec12 mg/L	Eff mg/L
8	29NOV89	289		995					615						990	3
	01DEC89	291	42	1305	1190				910			975			1245	6
	05DEC89	295		1870	1710				1290			1075			1795	3
	08DEC89	298	29	1540	1505	1460	1600	1515	1240	1175	1270	1255	1250	1095	1570	2
9	12DEC89	302		2035					1445						2135	2
	14DEC89	304	26	2065					1450						1640	1
	18DEC89	308		1230					1210						1480	2
	21DEC89	311		1985					1330						1710	4
10	27DEC89	317		1330					1260						1270	2
	30DEC89	320		1960					1160						1290	1
	03JAN90	324		817					877						917	3
	05JAN90	326	20	577					763						767	2
11	10JAN90	331	19	1480					1215						1705	2
	13JAN90	334		1600					1320						1775	1
	16JAN90	337		2090					1540						1640	3
	20JAN90	341		1815					1595						1790	2
	26JAN90	347	30	1590	1690	1745	1665	1565	1595	1675	1660	1665	1555	1615	1840	3
12	31JAN90	352		1335		1025			880						1140	125
	05FEB90	357	15	1300		1020			645						990	87
	08FEB90	360		1100		1330			1075						1470	4
	12FEB90	364				1315			1000						1180	6
	16FEB90	368		900		925			940						1175	12
	20FEB90	372		1105		3035			1075						720	18
	24FEB90	376	33	1035		1245			1035						950	24
	27FEB90	379													775	
	01MAR90	381	43	1210		795			765						770	18
	06MAR90	386		760		600			395						335	22
	09MAR90	389		800		665			755						735	40
	13MAR90	393		1095		875			1060						1200	11
	16MAR90	396		1025		970			840						955	14
	20MAR90	400	24	445		640			395						335	52
	22MAR90	402		1400		1340			870						1335	13
	26MAR90	406	24	1695		1475			1095						1335	8
	29MAR90	409	30	1175	1480	1340	1415	1260	1140	1135	1115	1085	1245	1645	1375	16
13	03APR90	414		927		943			773						797	10
	06APR90	417	29	773		893			710						803	4
	10APR90	421	35	790	960	690	833	627	580	530	513	577	620	530	647	2
14	13APR90	424		617		617			550						597	5
	16APR90	427													488	5
	17APR90	428	32	392	462	490	572	420	368	402	392	382	472	314	424	9

Table C-8. Raw Data: pH Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
1	24FEB89	11	6.9			6.7									6.8	
	01MAR89	16	6.9												6.8	
	06MAR89	21				6.7			6.7			6.9			6.8	7.2
	09MAR89	24	6.9			6.9			7.0			7.2			7.2	7.2
2	15MAR89	30	6.9			6.3			6.9							7.2
	28MAR89	43	6.9			6.8			6.8						6.8	7.0
	17APR89	63	7.0													6.5
	26APR89	72	7.0													6.9
	02MAY89	78	7.0	6.9	6.9	6.9	6.9	6.9	6.9	6.7	6.7	6.7	6.6	6.6	6.6	6.8
	12MAY89	88	7.6													7.4
	20MAY89	96	7.0													7.0
	25MAY89	101	7.1													7.1
	01JUN89	108	6.9			6.5			6.5						6.5	7.0
3	07JUN89	114	6.8													6.7
	12JUN89	119	7.4													7.1
	16JUN89	123	6.8													7.0
	26JUN89	133	6.8													7.4
	03JUL89	140	6.8		6.8		6.8				6.7		6.9		6.9	7.2
4	12JUL89	149	6.5			6.9									7.0	7.1
	17JUL89	154	6.6													7.5
	26JUL89	163	6.7													6.9
	03AUG89	171														7.1
	07AUG89	175	7.0													7.2
	08AUG89	176	6.9													7.1
5	29AUG89	197	7.0													6.7
	01SEP89	200	6.9													7.0
	06SEP89	205	7.0													7.0
	11SEP89	210	7.0													7.1
	20SEP89	219	7.0													7.3
	25SEP89	224	7.2													7.8
	27SEP89	226	7.7													7.8
	05OCT89	234				7.2			7.2	7.3						7.6
	06OCT89	235	7.0													6.7
	12OCT89	241				7.1			7.1						7.1	7.5
6	18OCT89	247	7.4													7.4
	27OCT89	256	7.1													7.1
	01NOV89	261	7.2	7.0	7.0	7.0	7.0	7.0	7.0	6.8	6.8	6.8	6.8	6.8	6.8	7.1
7	08NOV89	268	6.6													7.3
	13NOV89	273	7.2													7.4
	17NOV89	277	7.2													7.7
	21NOV89	281	7.1	7.3		7.2	7.4		7.5	7.7						7.4
8	29NOV89	289	7.3													7.7
	01DEC89	291	7.1													7.5
	07DEC89	297	7.0							7.4						7.5
9	12DEC89	302	7.2													7.7
	14DEC89	304	7.0			7.3										7.7
	21DEC89	311	7.1													7.8
10	03JAN90	324	8.6													7.9
	05JAN90	326	8.8													7.9
11	10JAN90	331	7.8													7.8
	13JAN90	334														7.8
	16JAN90	337	7.4													7.7
	20JAN90	341	6.6													7.6
	24JAN90	345	7.2		7.4					7.6	7.5					7.8

Table C-8 (Continued). Raw Data: pH Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
12	31JAN90	352	6.9													7.8
	05FEB90	357	7.4													7.9
	08FEB90	360	7.3													8.0
	12FEB90	364	7.2													8.2
	16FEB90	368	7.2													7.9
	20FEB90	372	7.2													7.9
	24FEB90	376	7.2													7.9
	01MAR90	381	7.3													7.7
	06MAR90	386														7.7
	09MAR90	389	7.0													7.3
	13MAR90	393	6.4													7.9
	20MAR90	400	7.4													7.7
	22MAR90	402	7.2													7.5
	26MAR90	406	7.3													7.5
	28MAR90	408	7.2		7.3			7.2				7.1				7.2
13	03APR90	414	6.9													7.5
	06APR90	417	7.0													7.5
	11APR90	422	6.8			7.2			7.4			7.4			7.4	7.4
14	13APR90	424	5.9													7.4
	19APR90	430	7.2	7.4		7.5			7.6			7.6				7.5

Table C-8 (Continued). Raw Data: pH Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
1	24FEB89	11	6.9			7.0									6.9	
	01MAR89	16	6.9												6.6	
	06MAR89	21				6.7			6.7			6.9			6.8	7.2
	09MAR89	24	6.9													7.2
2	15MAR89	30	6.9			6.3			6.9							7.2
	28MAR89	43	6.9			6.7			6.7						6.7	7.0
	17APR89	63	7.0												6.4	
	26APR89	72	7.0													6.9
	03MAY89	79	6.7			6.8			6.8						6.8	7.0
	12MAY89	88	7.6													7.4
	20MAY89	96	7.0													7.0
	25MAY89	101	7.1													7.1
	01JUN89	108	6.9			6.7			6.8						6.8	7.0
3	07JUN89	114	6.8													6.7
	12JUN89	119	7.4													7.1
	16JUN89	123	6.8													7.0
	26JUN89	133	6.8													7.4
	02JUL89	139	7.1		7.0		7.0				7.0		7.2		7.3	7.6
4	12JUL89	149	6.5													7.1
	17JUL89	154	6.6													7.5
	26JUL89	163	6.7													6.9
	03AUG89	171														7.0
	07AUG89	175	7.0													7.2
	09AUG89	177	7.0													7.0
5	29AUG89	197	7.0													6.7
	01SEP89	200	6.9													7.0
	06SEP89	205	7.0													7.0
	11SEP89	210	7.0													7.2
	20SEP89	219	7.0													7.3
	25SEP89	224	7.2													7.8
	05OCT89	234				7.1			7.2						7.2	7.5
	12OCT89	241				6.9			7.0						6.9	7.2
6	18OCT89	247	7.4													7.3
	02NOV89	262	7.1	7.0	6.9	7.0	6.8	6.9	6.9	7.0	7.0	7.0	6.9	6.8	6.8	7.1
7	08NOV89	268	6.6													7.3
	09NOV89	269	7.4	7.5	7.5	7.4	7.5	7.6	7.5	7.7	7.7	7.7	7.7	7.7	7.7	7.5
	13NOV89	273	7.2													7.3
	17NOV89	277	7.2													7.7
8	29NOV89	289	7.3													7.3
	01DEC89	291	7.1													7.1
9	12DEC89	302	7.2													7.6
	14DEC89	304	7.0			7.2										7.7
	21DEC89	311	7.1													7.7
10	03JAN90	324	8.6													7.9
	05JAN90	326	8.8													7.8
11	10JAN90	331	7.8													7.8
	13JAN90	334														7.8
	16JAN90	337	7.4													7.6
	20JAN90	341	6.6													7.6
	23JAN90	344	6.6			6.9			7.2			7.0				7.4

