THE USE OF OXIDATION-REDUCTION POTENTIAL (ORP) AS A PROCESS CONTROL PARAMETER IN WASTEWATER TREATMENT SYSTEMS

by

DAVID GERAINT WAREHAM

B.A.Sc.(Civil Engineering), The University of Waterloo, 1984
M.A.Sc.(Civil Engineering), The University of Waterloo, 1986

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

(Department of Civil Engineering)

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

January 1992

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

(Signature)

Department of Civil Engineering

The University of British Columbia
Vancouver, Canada

Date January 27 1992

DE-6 (2/88)

ABSTRACT

This research explored the use of Oxidation-Reduction Potential to control two lab-scale sequencing batch reactor (SBR) wastewater treatment processes. The treatment schemes investigated were the aerobic-anoxic digestion of activated sludge (AASD) and the excess biological phosphorus (Bio-P) removal process. Evaluation of each process consisted of a consideration of the reactor performances coupled with the control stability achieved using two different operating strategies.

The first strategy was known as "Fixed-Time Control" (FT), since it represents the "classical" management approach; control is based on conditions externally "fixed" by an operator. For the AASD set of experiments, the "fixed" variable was the ratio of air-on to air-off (3 hours each). For the Bio-P experiments, it was the time of addition of acetate to the reactor (1 hour 25 minutes into the non-aerated sequence).

The second strategy was known as "Real-Time Control" (RT), since it represents an optimization technique whereby control conditions are continuously evaluated as time progresses. The Real-Time aspect of control is derived from the fact that ORP measurements evaluate the reactor conditions on-line, by invoking a bacterial vision of the process scheme.

For the AASD experiments, this evaluation took the form of proportioning the ratio of air-on to air-off, based upon the bacterial "need" for sufficient time to reduce the nitrates completely to nitrogen gas (denitrification). Sufficient time is

determined by the distinctive breakpoint (correlated to nitrate disappearance) occurring in the ORP-time profile.

The first experiment (AASD#1), therefore, had an air-on/air-off ratio of 3 hours air-on/nitrate-breakpoint-determined air-off. The second experiment (AASD#2) had the length of aeration time determined by a match to the previous length of time for denitrification, as determined by the breakpoint. In the Bio-P experiments, the ORP breakpoint was used to "trigger" the addition of acetate to the reactor, thus ensuring the maximum amount of carbon was available for storage by Bio-P organisms.

Comparisons between the two reactors revealed that for the AASD strategies, the Real-Time reactor had essentially the same solids degradation as the Fixed-Time reactor (14% - 21%), depending upon the strategy considered, the type of solids (TSS or VSS) and the method of mass balancing used. The RT reactor was observed to obtain marginally better nitrogen removal (up to 6 % in some cases) over the FT reactor.

Evaluation of the ORP parameter as a "response indicator", by subjecting the AASD reactors to unsteady process input conditions, revealed that the Real-Time reactor more readily accommodated disturbances to the system.

Neither reactor in the Bio-P experiment was particularly successful in consistently removing phosphorus. A potentially useful screening protocol was developed for evaluating reactor performances, based upon the time-of-occurrence of the nitrate breakpoint, assessed against whether it hindered or aided the purpose of acetate addition to a Bio-P SBR.

TABLE OF CONTENTS

TABLE OF CONTENTS CONT'D

LIST OF TABLES

LIST OF TABLES CONT'D

LIST OF FIGURES

LIST OF FIGURES CONT'D

LIST OF FIGURES CONT'D

LIST OF FIGURES CONT'D

ACKNOWLEDGEMENTS

The interdisciplinary nature of this research is reflected in the variety of backgrounds, associated with the many individuals to whom I have become indebted, during the course of my stay at UBC.

Firstly, I would like to thank my supervisors, Drs. K. J. Hall and D. S. Mavinic for their patience and guidance during the difficult times of this research. Furthermore, I am indebted to the Natural Sciences and Engineering Research Council of Canada (NSERC) for the financial support they provided via grants to my supervisors.

I would like to acknowledge both the excellent technical assistance and the moral support of Susan Liptak, Paula Parkinson, Romy So, and Jufang Zhou, who cheerfully demonstrated the use of the lab instruments and always co-operated to the fullest extent, making the lab a pleasant environment within which to work.

I am also grateful to Guy Kirsch, for his skilled modifications to the lab apparatus, to Paul Milligan, John Wong and Dr. Peter Lawrence for their advice and assistance in solving the electrical problems, to Rod Nussbaumer and Jim Greig for their software support and Fred Koch for his explanation of fundamentals.

Thanks are owed to my many fellow graduate students, among others, Yves Comeau, Kirk Morrison, Pat Coleman, Bruce Anderson, Fongsatitkul Prayoon, and Takis Elefsiniotis, all of whom provided their unique brand of advice, humour and comradery, making my UBC experience most enjoyable.

Special thanks are in order for Tim Ma for his companionship, availability and general willingness to discuss any of life's intricacies both inside and outside of the laboratory.

Also valued is the on-going interest and support of both my families in Ontario. Their many calls of encouragement were deeply appreciated.

Finally, I would like to thank my beloved wife Julia, whose constant love, encouragement and spiritual support has been a real boon to me, as together we have endeavoured to know Him who is the author of all knowledge.

GLOSSARY OF TERMS

General Terms

AASD..........Aerobic-Anoxic Sludge Digestion (#1 and #2)
ATP/ADP.......Adenosine Triphosphate/Diphosphate
Bardenpho.....Barnard Denitrification Phosphorus Removal Process
Bio-P.........Biological Phosphorus Removal (#1 and #2)
COD...........Chemical Oxygen Demand
D.O...........Dissolved Oxygen
F:M...........Food:Microorganism Ratio
HRT...........Hydraulic Retention Time
MLSS/MLVSS....Mixed Liquor Suspended Solids/Volatile SS
N (%).........Nitrogen
NAD/$NADH^+$.....Nicotinamide Adenine Dinucleotide
ORP...........Oxidation-Reduction Potential
P (%).........Phosphorus
PHA/B/V.......Poly-β-hydroxyalkanoates/butyrates/valerates
RCTR..........Reactor
SBR...........Sequencing Batch Reactor
SCFA..........Short Chain Fatty Acids
SRT...........Sludge (Solids) Retention Time
TC/TOC/IC.....Total/Total Organic/Inorganic Carbon
TKN/TP........Total Kjeldahl Nitrogen/ Total Phosphorus
UBC/UCT.......University of British Columbia/Cape Town
VFA...........Volatile Fatty Acid