Table C-8 (Continued). Raw Data: pH Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
12	31JAN90	352	6.9													7.7
	05FEB90	357	7.4													8.1
	08FEB90	360	7.3													7.8
	12FEB90	364	7.2													8.1
	16FEB90	368	7.2													7.8
	20FEB90	372	7.2													7.8
	24FEB90	376	7.2													7.8
	01MAR90	381	7.3													7.6
	06MAR90	386														7.6
	09MAR90	389	7.0													7.3
	13MAR90	393	6.4													8.0
	20MAR90	400	7.4													7.7
	22MAR90	402	7.2													7.5
	26MAR90	406	7.3	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.0	7.1	7.1	7.1	7.1	7.5
13	03APR90	414	6.9													7.5
	06APR90	417	7.0													7.5
14	13APR90	424	5.9													7.6
	18APR90	429	7.0													7.2

Table C-8 (Continued). Raw Data: pH Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
1	24FEB89	11	6.9												6.8	
	01MAR89	16	6.9												6.6	
	06MAR89	21				6.6			6.4			6.3			6.1	6.0
	10MAR89	25	6.9			6.5			6.3			6.3			6.0	6.0
2	15MAR89	30	6.9													6.8
	28MAR89	43	6.9						6.2							6.4
	17APR89	63	7.0			6.0										5.8
	26APR89	72	7.0													6.1
	06MAY89	82	7.0	6.6		6.4			6.4			6.3				6.4
	12MAY89	88	7.6													7.4
	20MAY89	96	7.0													7.0
	25MAY89	101	7.1													7.2
	01JUN89	108	6.9						6.6						6.5	6.9
3	07JUN89	114	6.8													6.4
	12JUN89	119	7.4													6.9
	16JUN89	123	6.8													6.7
	26JUN89	133	6.8													7.2
	04JUL89	141	6.0		7.0		7.0		7.2		7.1		7.1		7.1	7.2
4	12JUL89	149	6.5												6.8	7.0
	17JUL89	154	6.6													7.5
	26JUL89	163	6.7													6.9
	03AUG89	171														7.1
	07AUG89	175	7.0													7.2
	10AUG89	178	7.0													6.9
5	29AUG89	197	7.0													5.4
	01SEP89	200	6.9													6.4
	06SEP89	205	7.0													5.8
	11SEP89	210	7.0													6.5
	20SEP89	219	7.0													7.3
	25SEP89	224	7.2													7.8
	28SEP89	227	7.0													7.3
	05OCT89	234														7.3
	12OCT89	241							6.4						6.4	6.6
6	18OCT89	247	7.4													6.3
	27OCT89	256	7.1													6.5
	31OCT89	260	7.1	7.4	7.2				7.0							7.0
7	08NOV89	268	6.6													6.6
	13NOV89	273	7.2													7.0
	17NOV89	277	7.2													7.5
	20NOV89	280	7.4	7.7	7.7				7.1							7.0
8	29NOV89	289	7.3													7.6
	01DEC89	291	7.1													7.5
	08DEC89	298	7.3	7.4												7.2
9	12DEC89	302	7.2													7.7
	14DEC89	304	7.0													7.7
	21DEC89	311	7.1													7.9
10	03JAN90	324	8.6													8.0
	05JAN90	326	8.8													7.9
11	10JAN90	331	7.8													7.8
	13JAN90	334														7.7
	16JAN90	337	7.4													7.5
	20JAN90	341	6.6													7.6
	26JAN90	347	7.2	7.4					7.3							7.5

Table C-8 (Continued). Raw Data: pH Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
12	31JAN90	352	6.9													7.7
	05FEB90	357	7.4													8.0
	08FEB90	360	7.3													7.9
	12FEB90	364	7.2													8.1
	16FEB90	368	7.2													7.9
	20FEB90	372	7.2													8.0
	24FEB90	376	7.2													8.0
	01MAR90	381	7.3													7.9
	06MAR90	386														7.6
	09MAR90	389	7.0													7.3
	13MAR90	393	6.4													7.9
	20MAR90	400	7.4													7.7
	22MAR90	402	7.2													7.4
	26MAR90	406	7.3													7.6
	29MAR90	409	7.3	7.0			6.8				6.6				6.6	6.8
13	03APR90	414	6.9													7.2
	06APR90	417	7.0													7.1
	10APR90	421	7.0	7.3	7.3	7.3			7.1							7.1
14	13APR90	424	5.9													7.3
	17APR90	428	7.1	7.6	7.6	7.5			7.5			7.4				7.3

Table C-9. Raw Data: Alkalinity Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
1	09MAR89	24														162
	10MAR89	25	166													
2	17APR89	63	184													56
	26APR89	72	173													56
	02MAY89	78	166						114							57
	20MAY89	96	211													109
4	08AUG89	176														85
5	29AUG89	197	179													46
	27SEP89	226	191													109
6	03NOV89	263	193													85
7	21NOV89	281	187													96
8	07DEC89	297	175													163
11	24JAN90	345	223													226
12	28MAR90	408	179													58
13	11APR90	422	180													100
14	19APR90	430	182													110

Table C-9 (Continued). Raw Data: Alkalinity Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
1	08MAR89	23														154
	10MAR89	25	166													
2	17APR89	63	184													55
	26APR89	72	173													58
	03MAY89	79	172													94
4	09AUG89	177	174													78
6	02NOV89	262	181													52
7	09NOV89	269	184	170	175	171	132	127	131	110	97	88	78	75	73	59
11	23JAN90	344	169													180

Table C-9 (Contiued). Raw Data: Alkalinity Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf	Sec1	Sec2	Sec3	Sec4	Sec5	Sec6	Sec7	Sec8	Sec9	Sec10	Sec11	Sec12	Eff
1	10MAR89	25	166													13
2	17APR89	63	184													8
	26APR89	72	173													47
	06MAY89	82	171												23	23
	20MAY89	96	211													78
3	04JUL89	141	108													70
4	10AUG89	178	164													43
5	29AUG89	197	179													4
6	31OCT89	260	147													44
7	20NOV89	280	212													34
8	08DEC89	298	175													80
11	26JAN90	347	207													121
12	29MAR90	409	175													24
13	10APR90	421	179													37
14	17APR90	428	200													77