Important Terms Specific to Program

Acetate.......Acetate not added to RT reactor yet
Baseaddr%.....The Base Address of the A//D Board (&H220)
Chan0%/15%....Lower (0) and Upper (15) Bounds of channels
Delta2a/2b/2c.The Critical ORP Slope Difference (-1.25)
Flagdiff......No Preceding Point in First Difference SUB
Flagloop......For Breaking into and out of Scanning Loop
Flag.RT.......Real-Time Control Requested by User
Flagscrn......Flag to Invoke Graphics Display
Ioadr%........The Base Address of the Relay Board (&H330)
KY.ESC........For Escaping/Terminating Program
KY.LN.........For <No> Decision Finished Viewing Probes
KY.LY.........For <Yes> Decision to Select Other Probes
Max.Anox......Fail-Safe Limit to Resupply the Air
Maxavoid......Variable Safety Factor Before Search for Knee
Nitrate.......Flag Signalling Nitrate Breakpoint Detected
Num.Channels..Number of Channels to be Scanned (16)
Num.Pts.......Dimensioning of Screen Display (181)
Numrings......The number of Rings in the Buffer (5)
Num.Scans.....Number of Scans/2 minute interval (60)
Realtime......Flag - Initially no Real-Time Control
Renew.........Flag to Clear/Reset Breakpoint Subroutine
Ringsize......The width of the BREAKPT Ring (5)
Scan.Time.....Polling interval for the probes (2 seconds).
VFAPass.......Counter to time the VFA Pump Operation
VFAPump.......Flag to Signal VFA Pump On or Off

CHAPTER 1

INTRODUCTION

1.1 Project Need

The fundamental theories of wastewater treatment have been well understood for many years. In recent times however, the emphasis has moved towards acquiring better control of the unit processes, thereby treating a waste more efficiently. A greater ability to control inherently returns benefits in the form of less wasteful unit operations, since specific control parameters can be fine-tuned at will to optimize system performance.

Classical examples in wastewater treatment include matching aeration supply to oxygen demand (to avoid overaeration) and correlating food supply to microbial biomass. The escalating demand for better control has generated in its wake a demand for increased reliability and development of sensing instruments. At the forefront of this movement are instruments capable of making in situ measurements, a fact already attested to by the development of the on-line dissolved oxygen probe.

Even more recently the advent of the microcomputer has brought automation to the sewage treatment field. For example the International Association on Water Pollution Research and Control (IAWPRC) has sponsored a series of workshops (London and Paris (1973), London and Stockholm (1977), Munich and Rome (1981), Houston and Denver (1985), and Yokohama and Kyoto (1990)), specifically devoted to the interchange of technical information on instrumentation and control of water and wastewater treatment and transport systems.

Instrumentation, control, and automation (ICA) is clearly an expanding field for research and development and interest in its application to wastewater treatment systems (and water supply in general) shows no signs of abatement.

In the very early years computers were employed simply as "plotters", recording operational data and doing elementary evaluations, such as printing maintenance lists (Lohmann, 1985) and/or tracking the number of occurrences in which data exceeded threshold limit values. In the eighties and now nineties, computers are moving beyond the data acquisition / process monitoring stage, to being increasingly used for more sophisticated wastewater treatment applications. Examples abound and range from complex forms of information management, linked through workstations (Williams et al., 1986), to process control (Vaccari et al., 1988). When coupled with reliable sensors they can provide rapid information, particularly with regards to real-time disturbances.

At the very least, computers commonly alert operators to problem area(s), while some computers possess enough sophistication to analyze both the problem scope and to implement remedial action. In addition a computer offers a major advantage over traditional hardwired systems (composed of timers and relays) due to the relative ease with which the sequencing logic can accommodate (through changes in either its format or time-base) improvements in the operating procedure.

As will be emphasized in Chapter 2, interest in Oxidation-Reduction Potential (ORP) has recently been renewed, partly as a result of the search for new process control parameters to couple with the innovative technologies being developed. Earlier criticisms regarding the meaningfulness of ORP measurements in biological systems (Harrison, 1972) have been re-evaluated in light of the knowledge that the emphasis can be transferred from the absolute value of the ORP (which is admitted to having debateable usefulness (other than in the most general sense of an environment being oxidizing or reducing)) to the ORP variation with time. For example, there is no question that ORP-time profiles in acclimated sludges undergoing alternating aerobic-anoxic sequences, contain certain distinctive features which can be correlated with known physical and chemical events of theoretical and engineering interest (Peddie et al, 1988b).

One such feature is the nitrate breakpoint or "knee" associated with the disappearance of nitrates in the ORP-time profile. (Section 4.1). This phenomenon correlates to the bacterial transformation from respiratory to non-respiratory processes, and has been well documented (Koch and Oldham, 1985) in both aerobic-anoxic sludge digestion (Jenkins, 1988) and biological phosphorus removal (Comeau et al., 1987a) processes. The regular occurrence of this feature provides a powerful impetus for process control.

The major truth evident here is that although the ORP probe does not achieve a well-defined thermodynamically-reversible equilibrium value (suggesting a specific solution composition of speciated ions), this should not hinder its use as a process control parameter in wastewater treatment systems. As long as the system is sufficiently electroactive to generate (at least at the electrode level) an observable biologically-meaningful response pattern, it reflects a reality which ultimately can be exploited for control purposes.

Thus this research addresses the need to re-evaluate the usefulness of the ORP probe as a process control parameter in light of the recent advances in computer and control technology. For example, the marked instability so often characteristic of past ORP measurements in biological wastewater and sludge treatment systems, can be easily smoothed out as part of the interfacing equipment before the signal is processed by the host computer. Elimination of these extreme fluctuations allows the computer to more readily control the process, based upon consistent detection of a real and reproducible feature in the ORP-time profile.

1.2 Research Approach and Objectives

The basic objective of this research is to demonstrate the usefulness of Oxidation-Reduction Potential, for automated control of Sequencing Batch Reactor (SBR) sewage treatment processes. More precisely, ORP-based process control is demonstrated in two specific wastewater treatment processes, the first accommodating the solids residuals generated from a sewage treatment plant (Aerobic-Anoxic Sludge Digestion (AASD)) and the second investigating bio-nutrient treatment of raw sewage (Biological Phosphorus (Bio-P) Removal). Control is based, in both cases, on the nitrate breakpoint phenomena which occurs in the ORP profile with time (Section 4.1).

Two operating strategies (more fully discussed in Chapter 3) are considered in the AASD set of experiments (Chapter 4). The first strategy (AASD#1 - Section 3.4.1) compares a control reactor (Fixed-Time Control) (operating with a "Fixed" 3 hour air-on, 3 hour air-off aerobic/anoxic sequence) to an experimental reactor (Real-Time Control) operating with a cycle partition of 3 hours air-on but a variable length of time for air-off, contingent upon computer detection of the nitrate knee.