Table C-10. Raw Data: Phosphorus Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/VSS %
1	20FEB89	7				16.0	14.5			18.2			19.0						2.4	4.9	4.4	5.47	7.50
	24FEB89	11					14.8			27.0			19.0						11.7	12.4			
	01MAR89	16				16.6	16.0			29.7			23.2						4.0	0.9	0.9	5.83	7.86
	06MAR89	21				15.2	13.7			29.5			24.1						7.7	5.8	6.2	6.79	9.28
	08MAR89	23				17.9	15.9																
	09MAR89	24				17.0	17.0	35.4	34.1	30.7	25.6	25.4	21.4	14.2	10.6	9.4	7.0	3.7	6.1	8.8	9.0	6.53	8.96
	10MAR89	25				17.6	16.7																
2	15MAR89	30				17.4	14.8			25.5			21.0						10.7	9.2		6.38	9.03
	22MAR89	37				16.8	15.5			27.3			16.3						5.3	5.3	5.5	6.19	8.63
	28MAR89	43				17.3	16.4			30.2			27.8						7.7	8.5	8.7	6.87	9.79
	03APR89	49				16.1				23.6			20.1						18.6	16.1	16.1	7.86	11.50
	07APR89	53	19.3	18.5	18.2					27.1	21.0		16.6			13.4			7.4	7.6	8.1	7.58	11.24
	12APR89	58	18.7	18.3	17.6	17.9	16.3			22.4			12.6						7.0	14.4	14.6	7.41	10.14
	17APR89	63	17.6	17.3	17.7	17.5	15.7			21.5			16.4						14.7	14.9	15.4	7.04	9.91
	21APR89	67	17.6	17.3	18.3	18.1	17.0			30.6	22.6		16.3			15.0			12.9	15.0	15.2	7.02	9.21
	26APR89	72	18.2	17.4	18.1	17.7	16.1			40.6	26.2		21.1			14.2			10.2	14.1	14.5	5.93	7.98
	02MAY89	78	16.2	15.9	17.7	17.7	16.3	27.1	27.5	25.7	21.6	20.8	16.0	15.5	14.4	13.8	13.0	12.8	12.8	13.5		6.43	8.76
	03MAY89	79	17.5		15.5	15.4	14.1																
	06MAY89	82				16.8	16.1																
	12MAY89	88				18.4				16.9			14.8							13.0	12.9	5.30	7.50
	20MAY89	96				18.6	16.0			20.0			15.8						13.0	12.0	12.2	5.20	6.90
	25MAY89	101				16.2	17.3			21.0			13.8						6.5	6.4	6.6	5.10	6.90
	01JUN89	108				16.9	16.5			30.9			16.6						0.6	0.3	0.5	11.80	16.20
3	07JUN89	114	15.9	13.8	16.2	16.0	14.8			27.1			21.6						13.6	14.9		5.30	7.45
	12JUN89	119	15.1	14.9	15.4	15.3	14.1			16.6			14.2	13.3					12.0			4.10	5.77
	16JUN89	123	15.6	15.0	13.6	16.9	15.9			21.6			13.9						10.8	11.0		5.28	7.06
	21JUN89	128	17.0	16.5	16.7	16.8	14.6			22.7			11.1						4.8	6.2		5.29	7.22
	26JUN89	133	16.8			12.9	13.1			13.7			11.3	10.5					9.7	9.7		5.67	8.93
	30JUN89	137	16.1	15.6	18.0	17.8	14.8			35.1			22.4	17.5					8.3	11.7		4.96	6.73
	02JUL89	139	15.5	15.6	15.2	15.1	13.6																
	03JUL89	140	16.5	18.2	16.8	15.9	13.8	22.5	23.2	19.7	18.3	17.9	15.7	14.3	13.0	11.6	12.5	12.1	11.5	11.7		4.58	6.26
	04JUL89	141	16.9	14.7	15.3	15.2	13.2																
4	12JUL89	149	15.1	15.4	16.8	15.3	15.0			24.6			18.1	17.1					14.8	15.6		4.03	5.20
	17JUL89	154	15.9	15.7	14.2	14.2	13.2			22.9			18.1	14.3					8.6	10.5		4.34	5.65
	21JUL89	158	16.3	16.1	16.0	15.9				22.3			16.4	12.7					6.1	9.7		4.02	5.33
	26JUL89	163	16.9	17.0	17.1	17.1	15.2			25.7			17.9	16.2		12.9			10.3	11.6		4.50	5.93
	31JUL89	168	15.6	15.9	13.4	13.6	13.3			13.9			12.1	11.5		10.9			10.4	10.1		4.84	6.54
	03AUG89	171	14.8	15.2	15.2		15.2			18.9			15.8	12.5		12.1			10.7	11.3		4.38	5.97
	07AUG89	175	15.4	15.2	14.4	14.3	13.6			14.7			12.2	12.0		11.7			11.2	10.9		5.10	6.97
	08AUG89	176	14.5	14.3	14.3	14.2	14.8	23.8	22.5	20.6	17.9	18.3	17.2	14.5	12.9	12.7	12.1	11.3	10.9	12.6		4.45	6.11
	09AUG89	177	16.9	16.1		15.8	14.2																
	10AUG89	178	15.6	15.5	15.7	15.8	14.5																

Table C-10 (Continued). Raw Data: Phosphorus Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/USS %
5	21AUG89	189	16.3	16.0	17.1					25.2			19.2						14.5	14.3		4.7	6.4
	25AUG89	193	17.5	16.3	18.8	17.3	16.3			29.1			15.0						0.7	0.9		7.1	9.8
	29AUG89	197	16.7	16.7	20.7	20.6	18.3	34.2	33.5	29.9	25.4	24.2	22.0	16.5	14.5	12.6	11.1	10.4	8.7	8.9		6.7	9.5
	01SEP89	200					17.4			35.3			22.9						2.7	3.5			
	06SEP89	205	20.1	19.8	19.8	19.3	18.9	48.8	45.5	45.3	33.4	31.5	26.9	19.2	15.6	12.9	7.8	7.7	7.4	6.3		6.5	9.6
	11SEP89	210		18.6	18.1	18.4				24.2			17.5						13.2	14.5		8.8	12.4
	15SEP89	214	18.5	18.2	20.0	19.9	18.3	43.6	47.9	40.5	33.6	31.8	29.0	18.7	17.2	16.7	15.7	14.6	14.9	16.1		7.4	11.0
	20SEP89	219	19.0	19.1	19.1	18.8				36.2			20.7						9.0	10.8		6.5	9.1
	25SEP89	224	17.1		16.3	16.1				17.3			17.0						17.4	17.1		7.0	10.1
	27SEP89	226	20.6	20.0	17.2	17.1	15.1	17.1	16.7	13.9	9.8	8.7	6.4	1.1	0.4	0.2	0.1	0.1	0.2	0.9	1.4	6.8	9.8
	05OCT89	234	18.8	18.5	19.8	19.6				25.4			16.3						8.6	10.7	11.0	6.7	9.5
	12OCT89	241	19.7			19.0				21.8			11.0						4.4	5.3	5.6	6.2	8.6
6	18OCT89	247	18.6	18.0	19.0	18.5				22.8			14.7						9.9	10.1		6.4	9.1
	23OCT89	252	16.5	16.6	15.2	15.1				14.2			14.2						13.3	12.9		6.8	9.7
	25OCT89	254	15.9	15.7	18.5	18.3				18.5			10.3						5.4	5.4		5.8	8.3
	27OCT89	256	17.7	17.4	17.6	17.4				16.2			11.2						5.1			6.5	9.1
	31OCT89	260	17.7	17.6	18.8	18.8	17.7																
	01NOV89	261	19.9	19.7	19.5	19.2	19.0	32.5	31.2	26.7	19.7	19.0	18.6	9.8	8.0	8.0	6.5	6.2	5.2	6.4	6.7	8.5	12.8
	02NOV89	262	19.4	19.6	18.6	18.2	17.5																
7	08NOV89	268	19.8	19.6	19.0	18.8				29.4			17.1						7.8	8.7		6.5	8.6
	09NOV89	269	18.8	18.3	19.5	19.3	20.2																
	13NOV89	273	20.3	19.1	18.8	19.1				17.1			12.4			7.5			6.4	6.4		8.2	11.6
	17NOV89	277	20.7	20.3	17.3	17.3				11.6			5.4			0.2			0.1	0.1		6.1	8.5
	20NOV89	280	17.9	18.2	18.3	18.2	17.5																
	21NOV89	281	17.5	17.2	19.1	18.9	17.7	26.8	28.3	26.3	22.9	22.2	22.3	19.3	19.5	18.4	17.9	17.6	17.9	18.5	18.6	6.4	8.7
8	29NOV89	289	18.3	18.3	20.2	20.2				21.6			18.6						17.6	17.2		3.5	4.4
	01DEC89	291	18.9	18.8	19.4	19.3				20.1			18.8						16.8	17.3		2.6	3.2
	05DEC89	295	18.2	18.3	19.4	19.3				20.3			18.8						17.2	17.2		2.9	3.4
	07DEC89	297	19.1	18.9	17.5	17.7	17.5	19.0	20.6	19.3	19.5	18.7	19.7	16.4	16.7	15.9	15.6	15.5	15.4	15.9	15.8	2.7	3.2
	08DEC89	298	18.4	18.4	18.6	18.5	18.1																
9	12DEC89	302	19.1	18.7	18.0	17.8				20.2			19.5						15.3	16.5		2.7	3.2
	14DEC89	304	16.5	16.0	17.4	17.4				18.5			18.4						14.5	15.0		2.2	2.6
	18DEC89	308		17.6	16.6	16.6				18.8			18.6						14.3	14.9		2.4	2.8
	21DEC89	311	18.3	18.1	19.1	19.1				19.7			20.1						16.8			3.2	3.8
10	27DEC89	317	16.1	15.8	16.9	15.5				16.3			12.9						14.0	13.9		3.2	4.1
	30DEC89	320	16.0	15.6	15.6	14.6				15.6			14.9						13.3	13.6		3.2	3.9
	03JAN90	324	9.3	8.6	9.5	8.7																3.4	4.2
	05JAN90	326	15.9	13.6	10.3	9.8				10.1			10.2						9.7	9.6		3.5	4.2