The second strategy (AASD#2 - Section 3.4.2) compares a control reactor operating as above (Fixed-Time mode), with an experimental reactor, now operating with the length of aeration time determined by a match to the previous time for air-off (i.e. the length of the preceding anoxic cycle). At the time this research was proposed, no information was available on whether an ORP-driven, 50/50 air-on/air-off mode of operation, would collapse in on itself due to the rapid on/off sequences. Conceivably, if the process showed stability (under what is likely a "stressful" operating strategy), there could be grounds for investigating an operating strategy which further shortened the cycle length, operating between an ORP-detected "nitrate knee" and an ORP-detected "dissolved oxygen elbow" (Section 4.1). This would essentially represent an oscillating balance between nitrification and denitrification, thus considerably saving the air supply associated with the dissolved oxygen plateau of the ORP-time curve (Section 4.1).

The Bio-P experiments (Chapter 5) compare a control reactor (operating with a "Fixed" time, (1 hour 25 minutes) for the addition of volatile fatty acids to the anaerobic regime) to an experimental reactor using nitrate breakpoints, to time the addition of acetate to the anaerobic phase of the cycle.

In both sewage processes an attempt has been made to evaluate the effectiveness of ORP as a process control parameter. In the AASD experiments, this included detailing the stability and responsiveness of the ORP controlled system to several stresses, (both artificial and natural). In the Bio-P experiment, this involved categorizing the nitrate breakpoints according to whether or not their time of occurrence maximized the objective of VFA addition to the process. For example, some breakpoints occurred well after the addition of VFAs, meaning that some of the acetate was likely used by denitrifers to reduce nitrates, rather than being exclusively used by Bio-P organisms for carbon storage.

CHAPTER 2

OPERATING THEORY AND LITERATURE REVIEW

2.1 Oxidation-Reduction Potential (ORP)

2.1.1 Redox Theory

Many ubiquitous processes found in the natural world can be reduced to electro-chemical reactions involving the transfer of electrons from one species to another. A substance which gains electrons is said to be reduced (in a reduction reaction), while a substance which loses electrons is said to be oxidized (in an oxidizing reaction). Since some species gain or lose electrons more readily than others, (a function of the number of electrons in the outer shell and the size of the atom or ion (Westcott, 1976)), a table of Standard Electrode Potentials can be compiled and is to be found in any standard text on water chemistry (ex. Benefield et al., 1982).

To assign a Standard Electrode Potential to a substance, unit activities of its oxidized and reduced forms are connected via a platinum wire and salt bridge, to a hydrogen half-cell containing water (pH = 0, (1 M H^+), T = 25 ^oC) and hydrogen gas at one atmosphere pressure. The electrode potential is the voltage that would have to be applied to prevent electrons flowing to or from the test half cell. By convention, a positive voltage means that the electrons are flowing from the hydrogen half-cell to the sample, while a negative voltage is defined when the electron flow is from the sample to the hydrogen half-cell.

Table 2.1 shows a selected subset of some of the half-reactions pertinent to this research (written as reduction equations). All of the equations shown are those substances which have a strong affinity for accepting electrons. They are allocated large positive potentials with respect to the hydrogen half-cell (arbitrarily assigned a zero volt potential), since the reaction as written has a strong tendency to proceed to the right. In contrast, those substances which lose electrons most easily (i.e. have the least tendency to exist in a reduced state), would be assigned more negative potentials with respect to the hydrogen half-cell.

As indicated, the reactions are half-reactions, that is, for every reduction equation there exists a complementary oxidation equation. Thus both the oxidized and reduced forms of a particular redox couple can concurrently exist in solution. Therefore, oxidation-reduction potential (ORP) is a measurement which establishes the ratio of oxidants to reductants prevailing within a solution of water or wastewater (ASTM, 1983).

In contrast to pH which measures a specific acid/base couple (in effect the hydrogen ion activity), the ORP measurement is non-specific (i.e. not a specific redox couple); instead, it senses the prevailing net direction of all electron transfers occurring, and thus the net solution potential is in effect the electron activity (Petersen, 1966).

Table 2.1 Selected List of Electrode Half-Reactions and their Standard Electrode Potentials

Reaction	E° (Volts)
$H^+ + e^- <=> 1/2\ H_{2(g)}$	0.00
$CO_{2(g)} + 8H^+ + 8e^- <=> CH_{4(g)} + 2H_2O$	+0.17
$AgCl_{(s)} + e^- <=> Ag_{(s)} + Cl^-$	+0.22
$SO_4^{2-} + 9H^+ + 8e^- <=> HS^- + 4H_2O$	+0.24
$Hg_2Cl_{2(s)} + 2e^- <=> 2Hg_{(l)} + 2Cl^-$	+0.27
$SO_4^{2-} + 10H^+ + 8e^- <=> H_2S_{(g)} + 4H_2O$	+0.34
$I_{2(aq)} + 2e^- <=> 2I^-$	+0.62
$NO_3^- + 2H^+ + 2e^- <=> NO_2^- + H_2O$	+0.84
$NO_3^- + 10H^+ + 8e^- <=> NH_4^+ + 3H_2O$	+0.88
$NO_2^- + 8H^+ + 6e^- <=> NH_4^+ + 2H_2O$	+0.89
$2NO_3^- + 12H^+ + 10e^- <=> N_{2(g)} + 6H_2O$	+1.24
$O_{2(aq)} + 4H^+ + 4e^- <=> 2H_2O$	+1.27
$Cr_2O_7^{2-} + 14H^+ + 6e^- <=> 2Cr^{3+} + 7H_2O$	+1.33
$Cl_{2(aq)} + 2e^- <=> 2Cl^-$	+1.39

Note: (1) All reactions with respect to the hydrogen standard electrode and at T = 25°C.
(2) List drawn from larger list presented in Snoeyink and Jenkins, 1980 Water Chemistry)

The ORP is expressed in mathematical form by the Nernst equation as shown below.

For the Reaction: $Ox + ne^- = Red$ (2.1)

The Nernst Equation: $E_h = E^o + \frac{RT}{nF} \ln\{Ox/Red\}$ (2.2)

where:

Ox - Oxidized species.

Red - Reduced species.

n - number of electrons participating in the reaction.

E_h - the voltage difference (V) between the oxidation-reduction half cell and the standard hydrogen electrode.

E^o - the voltage difference occurring in a pure system (i.e. when the activities of all oxidants and reductants are unity and at 25 °C).

R - Universal Gas Constant (8.315 joules/ °K/mole).

T - temperature - degrees Kelvin.

F - Faraday Constant (96,500 coulombs/equivalents).

{} - the activity of the oxidized and reduced species.

The derivation of the Nernst equation, arising from consideration of the interaction between the Gibbs Free energy equation and the Van't Hoff equation is included in Appendix A.

In practice, the gaseous hydrogen electrode is rarely used as the reference electrode, due to certain physical difficulties, such as bubbling hydrogen gas at 1 atmosphere pressure through a solution. The E_h however, can always be obtained by adding the measured potential to the potential of the reference electrode. The most common reference electrodes are the Ag/AgCl and the calomel electrode (Section 2.1.3).

2.1.2 Microbiological Aspects: Intracellular Redox

Molecular oxygen is the most powerful oxidizing agent found in natural water systems, since anything stronger would begin to react with the abundant surrounding water and liberate oxygen. Redox reactions initiated with oxygen as the oxidizing agent, should be quite slow based on theoretical considerations, since the solubility of oxygen in water is low (Henry's Law predicts $2x10^{-4}$ mol/L). Moreover, kinetic restraints arise since the synchronous transfer of 4 electrons (Table 2.1) to completely reduce oxygen to water is highly improbable, since most electron donors supply at best one or two electrons per molecule.

It is a well known fact however, that organic matter can be metabolized by living cells. Micro-organisms do not actually perform the chemical reactions, instead they catalyze them and use the material for purposes such as deriving energy for metabolic processes or as source materials for biosynthesis (Snoeyink and Jenkins, 1980). Thus the biochemical reduction of oxygen to water can take place extremely rapidly because biological systems have circumvented the need for multi-stage reduction (i.e. separate one or two electron steps) by using enzymes in which several electron donor centres are present in the same molecule and which ultimately provide all four electrons required (Eilbeck and Mattock, 1987). This fundamental principle is exploited in biological treatment systems designed to specifically oxidize the organic constituents in wastewater.

A detailed description of the many and various metabolic pathways, specific enzymes, energy balances and methods of phosphorylation etc. is beyond the needs of this research; however, any good text on microbiology (ex. Tortora et al. (1982)) can supply most of the necessary details. For the brief purpose of illustration however, the biochemical degradation of the energy-yielding carbohydrate glucose will be considered. Equation 2.3 describes the complete oxidation of this cellular fuel in the presence of oxygen to carbon dioxide and water.

$$C_6H_{12}O_6 \; + \; 6O_2 \; ==> \; 6CO_2 \; + \; 6H_2O \qquad \Delta G^{\circ} = -686 \text{ kcal/mole} \quad (2.3)$$

If a bacterial cell were to burn glucose in this manner (i.e. one step), it would literally burn itself up. Instead, the cell invokes a metabolic pathway that involves numerous stages, each catalyzed by its own specific enzyme and characterized by a free energy change that is rarely more than a few (ex. 10) kcal/mole (Dyson, 1974).

The first step usually involves the removal of two hydrogen atoms (with the accompanying two electrons) via the enzyme dehydrogenase. This is followed by several other sequential stages in which some of the intermediate products produced are broken down yet again. In terms of the specific route taken, numerous metabolic pathways exist (depending upon the physical environment and the ability of a specific organism to utilize a particular path); however, the most common pathway is the Tricarboxylic Acid (Krebs or TCA) Cycle (when respiration is occurring aerobically) and the Glycolytic (Embdon-Meyerhoff) Pathway (when non-respiratory processes such as fermentation are employed). The TCA cycle becomes an extension to the glycolytic pathway when oxygen or a combined form of it becomes available to an organism that can use this path.

At several points in the pathway the energy in the electrons is captured by one of a class of electron deficient carrier molecules such as nicotinamide adenine dinucleotide (NAD^+), which is reduced to a high energy level compound NADH. Since NAD^+ is generally in short supply in the cell, the rest of the cells efforts are directed towards regenerating the pool of NAD^+ by one of several mechanisms.

Again if NAD^+ was regenerated by directly combining with oxygen,

$$NADH + H^+ + 1/2\ O_2 \Longrightarrow NAD^+ + H_2O \quad \Delta G^o = -53.8 \text{ kcal/mole} \quad (2.4)$$

the resulting free energy change of 53.8 kcal/mole (calculated in Appendix B), would still be too large to be captured by a single adenosine triphosphate (ATP) molecule (or its equivalent) and much of the energy would be lost as heat (Boyd, 1984). The most efficient way to regenerate NAD^+ (i.e. maximizing the capture of energy) is to transfer the electrons from NADH to oxygen in a series of discrete steps via the electron transport chain.

The electron transport chain (Figure 2.1) located in the cytoplasmic membrane of prokaryotes, consists of a series of closely linked electron carrying species, such as flavins, quinones and certain proteins containing metal ions. The NADH passes its electrons to the first carrier molecule in the chain and in the process regenerates NAD^+. Each couple then reduces the