Table C-10 (Continued). Raw Data: Phosphorus Profiles, BNR System (Reactor 1)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/USS %
11	10JAN90	331	18.2	17.9	17.2	17.1				17.7			17.8						15.3	15.7		2.6	3.0
	13JAN90	334	17.7	17.4	18.1	18.1				18.0			17.9						16.2	16.8		2.7	3.2
	16JAN90	337	18.9	17.4	18.2	18.0				17.6			17.5						15.7	16.5		3.3	3.9
	20JAN90	341	17.9	18.0	18.3	18.0				18.0			16.9						15.5	15.7		2.8	3.4
	23JAN90	344	18.0	18.0	18.9	18.7	18.4																
	24JAN90	345		18.0		18.0	17.5	18.5	17.5	17.8	18.0	18.2	17.9	16.5	16.6	16.4		16.0	15.8	16.4	16.1	3.0	3.6
	26JAN90	347	19.5	19.0	17.7	17.7	16.7																
12	31JAN90	352	16.0	16.0	17.5	17.9				17.7			17.3						15.3	15.5		3.0	3.6
	05FEB90	357	16.3	16.3	16.2	15.7				17.0			14.5						12.5	13.0		3.8	4.6
	08FEB90	360	18.3	18.1	18.9	18.5				17.6			16.8						15.7	16.3		3.5	4.4
	12FEB90	364	18.5	18.3	16.4	16.1				15.5			14.9						14.9	14.8		3.4	4.2
	16FEB90	368	18.6	18.3	20.0	19.6				19.9			19.2						17.0	16.8		2.5	3.0
	20FEB90	372	19.1	18.8	19.3	19.1				21.0			17.8						13.5	14.5		3.4	4.2
	24FEB90	376	18.1	17.7	18.7	18.6				27.0			20.3						8.6	10.8		6.4	8.7
	27FEB90	379																	0.0			10.4	15.9
	01MAR90	381	19.5	19.3	19.7	19.1				48.2			17.2						0.0	0.2		9.4	14.9
	06MAR90	386	19.5	19.4	17.8	17.7				18.2			16.8						15.7	15.1		10.7	17.8
	09MAR90	389	19.7	19.4	19.5	19.1				30.9			18.7						13.9	13.7		10.1	16.1
	13MAR90	393	18.4	18.4	18.9	19.0				42.6			30.6						11.6	19.1		8.1	11.8
	16MAR90	396	18.0	18.0	20.2	19.8				22.2			18.0						18.3	17.0		8.2	11.9
	20MAR90	400	19.4	18.7	19.5	19.4				16.8			12.1						8.7	9.6		7.6	10.7
	22MAR90	402	20.6	20.3	19.7	19.5				24.3			13.5						6.0	6.2		7.6	10.5
	26MAR90	406	18.4	18.3	17.5	17.4	15.0			14.0			12.3						11.8	11.3		8.7	12.5
	28MAR90	408	19.6	20.7	19.5	21.0	19.0	24.5	23.1	21.7	18.2	19.0	16.3	14.4	13.6	13.7	13.3	12.6	12.9	12.8	13.4	8.4	12.4
	29MAR90	409	20.8	20.7	20.4	20.1	19.1																
13	03APR90	414	17.4	17.3	17.9	17.9				23.4			17.4						12.8	13.5		7.9	11.4
	06APR90	417	18.2	18.1	18.1	18.0				21.9			16.2						11.3	12.0		7.5	10.5
	10APR90	421	18.6	18.5	19.2	18.9	17.7																
	11APR90	422		17.8	18.8	18.6	17.7	25.1	25.6	24.8	19.7	19.0	17.6	14.4	13.0	12.6	11.5	11.7	11.6	11.6	12.0	6.9	9.4
14	13APR90	424	19.1	19.2	19.3	19.2				24.7			21.7						16.0	15.7		4.8	5.8
	17APR90	428	19.7	19.4	19.2	19.1	17.6															5.7	7.4
	18APR90	429	19.5	19.1	19.5	19.3																	
	19APR90	430	19.4	19.2	19.5	19.5	18.3	20.6	21.3	20.6	19.4	18.8	17.2	16.4	15.3	15.0	14.7	14.7	14.7	14.9	15.3	4.4	5.6

Table C-10 (Continued). Raw Data: Phosphorus Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/USS %
1	20FEB89	7				16.0	14.5			15.9			18.1						4.6	4.3	4.6	5.3	7.3
	24FEB89	11					14.8			27.8			22.4						10.5	12.4			
	01MAR89	16				16.6	16.0			29.3			22.7						5.3	2.1	2.2	6.5	8.9
	06MAR89	21				15.2	13.7			29.3			27.4						11.1	10.4	10.8	6.9	9.6
	08MAR89	23				17.9	15.9	41.8	41.7	37.7	33.4	33.8	29.7	19.5	15.3	14.0	10.3	10.4	11.0	13.3	13.5	6.5	8.9
	09MAR89	24				17.0	17.0																
	10MAR89	25				17.6	16.7																
2	15MAR89	30				17.4	14.8			29.6			26.2						10.7	10.2		6.4	9.0
	22MAR89	37				16.8	15.5			33.4			20.0						5.6	5.7	6.2	6.6	9.2
	28MAR89	43				17.3	16.4			39.1			24.2						7.1	7.7	7.6	7.2	10.4
	03APR89	49				16.1				25.2			19.2						18.1	15.9	16.1	7.8	
	07APR89	53	19.3	18.5	18.2					28.0			18.8						6.9	7.2	7.7	7.4	11.0
	12APR89	58	18.7	18.3	17.6	17.9	16.3			31.4			34.1						16.4	19.7	20.1	7.9	10.3
	17APR89	63	17.6	17.3	17.7	17.5	15.7			22.7			18.2						15.4	15.5	15.7	7.0	9.7
	21APR89	67	17.6	17.3	18.3	18.1	17.0			33.1			18.0						12.7	14.7	15.0	6.1	
	26APR89	72	18.2	17.4	18.1	17.7	16.1			39.3			23.5						9.7		14.0	5.7	7.6
	02MAY89	78	16.2	15.9	17.7	17.7	16.3																
	03MAY89	79	17.5		15.5	15.4	14.1	28.6	28.0	26.3	19.9	20.0	17.9	15.5	14.4	13.5	12.3	11.5		12.7		6.2	8.5
	06MAY89	82				16.8	16.1																
	12MAY89	88				18.4				17.3			15.0							14.6	15.3	5.4	7.7
	20MAY89	96				18.6	16.0			17.9			15.0						12.9	12.5	12.0	5.1	6.9
	25MAY89	101				16.2	17.3			23.5			15.5						8.8	8.9	9.4	4.6	6.1
	01JUN89	108				16.9	16.5			24.4			16.5						6.7	6.9		10.7	14.5
3	07JUN89	114	15.9	13.8	16.2	16.0	14.8			25.8			19.7						12.6	14.1		4.5	6.1
	12JUN89	119	15.1	14.9	15.4	15.3	14.1			17.1			13.7						12.5	11.7		4.7	6.5
	16JUN89	123	15.6	15.0	13.6	16.9	15.9			19.6			13.7						10.3	10.8		5.1	6.7
	21JUN89	128	17.0	16.5	16.7	16.8	14.6			22.9			11.8						5.3	7.0		5.1	6.9
	26JUN89	133	16.8			12.9	13.1			13.5			12.7						11.5	9.8		5.4	7.9
	30JUN89	137	16.1	15.6	18.0	17.8	14.8			33.8			19.8						8.0	10.7		6.3	8.5
	02JUL89	139	15.5	15.6	15.2	15.1	13.6	19.9	18.1	15.6	13.1	12.8	11.7	9.6	9.3	9.2	9.9	8.3	8.1	7.3		6.0	8.3
	03JUL89	140	16.5	18.2	16.8	15.9	13.8																
	04JUL89	141	16.9	14.7	15.3	15.2	13.2																
4	12JUL89	149	15.1	15.4	16.8	15.3	15.0			22.9			19.5						15.1	16.5		3.0	3.8
	17JUL89	154	15.9	15.7	14.2	14.2	13.2			23.1			18.4						8.6	10.3		4.0	5.1
	21JUL89	158	16.3	16.1	16.0	15.9				24.6			18.1						7.3	10.6		3.7	4.8
	26JUL89	163	16.9	17.0	17.1	17.1	15.2			27.9			20.4						11.0	11.8		4.3	5.5
	31JUL89	168	15.6	15.9	13.4	13.6	13.3			13.0			12.3						10.5	9.8		5.4	7.3
	03AUG89	171	14.8	15.2	15.2		15.2			20.0			15.0						10.8	11.5		4.9	6.5
	07AUG89	175	15.4	15.2	14.4	14.3	13.6			14.2			13.2						11.4	10.9		5.2	7.0
	08AUG89	176	14.5	14.3	14.3	14.2	14.8																
	09AUG89	177	16.9	16.1		15.8	14.2	19.4	18.9	17.5	15.9	15.2	14.1	13.2	12.5	12.5	12.0	11.7	10.4	11.3		5.2	7.0
	10AUG89	178	15.6	15.5	15.7	15.8	14.5																