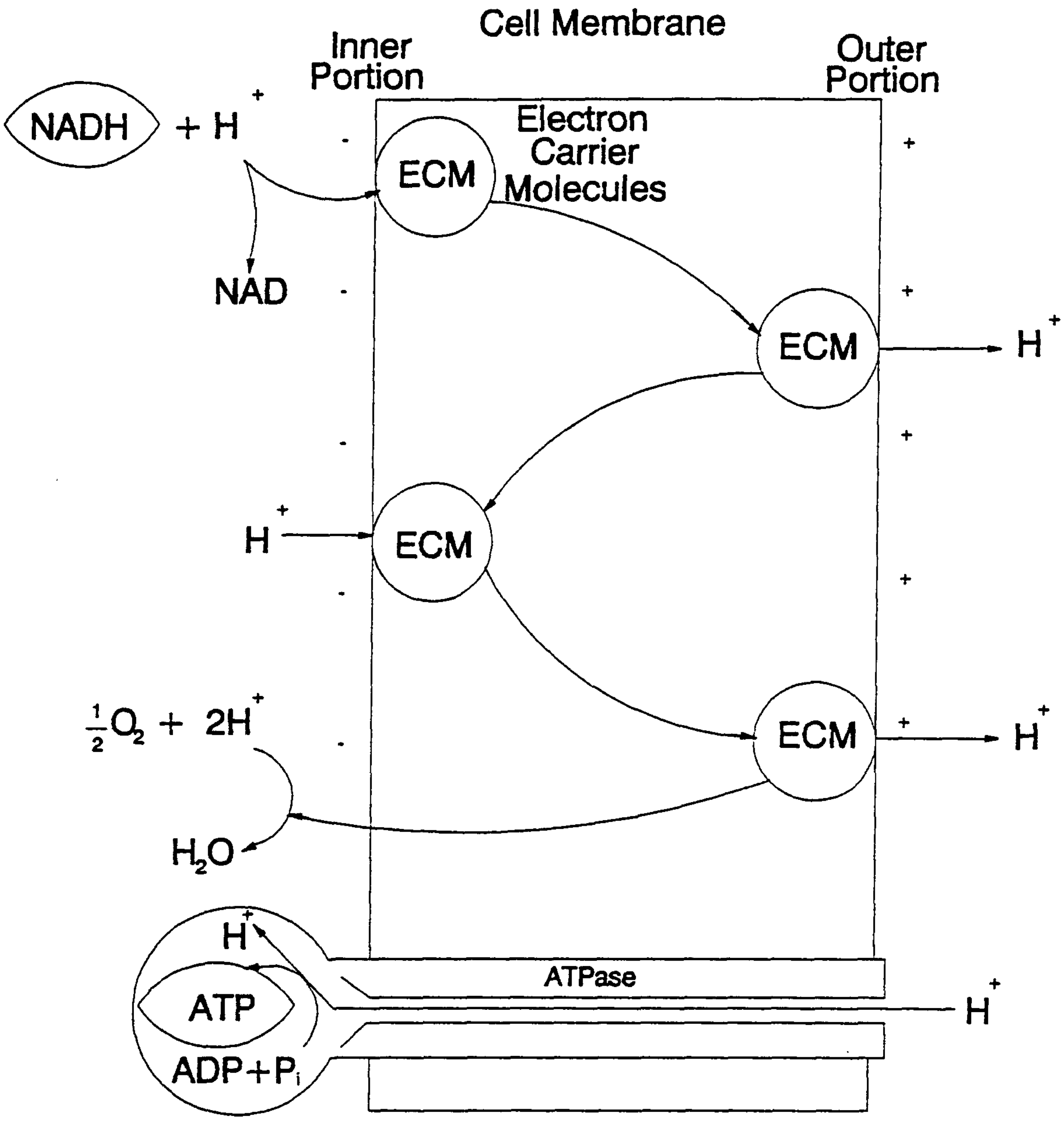


Figure 2.1 Typical Bacterial Electron Transport Chain
(Adapted from Tortora et al., (1982))

next in line until the terminal electron acceptor is reached and reduced to its final form.

Each of the electron carriers in the respiratory chain has its own characteristic ORP. Electrons gravitate from more negative carrier molecules to more positive ones and therefore this governs the structure of the chain. Moreover, there is a small decline in free energy between adjacent molecules in the chain. The magnitude of the energy release is directly proportional to the difference in magnitude of the intracellular redox potentials of adjacent molecules.

At certain strategic points (three when oxygen is the final electron acceptor), there is a sufficient drop in free energy that a high energy phosphate can be donated to adenosine diphosphate (ADP) to form ATP (a process known as oxidative phosphorylation). ATP is the most common energy reserve molecule or retrievable form of energy currency in which the micro-organism stores energy; however, other energy reserve molecules do exist. The micro-organism can draw upon this energy bank by coupling ATP hydrolysis to unfavourable reactions that need to be driven such as some biosynthesis processes. It is estimated that for every mole of glucose oxidized aerobically to CO_2 and water (via the glycolytic pathway/TCA combination), 38 ATP-like molecules are formed (Boyd, 1984). As shown in Appendix B, this represents a 39-45 % capture of the original energy (686 cal/mole) stored in a mole of glucose molecules.

This can be compared with the mere 2 ATP molecules generated by the incomplete oxidation of glucose under anaerobic conditions (i.e. ATP generation by substrate level phosphorylation) by organisms that halt at the end of the glycolytic pathway. Thus aerobic organisms grow much faster than anaerobic organisms because the potential for energy release during aerobic respiration is much greater than anaerobic conditions, since many electron pairs are released and shuttled down the chain to produce ATP. A facultative organism for example might require 48 hours of optimal growth conditions to produce a population of cells that, under aerobic conditions, could be established in 16 hours or less (Boyd, 1984).

Many micro-organisms possess the capability of using an alternate terminal electron acceptor in the electron transport chain, if their primary choice is unavailable. For example, Pseudomonas and Bacillus can use nitrates; however, they only utilize them when the concentration of dissolved oxygen is minute or nonexistent, since fundamentally they are unable to extract as much energy per mole out of doing so. Again, when nitrate is utilized, the reaction to produce N_2 (gas) is favoured over the reduction of NO_3^- through NO_2^- to NH_4^+ because it yields more useable energy to the micro-organism catalyzing it (using the enzyme nitrate reductase) (Snoeyink and Jenkins, 1980). Again, this is a function of the intracellular redox levels of the various reaction couples.

Other bacteria are restricted to the use of one electron acceptor such as Desulfovibrio which reduces sulphate (SO_4^{-2}) to hydrogen sulphide (H_2S). Still others use carbonate (CO_3^{-2}) to form methane (CH_4). A few microbes anaerobically use compounds such as fumaric acid as the final electron acceptor.

Depending upon the electron donor, the micro-organism, the pathway chosen and the terminal electron acceptor, the number of ATP molecules generated from the chain may be only 1 or 2 rather than 3 when free oxygen is used. As mentioned, this essentially translates to the difference in the oxidation reduction potential between the donor (NADH) and the final electron acceptor.

In this general sense the intracellular redox level helps to determine the type of biological community that develops. The exact relationships between the intracellular redox level, the NADH level and the extracellular ORP probe measurement is subject to on-going research (Wang and Stephanopoulos (1987), Armiger et al. (1990)). Nicotinamide adenine nucleotides are known to be the coenzymes of a good fraction of the intracellular oxidation-reaction steps, and therefore by following the $NADH/NAD^+$ level important process control strategies can be formulated. In fact, Armiger et al (1990) have already demonstrated how a fluorescence method (which measures the ratio of NADH to NAD^+) can be used to provide a characteristic "fingerprint" of the optimal operation of a bionutrient removal process. This procedure is very similar to the method used in this research except that it assesses the reductive (rather than the oxidative) status of the sludge.

Whatever the exact relationship between intracellular and extracellular redox is, there is little question that the external ORP reading is a direct reflection of the activity at the cellular level. This is not to imply that ORP is the sole governing mechanism that drives the community type. It can be appreciated that in a wastewater treatment system there is both a complex mix of micro-organisms and a virtual "cocktail" of organic wastes. Which reactions are used is still very much a function of the physical environment. However, whether a particular ORP value is the cause or effect of a given bacterial population is of secondary importance, for the correlation between the two is real enough (Whitfield, 1969) such that a link of this kind can be effectively exploited.