Table C-10 (Continued). Raw Data: Phosphorus Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/VSS %
5	21AUG89	189	16.3	16.0	17.1					28.6			21.6						15.3	15.1		4.5	6.0
	25AUG89	193	17.5	16.3	18.8	17.3	16.3			30.5			16.6						0.7	0.4		4.9	6.7
	29AUG89	197	16.7	16.7	20.7	20.6	18.3			33.1			22.1						8.8	9.9		5.9	8.3
	01SEP89	200					17.4			38.7			25.2						2.4	4.1			
	06SEP89	205	20.1	19.8	19.8	19.3	18.9			44.4			25.0						7.3	6.7		5.5	8.1
	11SEP89	210		18.6	18.1	18.4				24.5			16.4						11.7	11.1		7.7	11.3
	15SEP89	214	18.5	18.2	20.0	19.9	18.3			42.7			30.1						15.0	16.4		7.2	10.5
	20SEP89	219	19.0	19.1	19.1	18.8				32.3			18.2						7.8	9.3		6.3	8.7
	25SEP89	224	17.1		16.3	16.1				18.5			19.1						17.7	16.5		7.1	10.2
	27SEP89	226	20.6	20.0	17.2	17.1	15.1																
	05OCT89	234	18.8	18.5	19.8	19.6				24.0			11.1						6.6	7.7	7.9	7.6	11.1
	12OCT89	241	19.7			19.0				20.1			10.3						7.2	7.9	7.9	7.1	10.3
6	18OCT89	247	18.6	18.0	19.0	18.5				32.1			18.6						10.1	10.2		7.2	10.6
	23OCT89	252	16.5	16.6	15.2	15.1				13.7			12.9						14.0	13.4		7.3	10.6
	25OCT89	254	15.9	15.7	18.5	18.3				25.9			15.4						3.4	5.7		7.3	10.9
	27OCT89	256	17.7	17.4	17.6	17.4																	
	31OCT89	260	17.7	17.6	18.8	18.8	17.7																
	01NOV89	261	19.9	19.7	19.5	19.2	19.0																
	02NOV89	262	19.4	19.6	18.6	18.2	17.5	39.5	40.5	37.3	28.0	28.3	23.3	11.1	9.4	8.7	8.2	11.2	12.9	5.6	5.7	8.2	12.4
7	08NOV89	268	19.8	19.6	19.0	18.8				35.6			17.4						3.9	5.0		7.8	11.2
	09NOV89	269	18.8	18.3	19.5	19.3	20.2	44.0	43.7	44.8	29.4	35.0	27.7	18.1	16.0	15.2	13.3	12.5	10.7	13.0		10.9	13.3
	13NOV89	273	20.3	19.1	18.8	19.1				19.9			16.5						11.9	9.9		8.3	12.2
	17NOV89	277	20.7	20.3	17.3	17.3							11.1						0.8	2.0		8.4	12.0
	20NOV89	280	17.9	18.2	18.3	18.2	17.5																
	21NOV89	281	17.5	17.2	19.1	18.9	17.7																
8	29NOV89	289	18.3	18.3	20.2	20.2				19.9			18.3						17.1	17.8		6.2	8.5
	01DEC89	291	18.9	18.8	19.4	19.3				21.0			19.3						17.7	17.1		5.2	6.8
	05DEC89	295	18.2	18.3	19.4	19.3				21.5			18.3						16.7	17.2		4.7	6.0
	07DEC89	297	19.1	18.9	17.5	17.7	17.5																
	08DEC89	298	18.4	18.4	18.6	18.5	18.1																
9	12DEC89	302	19.1	18.7	18.0	17.8				34.0			29.1						17.8			4.1	5.1
	14DEC89	304	16.5	16.0	17.4	17.4				27.5			25.0						12.7			3.5	4.4
	18DEC89	308		17.6	16.6	16.6				34.4			22.8						1.7	7.1			5.2
	21DEC89	311	18.3	18.1	19.1	19.1				41.9			34.7						20.3	20.6		4.0	5.1
10	27DEC89	317	16.1	15.8	16.9	15.5				20.7			13.5						5.6	2.8		6.3	8.7
	30DEC89	320	16.0	15.6	15.6	14.6				21.8			15.6						11.2	10.5		6.6	9.1
	03JAN90	324	9.3	8.6	9.5	8.7																5.8	8.2
	05JAN90	326	15.9	13.6	10.3	9.8				14.5			13.0						12.7	12.5		5.7	7.6

Table C-10 (Continued). Raw Data: Phosphorus Profiles, Test BNR System (Reactor 2)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/USS %
11	10JAN90	331	18.2	17.9	17.2	17.1				38.8			19.8						3.7	9.0		4.8	6.3
	13JAN90	334	17.7	17.4	18.1	18.1				49.8			30.4						12.8	14.1		4.9	6.5
	16JAN90	337	18.9	17.4	18.2	18.0				53.8			24.5						0.7	3.7		6.9	9.7
	20JAN90	341	17.9	18.0	18.3	18.0				56.5			28.3						2.1	2.5		6.6	9.9
	23JAN90	344	18.0	18.0	18.9	18.7	18.4	54.6	58.4	61.1	46.8	44.9	39.4	20.2	10.6	7.8	0.3	0.3	0.1	5.0	5.1	7.7	11.1
	24JAN90	345		18.0		18.0	17.5																
	26JAN90	347	19.5	19.0	17.7	17.7	16.7																
12	31JAN90	352	16.0	16.0	17.5	17.9				73.4			25.9						1.9	3.2		9.1	14.1
	05FEB90	357	16.3	16.3	16.2	15.7				46.0			15.1						1.1	6.6		10.2	16.8
	08FEB90	360	18.3	18.1	18.9	18.5				62.1			10.9						0.8	5.3		10.9	18.1
	12FEB90	364	18.5	18.3	16.4	16.1				47.5			17.8						1.6	6.6		11.6	19.5
	16FEB90	368	18.6	18.3	20.0	19.6				73.8			37.6						1.1	5.3		10.2	16.1
	20FEB90	372	19.1	18.8	19.3	19.1				54.8			20.1						0.4	4.7		11.1	18.6
	24FEB90	376	18.1	17.7	18.7	18.6				52.7			15.4						0.6	2.4		10.9	17.5
	27FEB90	379																	0.0			11.5	20.2
	01MAR90	381	19.5	19.3	19.7	19.1				52.4			18.3						0.5	4.0		10.8	18.3
	06MAR90	386	19.5	19.4	17.8	17.7				19.8			19.4						18.8	17.8		11.1	18.3
	09MAR90	389	19.7	19.4	19.5	19.1				39.9			25.2						18.1	18.1		10.6	17.1
	13MAR90	393	18.4	18.4	18.9	19.0				58.4			31.9						5.2	14.0		10.3	14.4
	16MAR90	396	18.0	18.0	20.2	19.8				25.0			20.6						19.4	19.3		9.1	14.1
	20MAR90	400	19.4	18.7	19.5	19.4				16.3			6.3						2.0	2.9		9.3	15.0
	22MAR90	402	20.6	20.3	19.7	19.5				22.0			7.6						1.1	0.4		9.1	14.9
	26MAR90	406	18.4	18.3	17.5	17.4	15.0	10.2	10.6	9.5	8.4	9.6	6.9	6.3	6.0	6.1	5.8	5.8	6.0	4.9		9.1	15.9
	28MAR90	408	19.6	20.7	19.5	21.0	19.0																
	29MAR90	409	20.8	20.7	20.4	20.1	19.1																
13	03APR90	414	17.4	17.3	17.9	17.9				32.9			19.6						14.8	15.9		8.8	15.1
	06APR90	417	18.2	18.1	18.1	18.0				27.7			19.3						13.7	14.3		8.6	14.3
	10APR90	421	18.6	18.5	19.2	18.9	17.7																
	11APR90	422		17.8	18.8	18.6	17.7																
14	13APR90	424	19.1	19.2	19.3	19.2				54.6			28.4						4.1	8.8		8.5	13.4
	17APR90	428	19.7	19.4	19.2	19.1	17.6																
	18APR90	429	19.5	19.1	19.5	19.3				33.4			19.4						8.0	8.3		9.2	14.7
	19APR90	430	19.4	19.2	19.5	19.5	18.3																