2.1.3 Physical Characteristics: Probe Operation

Electro-chemical theory suggests two kinds of electro-chemical cells. The electrolytic cell occurs when non-spontaneous reactions are forced to proceed by the external application of a voltage across the two electrodes. Thus, electrical energy is consumed during the reaction. Conversely, the Galvanic cell, of which type the ORP electrode is representative, is an electro-chemical cell in which the spontaneous occurrence of electrode reactions produces electrical energy.

The ORP electrode consists of a reference electrode (ex. silver/silver chloride or calomel) and an indicating electrode constructed of a highly noble metal (ex. platinum or gold). The reference electrode or cathode has a fixed potential since the concentration of the cation associated with the electrode metal is maintained through the solubility-product principle. The reference electrode is separated from the test solution by a porous ceramic plug which allows charged ions to pass through to each solution preventing charge differentials building up and halting the reactions.

A highly noble (inert) metal is chosen as the anode primarily because its potential for oxidation is less than that of any oxidizable components in the test solution. The anode therefore ideally should not participate in any reaction, but rather just provide a surface for the oxidation of the solution constituents. The area of the noble metal in contact with the test solution should be approximately 1 cm^2 (ASTM 1983). A sketch of the ORP electrodes used throughout the duration of this research is shown in Figure 2.2.

In order to describe how the probe functions, it is assumed that initially the probe is immersed in a highly reducing environment, that is, one in which anaerobic respiration processes prevail (ex. sludge which has been unaerated for several hours). The organic materials in the sludge are continuously subjected to degradation by bacterial enzymes and thus a variety of numerous, successive and parallel biological reactions occur as electrons are shuttled back and forth between oxidized and reduced species.

Some of the electrons will naturally gravitate along the platinum wire to the cathode, since the Ag/AgCl reference electrode has a large positive electrode potential of +.22 volts (Table 2.1). The silver chloride paste will then undergo a reduction equation forming solid silver and free chloride ions as shown in Equation 2.5.

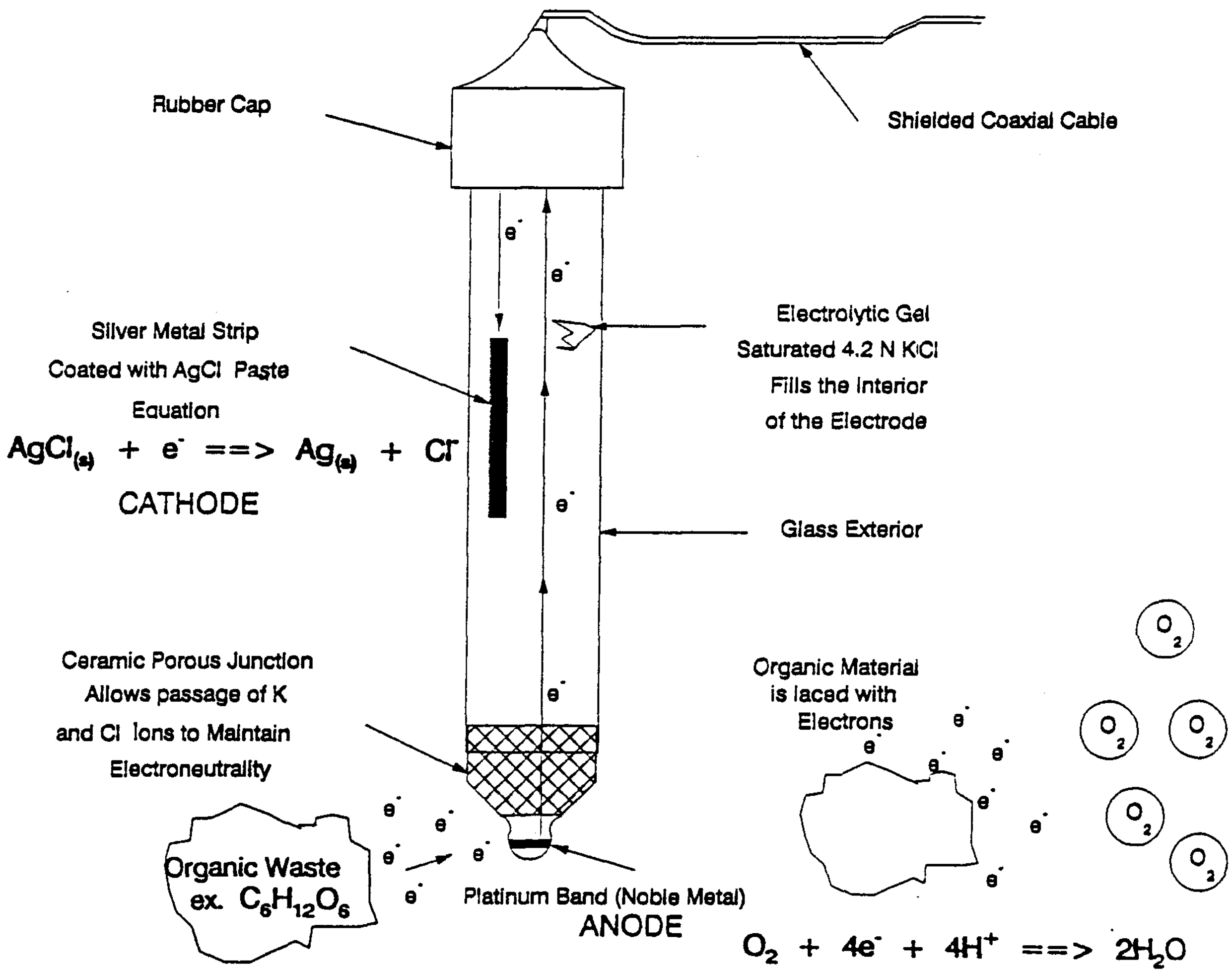


Figure 2.2 Diagram of ORP Electrode and Operation

$$AgCl_{(s)} + e^- \Longrightarrow Ag_{(s)} + Cl^- \quad (2.5)$$

Again by convention, when the flow of the electrons is from the test solution to the reference electrode the ORP value recorded is negative.

Upon introducing a continuous supply of oxygen into the solution, many of the electrons normally travelling to the reference electrode will be enzymatically rerouted towards reducing the oxygen to water, since it has an even larger positive potential (E^o = 1.27 (Table 2.1)) than the reference Ag/AgCl electrode. As the number of electrons travelling along the platinum wire diminishes, so too will the ORP value become more positive. Eventually the flow of electrons will reverse itself, consistent with the definition that when the flow is from the reference electrode to the test solution the ORP is defined positively. Therefore, in any given water system, the variation of ORP potential with time may serve as a relative guide to the oxidizing or reducing conditions in that system (Bockris, 1972).