Table C-10 (Continued). Raw Data: Phosphorus Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/USS %
1	20FEB89	7				16.0	14.5			13.9			13.0						12.4	12.1	15.3	1.9	2.2
	24FEB89	11					14.8			15.2			14.7						15.1	14.3			
	01MAR89	16				16.6	16.0			14.0			12.9						16.7	14.3	15.2	2.0	2.3
	06MAR89	21				15.2	13.7			14.4			14.1						15.5	14.4	15.6	2.3	2.6
	08MAR89	23				17.9	15.9																
	09MAR89	24				17.0	17.0																
	10MAR89	25				17.6	16.7	17.1	17.0	16.6	16.6	16.6	16.7	16.2	16.4	16.1	16.9	16.5	16.4	15.3	16.3	1.9	2.2
2	15MAR89	30				17.4	14.8			16.6			16.6						18.2	15.5		1.9	2.2
	22MAR89	37				16.8	15.5			16.3			15.9						16.2	14.9	15.6	1.9	2.2
	28MAR89	43				17.3	16.4			16.3			16.9						18.1	15.8	15.8	1.9	2.3
	03APR89	49				16.1				17.8			16.3						16.4	14.1	15.6	2.0	2.3
	07APR89	53	19.3	18.5	18.2					16.2			16.4						15.3	15.8	16.2	2.1	2.5
	12APR89	58	18.7	18.3	17.6	17.9	16.3			16.4			16.8						19.9	15.7	16.5	2.2	2.3
	17APR89	63	17.6	17.3	17.7	17.5	15.7			15.9			16.3						16.4	15.6	16.5	2.0	2.3
	21APR89	67	17.6	17.3	18.3	18.1	17.0			14.7			17.0						17.2	17.1	17.1	1.9	2.1
	26APR89	72	18.2	17.4	18.1	17.7	16.1			15.3			15.7						15.8	16.2	17.6	1.8	2.1
	02MAY89	78	16.2	15.9	17.7	17.7	16.3																
	03MAY89	79	17.5		15.5	15.4	14.1												13.5				
	06MAY89	82				16.8	16.1	15.4	15.6	15.7	16.0	15.9	16.1	16.1	16.1	16.1	16.2	15.8	15.9	15.3		1.9	2.3
	12MAY89	88				18.4														14.8	15.6	2.1	2.7
	20MAY89	96				18.6	16.0						15.4						15.6	15.0	16.8	2.1	2.6
	25MAY89	101				16.2	17.3						14.9						15.0	14.2	15.0	1.7	2.1
	01JUN89	108				16.9	16.5						15.0						15.8	14.7	15.4	2.1	2.6
3	07JUN89	114	15.9	13.8	16.2	16.0	14.8			14.7			14.9						13.9	14.9	15.9	1.9	2.5
	12JUN89	119	15.1	14.9	15.4	15.3	14.1	15.2		14.4			14.6						13.9	14.2	14.7	2.0	2.6
	16JUN89	123	15.6	15.0	13.6	16.9	15.9			15.0			15.2						14.9	15.1	15.7	1.8	2.3
	21JUN89	128	17.0	16.5	16.7	16.8	14.6			14.7			14.9						14.8	14.9	15.5	1.7	2.2
	26JUN89	133	16.8			12.9	13.1	13.5		13.5			13.9						13.7	12.9	13.4	1.6	2.4
	30JUN89	137	16.1	15.6	18.0	17.8	14.8	14.9		14.4			14.8						15.6	14.2	16.3	1.6	1.8
	02JUL89	139	15.5	15.6	15.2	15.1	13.6																
	03JUL89	140	16.5	18.2	16.8	15.9	13.8																
	04JUL89	141	16.9	14.7	15.3	15.2	13.2	13.3	13.1	13.0	12.8	13.0	12.9	13.1	13.2	12.9	12.0	12.7	12.9	13.0	13.6	1.2	1.5
4	12JUL89	149	15.1	15.4	16.8	15.3	15.0	13.6		13.8			14.1						15.5	14.8	15.1	1.7	2.1
	17JUL89	154	15.9	15.7	14.2	14.2	13.2	13.8		13.5			13.6						13.4	12.9	13.3	1.5	1.9
	21JUL89	158	16.3	16.1	16.0	15.9		15.0		14.9			14.9						14.9	14.7	14.8	1.9	2.4
	26JUL89	163	16.9	17.0	17.1	17.1	15.2	15.0		15.1			14.2						15.0	14.7	15.3	2.0	2.4
	31JUL89	168	15.6	15.9	13.4	13.6	13.3	10.9		13.1			13.7						12.8	13.3	13.4	1.7	2.1
	03AUG89	171	14.8	15.2	15.2		15.2	14.4		14.1			14.1						13.7	14.1	14.1	1.9	2.3
	07AUG89	175	15.4	15.2	14.4	14.3	13.6	13.7		13.4			13.6						13.6	13.3	13.8	1.8	2.1
	08AUG89	176	14.5	14.3	14.3	14.2	14.8																
	09AUG89	177	16.9	16.1		15.8	14.2																
	10AUG89	178	15.6	15.5	15.7	15.8	14.5	14.3	14.8	15.0	14.7	14.6	14.8	14.6	14.7	14.6	14.6	14.5	14.5	14.1	13.3	1.9	2.4

Table C-10 (Continued). Raw Data: Phosphorus Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/USS %
5	21AUG89	189	16.3	16.0	17.1														16.3	15.5	14.8	1.4	1.7
	25AUG89	193	17.5	16.3	18.8	17.3	16.3												16.0	15.8		2.0	2.4
	29AUG89	197	16.7	16.7	20.7	20.6	18.3												18.9	19.0	19.1	1.9	2.3
	01SEP89	200					17.4												19.3	17.2			
	06SEP89	205	20.1	19.8	19.8	19.3	18.9												19.8	18.3	18.5	1.9	2.2
	11SEP89	210		18.6	18.1	18.4													17.7	17.5	18.6	1.7	1.9
	15SEP89	214	18.5	18.2	20.0	19.9	18.3												19.4	18.1	18.3	1.7	2.0
	20SEP89	219	19.0	19.1	19.1	18.8													17.4	18.2	18.0	1.9	2.2
	25SEP89	224	17.1		16.3	16.1													16.0	15.8	16.1	1.7	2.1
	27SEP89	226	20.6	20.0	17.2	17.1	15.1																
	05OCT89	234	18.8	18.5	19.8	19.6													18.3	17.8	20.5	2.0	2.3
	12OCT89	241	19.7			19.0													18.7	17.9	18.3	1.8	2.0
6	18OCT89	247	18.6	18.0	19.0	18.5													18.2	18.9	18.9	2.1	2.5
	23OCT89	252	16.5	16.6	15.2	15.1													15.1	15.3			
	25OCT89	254	15.9	15.7	18.5	18.3													17.0	16.7		1.9	2.3
	27OCT89	256	17.7	17.4	17.6	17.4													16.6	16.2	16.8	1.3	1.5
	31OCT89	260	17.7	17.6	18.8	18.8	17.7	17.2	17.2	17.0	16.9	16.8	16.7	16.8	16.9	16.8	16.4	16.9	17.1	16.3	16.7	1.4	1.5
	01NOV89	261	19.9	19.7	19.5	19.2	19.0																
	02NOV89	262	19.4	19.6	18.6	18.2	17.5																
7	08NOV89	268	19.8	19.6	19.0	18.8														17.8			
	09NOV89	269	18.8	18.3	19.5	19.3	20.2																
	13NOV89	273	20.3	19.1	18.8	19.1													18.7	17.7		2.7	3.0
	17NOV89	277	20.7	20.3	17.3	17.3													16.6	16.1		2.4	2.8
	20NOV89	280	17.9	18.2	18.3	18.2	17.5	17.6	18.2	17.5	17.4	17.6	17.8	17.5	17.6	17.6	17.6	17.7	18.0	17.6	17.8	2.5	2.9
	21NOV89	281	17.5	17.2	19.1	18.9	17.7																
8	29NOV89	289	18.3	18.3	20.2	20.2													17.9	17.7		2.0	2.3
	01DEC89	291	18.9	18.8	19.4	19.3													17.8	17.5		2.2	2.6
	05DEC89	295	18.2	18.3	19.4	19.3													18.6	18.2		2.2	2.5
	07DEC89	297	19.1	18.9	17.5	17.7	17.5																
	08DEC89	298	18.4	18.4	18.6	18.5	18.1	17.7	17.4		17.6	17.7	17.5	17.5	17.4	18.0	17.5	17.2	17.6	17.8	17.4	2.8	3.2
9	12DEC89	302	19.1	18.7	18.0	17.8													16.8	16.6		2.0	2.3
	14DEC89	304	16.5	16.0	17.4	17.4													15.8	16.8		2.6	3.0
	18DEC89	308		17.6	16.6	16.6													16.2	15.9		2.5	2.9
	21DEC89	311	18.3	18.1	19.1	19.1													18.1	18.0		1.9	2.2
10	27DEC89	317	16.1	15.8	16.9	15.5													16.8	14.6		3.5	4.1
	30DEC89	320	16.0	15.6	15.6	14.6													16.1	14.6		2.3	2.7
	03JAN90	324	9.3	8.6	9.5	8.7																2.4	2.9
	05JAN90	326	15.9	13.6	10.3	9.8													10.2	10.4		2.5	2.9

Table C-10 (Continued). Raw Data: Phosphorus Profiles, Conventional System (Reactor 3)

Phase	Date	Day No.	Inf''' TP mg/L	Inf'' TP mg/L	Inf' TP mg/L	Inf TP mg/L	Inf SP mg/L	Sec1 SP mg/L	Sec2 SP mg/L	Sec3 SP mg/L	Sec4 SP mg/L	Sec5 SP mg/L	Sec6 SP mg/L	Sec7 SP mg/L	Sec8 SP mg/L	Sec9 SP mg/L	Sec10 SP mg/L	Sec11 SP mg/L	Sec12 SP mg/L	Eff SP mg/L	Eff STP mg/L	P/SS %	P/VSS %
11	10JAN90	331	18.2	17.9	17.2	17.1													16.5	18.0		2.2	2.6
	13JAN90	334	17.7	17.4	18.1	18.1													17.1	17.6		2.3	2.6
	16JAN90	337	18.9	17.4	18.2	18.0																1.9	2.3
	20JAN90	341	17.9	18.0	18.3	18.0													16.6	16.0		2.3	2.7
	23JAN90	344	18.0	18.0	18.9	18.7	18.4																
	24JAN90	345		18.0		18.0	17.5																
	26JAN90	347	19.5	19.0	17.7	17.7	16.7	16.3	16.8	16.3	16.0	16.3	16.7	16.4	16.7	16.0	16.2	16.3	16.3	15.9	16.1	2.3	2.6
12	31JAN90	352	16.0	16.0	17.5	17.9													16.8	18.9		2.0	2.4
	05FEB90	357	16.3	16.3	16.2	15.7													15.1	14.8		2.6	3.0
	08FEB90	360	18.3	18.1	18.9	18.5													16.5	17.8		2.6	3.0
	12FEB90	364	18.5	18.3	16.4	16.1													15.7	17.0		2.3	2.7
	16FEB90	368	18.6	18.3	20.0	19.6													19.6	21.7		2.4	2.7
	20FEB90	372	19.1	18.8	19.3	19.1													18.2	20.4		1.8	2.1
	24FEB90	376	18.1	17.7	18.7	18.6													18.1	18.7		2.2	2.6
	27FEB90	379																	15.6			1.9	2.3
	01MAR90	381	19.5	19.3	19.7	19.1													18.1	18.9		1.6	2.0
	06MAR90	386	19.5	19.4	17.8	17.7													16.6	16.2		2.1	2.6
	09MAR90	389	19.7	19.4	19.5	19.1													16.1	16.9		2.3	2.6
	13MAR90	393	18.4	18.4	18.9	19.0													16.4	16.4		1.6	1.9
	16MAR90	396	18.0	18.0	20.2	19.8													18.4	17.7		2.0	2.4
	20MAR90	400	19.4	18.7	19.5	19.4													20.6	16.9		3.2	4.1
	22MAR90	402	20.6	20.3	19.7	19.5													17.9	16.7		2.2	2.6
	26MAR90	406	18.4	18.3	17.5	17.4	15.0												17.1	16.2		2.5	2.8
	28MAR90	408	19.6	20.7	19.5	21.0	19.0																
	29MAR90	409	20.8	20.7	20.4	20.1	19.1	18.7	18.6	18.3	18.7	18.4	17.8	18.5	18.6	18.7	18.7	19.2	19.3	18.5	19.2	1.6	1.9
13	03APR90	414	17.4	17.3	17.9	17.9													16.8	16.9		2.5	3.0
	06APR90	417	18.2	18.1	18.1	18.0													17.4	17.3		2.0	2.3
	10APR90	421	18.6	18.5	19.2	18.9	17.7	17.6	17.8	17.6	17.8	16.9	17.6	16.9	17.5	17.5	17.1	17.3	17.6	16.8	17.4	2.7	3.1
	11APR90	422		17.8	18.8	18.6	17.7																
14	13APR90	424	19.1	19.2	19.3	19.2													17.3	16.8		2.9	3.3
	17APR90	428	19.7	19.4	19.2	19.1	17.6	18.1	18.3	17.9	18.2	17.2	17.8	17.8	17.5	17.4	18.0	17.3	18.0	17.2	17.8	3.6	3.9
	18APR90	429	19.5	19.1	19.5	19.3																	
	19APR90	430	19.4	19.2	19.5	19.5	18.3																

Appendix D

Maintenance Tasks Performed on Experimental Treatment Systems

Task	Frequency
Feed tanks were emptied, cleaned, and refilled. Temperature was checked and adjusted. Tubing from reactor to clarifier cleaned.	Twice daily
All pumps, mixers, and aeration devices were visually inspected for proper operation.	Twice daily
Solids were stirred in all aerobic sections.	Daily
All reactor sections and clarifier were cleaned. Tubing in peristaltic pumps was replaced. Flow rates in pumps were adjusted.	Twice weekly
Dissolved oxygen profiles were monitored.	As required
Aeration was adjusted to maintain greater than 2 mg/L DO in all aerobic sections and less than 0.5 mg/L DO in all anoxic and anaerobic sections. Water from air compressors was drained.	As required
Auxiliary metals feed pump was calibrated.	Twice weekly

Appendix E

Summary of Oxygen Requirement and Anaerobic Stabilization Data

Table E-1. Oxygen Utilization Rates (mg/L/min)

BNR SYSTEM						
	MCRT = 15 d			MCRT = 5 d		
Sec. No.	T=10C	T=15C	T=20C	T=10C	T=15C	T=20C
7	0.888	1.060	1.152	0.467	0.423	1.201
8	0.663	0.557	0.527	0.397	0.463	0.935
9	0.394	0.505	0.368	0.405	0.451	0.869
10	0.367	0.418	0.366	0.342	0.457	0.730
11	0.222	0.441	0.380	0.341	0.403	0.604
12	0.217	0.231	0.250	0.373	0.403	0.596

CONVENTIONAL SYSTEM						
	MCRT = 15 d			MCRT = 5 d		
Sec. No.	T=10C	T=15C	T=20C	T=10C	T=15C	T=20C
1	0.491	0.920	0.461	0.609	1.164	1.791
2	0.579	0.825	0.552	0.621	0.509	0.997
3	0.414	0.526	0.791	0.459	0.375	0.788
4	0.433	0.583	0.382	0.434	0.447	0.526
5	0.266	0.410	0.384	0.339	0.308	0.429
6	0.279	0.285	0.634	0.250	0.211	0.432
7	0.210	0.330	0.429	0.229	0.213	0.445
8	0.191	0.491	0.434	0.223	0.237	0.483
9	0.333	0.460	0.462	0.185	0.338	0.330
10	0.371	0.359	0.361	0.221	0.278	0.295
11	0.221	0.198	0.417	0.245	0.194	0.289
12	0.449	0.246	0.347	0.310	0.258	0.272

Table E-2. Total Oxygen Requirement (TOR) Measured in Experimental Systems

MCRT (d)	System	Temp (C)	Dates	DO Conc. in Sec. 12 (mg/L)	DO Conc. in Clarifier (mg/L)	O2 Used in RAS (g/d)	O2 Used in NOx-N Rcy (g/d)	O2 Used in Clarifier (g/d)	Total O2 Used in Reactors (Table E-1)	TOR (g/d)
15	BNR	10	07AUG89-09AUG89	7.8	5.0	0.76	1.18	0.42	19.5	21.9
	BNR	15	26MAY89-29MAY89	6.7	5.0	0.76	1.01	0.26	26.7	28.7
	BNR	20	28JUN89-05JUL89	7.5	5.0	0.76	1.13	0.38	27.1	29.4
5	BNR	10	07DEC89-08DEC89	5.8	1.5	0.23	0.88	0.65	18.5	20.2
	BNR	15	19NOV89-21NOV89	7.2	5.0	0.76	1.09	0.33	17.4	19.6
	BNR	20	30OCT89-03NOV89	8.2	4.5	0.68	1.24	0.56	33.6	36.1
15	Conv.	10	07AUG89-09AUG89						25.8	25.8
	Conv.	15	26MAY89-29MAY89						34.6	34.6
	Conv.	20	28JUN89-05JUL89						33.6	33.6
5	Conv.	10	07DEC89-08DEC89						23.9	23.9
	Conv.	15	19NOV89-21NOV89						31.4	31.4
	Conv.	20	30OCT89-03NOV89						42.8	42.8

Table E-3. Calculation of Total Oxygen Requirement (TOR) from Oxygen Balances on Experimental Treatment Systems