2.2 Applications of Oxidation-Reduction Potential

2.2.1 General Activated Sludge Processes

A survey of the relevant literature indicates that interest in ORP as applied to activated sludge processes, flourished for the most part during the middle years of this century. Researchers such as Rohlich (1948), Hood (1948), Eckenfelder and Hood (1951), and Nussberger (1953) investigated and debated the significance of ORP measurements, primarily in aerobic treatment processes. It quickly became evident that exact potentials for aerobic and anaerobic regimes of a treatment process were questionable (Rohlich, 1948), since measurements varied widely both between plants and amongst probes inserted in the same tank within a given plant. However, Rohlich (1948) did maintain that the time-potential ORP curves could be used to maintain better operational control of a sewage treatment plant.

Despite initial optimism, a note of caution dictated that perhaps the most that could be said was that ORP showed promise, as a diagnostic tool to indicate whether aerobic or anaerobic conditions prevailed (Hood, 1948). Nussberger (1953) (in an effort to practically integrate ORP into the routine operation of a step-aeration sewage treatment plant) developed a series of characteristic ORP curves, which he proposed could be used as a guideline to indicate whether a plant was being under- or overloaded, and under- or overaerated.

The next spate of papers occurred roughly 10 years later, commencing with the research of Grune and Chueh (1958). This again involved investigating ORP variability in sewage treatment plants. Some of the research however began to concentrate more closely on the practical aspects of control such as aeration. For example, O'Rourke et al, (1963) used ORP to estimate the utilization of the aeration capacity of an aeration basin. Rudd et al., (1961) and Roberts and Rudd (1963) demonstrated that the diurnal rise in ORP (corresponding to the noonday decline in sewage throughput to the plant) could be used to scale back aeration on-line time, thus realizing significant economic benefits.

In an interesting discussion to Grune and Chueh 's paper, Eckenfelder (1958), in commenting about his own work, notes that both the rate of change of the ORP potential and the ultimate ORP value reached is of importance. In several tests, inflection points (sharp breaks in the ORP profile with time) could be correlated to the disappearance of an oxidant or reductant such as oxygen or sulphate. This seems to be the earliest recorded reference to a breakpoint phenomena.

The wide fluctuations in ORP readings are partly a result of the fact that, in biological systems, the ORP is a mixed potential, that is, it is a potential that is derived from many concurrent electro-chemical reactions, none of which (in open systems) are in equilibrium. As Stumm (1966), and Morris and Stumm (1967) comment "... for a multi-redox component system, that is not in equilibrium.... the redox potential (which is by conceptual and operational definition, an equilibrium potential) becomes meaningless." Harrison (1972) concluded that the overall redox potential seemed to be of little value in studies of growing microbial cultures. Such criticisms coupled with the appearance of a reliable commercially-available dissolved oxygen probe (Koch and Oldham, 1985) tended to effectively dissipate the initial interest displayed in discovering the role ORP played in sewage treatment processes.

For the most part, ORP was all but forgotten for the next two decades except for some sporadic citations such as

Dickenson (1969). He sought to characterize the relative ease with which an aerated sludge could oxidize a substrate, based upon the recovery profile of the ORP-time curve, after the sludge had received a slug dose of the substrate of interest. Other notable exceptions were researchers such as Blanc and Molof (1973) who continued to direct efforts towards understanding the role ORP measurements played in anaerobic systems where, by definition, the D.O. probe was not applicable. In particular, in some anaerobic digestion studies, they were able to correlate specific ORP ranges (-450mv to -550mv, E_c) to good production of methane.

2.2.2 Fermentation Studies: ORP Control

The use of oxidation-reduction potential in fermentation research has been the focal point of several studies for a considerable period of time (Wimpenny, 1969, Wimpenny and Necklen, 1971, and Kjaergaard, 1976). Many aerobic microbial fermentation processes take place at concentrations of dissolved oxygen (D.O.), which are impossible to measure using commercial dissolved oxygen probes. It is important however, to have some tool which can effectively provide information about the degree of oxygen limitation to the culture (Kjaergaard, 1977). The useful operating range of the redox probe is much larger than the D.O. probe due to the availability of negative redox potentials. Thus, Shibai et al. (1974) was able to show a good correlation between E_h and very low oxygen concentrations (as measured by an oxygen analyzer) in studying inosine fermentation processes.

In a review of several investigations into ORP values and microbial cultures, Kjaergaard (1977) noted special interest evidenced in the fluctuations in the ORP value as it related to the efficiency of production of particular metabolites. Their own work experimented with the regulated addition of glucose controlled by maintaining a constant redox potential in the medium. Upon depletion of the initial glucose media, the microbial oxygen consumption would decrease, reflected in an increase in both the oxygen level and ORP value. Since ORP is more readily measurable in the micro-aerophilic range than D.O., any change in its value could be easily detected and used to close a relay. This initiated a pump which delivered glucose until the redox potential returned to its original value. Since the additional glucose was used by the microorganism before a new pulse was added, the growth of the organism (and consequently the production of the metabolite) was also regulated.

The use of ORP setpoints in fermentation studies has continued to grow and further work (Kjaergaard and Joergensen, 1979, 1981) led to the proposition that ORP could be classed as a "state variable" in fermentation systems operating at minute dissolved oxygen levels.

Dahod (1982), investigating the production of penicillin, maintained that ORP was a much better parameter than dissolved oxygen for fermentation process control, primarily because D.O. measures only the oxidizing potential of the O_2 metabolic chain, while redox measures the oxidizing potential of all the species formed in the broth (i.e. all oxidation chains). This can be critical when mass transfer limitations create a discrepancy between the oxygen concentration in the bulk phase and the actual oxygen availability (Wang and Stephanopoulos, 1987). This will cause other electron acceptors to be employed.

Radjai et al. (1984) searched for the best redox conditions to optimize the production of amino acids such as homoserine, valine and lysine. The flow of dissolved oxygen to the fermentation broth was varied by manipulating the agitator speed and the change in the ORP value was recorded. The specific ORP value corresponding to the optimum production rate of the amino acid was noted and this value was once again used as an ORP setpoint in further pure culture work.

2.2.3 ORP Control of Wastewater Treatment Processes

Interest in ORP and its applications to wastewater treatment systems has been rekindled as advances in automation have led to a search for reliable process control parameters. Burbank (1981), discusses several field experiences, in which operators examined the ORP fluctuations with time and made appropriate operating decisions for the plant. Many of their resolutions correspond to the type of observations and guidelines Nussberger had proposed almost 30 years earlier.