MCRT (d)	System	Temp (C)	Dates	CODin (mg/L)	CODef (mg/L)	TKNin (mg/L)	TKNef (mg/L)	TKNu (mg/L)	MLVSS (mg/L)	NOD (mg/L)	NO2-Ne (mg/L)	NO3-Ne (mg/L)	NOx-Ne (mg/L)	NODrec (mg/L)	CODu (mg/L)	TOR (g/d)
15	BNR	10	07AUG89-09AUG89	170	17.0	24.4	0.2	5.09	2290	87.3	0.1	9.5	9.6	27.1	68.7	21.9
	BNR	15	26MAY89-28MAY89	228	24.0	28.5	1.0	5.89	2650	98.8	0.2	9.7	9.9	33.2	79.5	28.7
	BNR	20	28JUN89-05JUL89	219	11.5	24.9	0.3	5.10	2296	89.3	0.0	8.0	8.0	33.0	68.9	29.4
5	BNR	10	07DEC89-08DEC89	262	23.5	33.7	21.1	8.64	1178	18.1	0.5	1.1	1.6	5.9	117.0	20.2
	BNR	15	19NOV89-21NOV89	190	19.3	31.1	6.2	7.18	1077	81.0	2.7	6.1	8.9	24.9	96.9	19.6
	BNR	20	30OCT89-03NOV89	320	21.2	32.5	0.4	9.47	1421	103.4	0.1	10.0	10.1	35.7	127.9	36.1
15	Conv.	10	07AUG89-09AUG89	170	23.0	24.4			2092	85.9	0.0	18.8	18.8		62.8	25.8
	Conv.	15	26MAY89-28MAY89	228	28.0	28.5			2095	91.4	0.0	20.0	20.0		62.9	34.6
	Conv.	20	28JUN89-05JUL89	219	36.0	24.9			1274	77.9	0.0	17.1	17.1		38.2	33.6
5	Conv.	10	07DEC89-08DEC89	262	35.6	33.7			1373	55.5	2.0	10.6	12.7		123.6	23.9
	Conv.	15	19NOV89-21NOV89	190	11.2	31.1			1050	123.6	1.4	26.0	27.4		94.5	31.4
	Conv.	20	30OCT89-03NOV89	320	39.3	32.5			973	89.8	1.4	18.6	20.0		87.6	42.8

CODin = Influent COD   Q = Influent or Recycle Flow Rate = 151.2 L/d
CODef = Effluent COD   V = Total Reactor Volume
CODu = COD of Waste Sludge = (V/MCRT d)(Sec. 12 MLVSS mg/L)(COD of Waste Solids)/Q
Where measured COD of Waste Solids = 1.35 mgCOD/mgVSS (BNR) = 1.30 mgCOD/mgVSS (Conventional)
TKNin = Influent TKN
TKNef = Effluent TKN
TKNu = (V/MCRT d)(0.1 mgN/mgVSS)(MLVSS)/Q

BNR:
NODin = Nitrogenous Oxygen Demand = (TKNin - TKNef - TKNu)(4.57 mgO2)
NODrec. = NOD Recovered through Denitrification = (TKNin - TKNef - TKNu - NOx-Nef)(2.86 mgO2/mgNO3-N)
+ (TKNin - TKNef - TKNu - NOx-Nef)(NO2-Nef/NOx-Nef)(1.71 mgO2/mgNO2-N)
TOR (g/d) = (CODin + NODin - CODef - CODu - NODrec)(Q)/1000 g/mg

Conventional:
NODin = (NO3-Nef)(4.57 mgO2/mgNO3-N) + (NO2-Nef)(3.43 mgO2/mgNO2-N)
TOR (g/d) = (CODin + NODin - CODef - CODu - NODrec)(Q)/1000 g/mg

Appendix F

Calculation of *Nitrosomonas* VSS Concentrations

The yield coefficient for *Nitrosomonas* is given by (McCarty, 1964; Gee *et al.*, 1990a):

$$Y_N = 0.28 \text{ mgVSS/mgNH}_3\text{-N}.$$

The overall decay rate for the conventional system was 0.110 d^{-1} (see *V. Discussion*). This is equal to the decay rate for nitrifiers reported by Yoshioka *et al.* (1982), and is in close agreement with the nitrifier decay rates reported by Gee *et al.* (1990), and Hanaki *et al.* (1990) under fully aerobic conditions at temperatures of 20-25 °C. Therefore, for the conventional system:

$$b_{Nitrosomonas} = 0.110 \text{ d}^{-1} \text{ at } 20\ °\text{C}.$$

Since under fully aerobic conditions, the decay rate for nitrifiers was equal to the system decay rate found in this study, it is reasonable to assume that the decay rate for nitrifiers in the BNR system will be the same as the system decay rate for the BNR system. Therefore, for the BNR system:

$$b_{Nitrosomonas} = 0.063 \text{ d}^{-1} \text{ at } 20\ °\text{C}.$$

Decay rates were corrected for temperature with the following relationship (Benefield and Randall, 1980):

$$b_T = b_{20}\,(1.04)^{T-20}.$$

The VSS concentrations of *Nitrosomonas* were determined from the following equation (USEPA, 1975):

$$\text{VSS } (\textit{Nitrosomonas}) = Y_N(NH_3\text{-N oxidized})/(1+(b_N)(MCRT)).$$

Appendix G

Glossary of Terms

Abbreviation or Symbol	Definition
ADP	Adenosine Diphosphate
Aer	Aerobic
Alk	Alkalinity
Ana(er)	Anaerobic
AnS	Anaerobic Stabilization
Anx	Anoxic
ATP	Adenosine Triphosphate
Avg	Average
b	Decay Coefficient
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
BPR	Biological Phosphorus Removal
COD	Chemical Oxygen Demand
COD_e	Effluent Chemical Oxygen Demand
COD_i	Influent Chemical Oxygen Demand
COD_w	Chemical Oxygen Demand of Solids Removed via Waste Sludge
d	Day(s)
DO	Dissolved Oxygen
Eff	Effluent
F/M	Food to Microorganism (Ratio)
h	Hour(s)
HRT	Hydraulic Retention Time
Inf	Influent
K_s	Michaelis-Menten Half Saturation Constant
MCRT	Mean Cell Residence Time
mg/L	Milligrams per Liter
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
NH_3-N/NH_4^+-N	Ammonia Nitrogen
NO_2^--N	Nitrite Nitrogen
NO_3^--N	Nitrate Nitrogen
NO_x-N	Oxidized Nitrogen (NO_2^--N+NO_3^--N)
NOD	Nitrogenous Oxygen Demand

Glossary of Terms (Continued)

Abbreviation or Symbol	Definition
OP	Orthophosphate Phosphorus
ORP	Oxidation-Reduction Potential
OUR	Oxygen Utilization Rate
%P/VSS	Percent Phosphorus Content of the Volatile Suspended Solids
P_i	Inorganic (Orthophosphate) Phosphorus
PHB	Poly-ß-hydroxybutyrate
PolyP	Polyphosphate
q	Specific Substrate Utilization Rate
RAS	Return Activated Sludge
Rcy	Recycle
Rem	Removal/Removed
S	Substrate Concentration
Sec	Section
SCOD	Soluble Chemical Oxygen Demand
Sol/S	Soluble
SP	Soluble Phosphorus
TCOD	Total Chemical Oxygen Demand
Temp	Temperature
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TOR	Total Oxygen Requirement
TSS	Total Suspended Solids
UCT	University of Cape Town (South Africa)
VSS	Volatile Suspended Solids
WAS	Waste Activated Sludge
Y_{max}	Maximum Yield Coefficient
Y_N	Yield Coefficient for *Nitrosomonas*

Vita

Samuel Alan McClintock was born on March 9, 1957, in Richlands, Virginia. He graduated from Richlands High School in June, 1975. In September, 1975, he entered Virginia Polytechnic Institute and State University (VPI&SU) in Blacksburg, Virginia. He received a B.S. degree in Mining Engineering in June, 1979. On March 17, 1979, he was married to the former Victoria Lea Osborne of Richlands, Virginia.

In June, 1979, he began work for Island Creek Coal Company in Oakwood, Virginia. He held many positions with increasing responsibility, including management trainee, industrial engineer, production foreman and assistant mine foreman. On June 5, 1982, he was seriously burned in a methane gas explosion in an underground coal mine while at work. During his recovery from burn injuries, he became very interested in water and wastewater treatment.

He enrolled in the graduate program in Environmental Engineering at VPI&SU, receiving an M.S. degree in December, 1986. He received a Ph.D. degree in Civil Engineering in the same program in July, 1990.

Beginning in August, 1990, he will be employed as Assistant Professor in the Science, Engineering and Technology department at Penn State Harrisburg, The Capitol College, in Middletown, Pennsylvania, where he will reside with his wife, Victoria, and their two children, Erica and Amy.