Poduska and Anderson (1981) discuss the use of ORP to control hydrogen sulphide odours, which develop during warm weather spells in lagoons storing aerobically digested sludge. Application of a local industry's wastestream (40 % $NaNO_3$) was shown to be effective in eliminating odours due to the preferential selection of electron acceptors (ie. NO_3^- over SO_4^{-2}) in metabolism. A specific ORP setpoint was not used; however, a high positive ORP value (> +100 mv) was shown to be effective in controlling odours.

Eilbeck (1984) investigated breakpoint chlorination of free and metal complexed ammonia, in wastestreams originating from metal finishing and electronic industries. Redox titration curves were superimposed on the chlorine breakpoint curves and the sharp jump in redox when the residual chlorine broke through was noted. Prior to the breakpoint, the ORP remained constant as chloramine complexes were formed with hypochlorous acid. Thus the redox breakpoint, detecting when a residual became available, was of great assistance in ascertaining dosage rates.

Rimkus et al. (1985) used ORP to control raw sewage odours generated when low weather flows into the Chicago O'Hare Water Reclamation Plant (a combined sewer inlet) led to the production of hydrogen sulphide. A computer continuously analyzed ORP signal inputs and when the ORP dropped below +100 mv, sodium hypochlorite was added to increase the ORP.

Sekine et al., (1985) described an activated sludge process which used ORP as a supervisory index for nitrification. A circuit converted the ORP value into a nitrification rate (based on experimental observations) and made a time-series correction to the D.O. value to obtain good nitrification. Watanabe et al. (1985), in a series of lab experiments, used an ORP setpoint of approximately -150 mv to control the addition of an external carbon source (methanol) in order to ensure denitrification. As the biomass exhausted the carbon, the ORP would rise above the setpoint and initiate methanol addition. In this way , ORP became a control index for methanol regulation and allowed consistent effluent NO_x-N levels of less than 1 mg/L.

Charpentier et al., (1987) discussed both laboratory and full scale applications of ORP control in France. In a low loaded activated sludge plant, various NH_4^+ and NO_3^- effluent concentrations were recorded along with the attendant variations in ORP. Subsequently, ORP values of -80 to +120 mv were targeted and air was cycled on and off to the aeration basin, at a rate just sufficient to keep the ORP between these limits. In this way, consistent effluent nitrogen levels were maintained. They concluded that with redox based control, electricity consumption could be more accurately determined, thanks to constant regulation of the aerators correlated to specific pollution levels.

Research into ORP continues to progress as investigators have recognized the potential ORP offers for *in situ* process control. Heduit and Theunot (1989) mention that the constants in the relationship between the D.O. concentration and ORP (of the form $E_h = a + b \log[O_2]$) depend upon the sludge loading, the aeration conditions, the sludge concentration and other redox species.

Charpentier et al., (1989) furthered this work by investigating relationships between effluent nitrogen and ORP. They found that targeting upper and lower ORP values in the aeration cycle, simultaneously optimized the effluent quality and electrical costs. De la Menardiere (1991) in a similar study, observed high removal levels for carbon, nitrogen and phosphorus as a function of targeting different ranges for the ORP values in the aeration basin. Both of these latter two studies make some poignant observations relating to ORP inflection points and nitrate disappearance. They comment about the possibility of new ORP applications using these inflection points in the control of biological nutrient removal processes.

2.3 ORP and Aerobic Anoxic Sludge Digestion (AASD)

One of the most significant expenditures associated with the construction and operation of a pollution control plant, is the cost of stabilization and disposal of the waste activated sludge solids. Estimates vary but are generally in the range of 40-50 % of the total cost (both capital and operating) of the wastewater treatment plant (Rich, (1982), Evans and Filman (1988)). For small plants (< 5 MGD) an attractive option is to aerobically digest the sludge, since this method is not as prone to process upsets, which can periodically afflict the anaerobic digesters in larger plants. Aerobic digestion is somewhat similar to extended aeration, except that there is assumed to be no influent source of carbon other than that derived through the auto-oxidation (endogenous respiration) of the bacterial protoplasm itself.

An obvious disadvantage of aerobically digesting sludge is the energy cost associated with a continuous supply of air. In addition, since aerobic digestion processes tend to consume alkalinity as shown in Equation 2.7 (the bacterial mass is assumed to be represented by the chemical formula $C_5H_7NO_2$ (Hoover et al., 1952)), there is an added chemical cost to maintain the pH in the neutral range.

$$C_5H_7NO_2 + 7O_2 \Longrightarrow 5CO_2 + 3H_2O + NO_3^- + H^+ \quad (2.7)$$

Currently, there are at least 20 digesters in B.C. aerobically treating waste activated sludge (Minister of Supply and Services Canada, 1981). Recently, a modified form of the conventional aerobic sludge digestion process has been proposed (Hashimoto et al., 1982). This involves an additional anoxic tank which receives the nitrate-rich effluent of the aerobic tank and denitrifies it according to the equation below.

$$C_5H_7NO_2 + 4NO_3^- \Longrightarrow 5CO_2 + NH_3 + 2N_2 + 4OH^- \quad (2.8)$$

This not only reduces more volatile suspended solids but also acts to reduce the total nitrogen content generated in the sludge digestion process.

A more innovative design that appears to significantly offset the major disadvantages of aerobic digestion, is the practice of cycling the air in an on/off manner. This method intrinsically induces considerable savings in energy (air supplied) as well as reduces or even eliminates the extra chemical cost (since, during the anoxic portion, alkalinity is recovered (Equation 2.8)). Moreover there is no need for an additional tank as the previous solution (Hashimoto et al., (1982)) proposed.

The first published research into this sludge digestion method appears to be that of Warner et al., (1985). They discuss aerobic-anoxic theory as a subset of the general activated sludge model, originally developed by Dold, Ekama and Marais (1980) and extended by van Haandel, Ekama and Marais (1981). This model, based on steady state activated sludge theory, is flexible enough to incorporate nitrification-denitrification, variable influent conditions and series reactor configurations. It can predict COD removal, nitrification-denitrification, alkalinity changes, oxygen demand and volatile solids degradation.

The major conclusions of this research (from both theoretical considerations and lab scale experimental data) was that the incorporation of anoxic intervals in aerobic digestion of waste activated sludge, did not appear to adversely affect the degradation rate of the active bug mass, provided the anoxic portion of the cycle was not overly long. According to their observations the anoxic segment should not comprise more than 50 to 60 % of the total cycle length, nor should the duration of any single anoxic portion of the cycle be greater than 3 hours. It was also noticed that, for the digesters operating at a 50 % anoxic time, the nitrate generated by the nitrification reaction (during the aerobic portion of the cycle) was completely denitrified during the anoxic portion of the cycle. This meant that sufficient alkalinity was generated to keep the pH stable and in the neutral range. The balancing effect of alkalinity and pH resulting from an alternating aerobic-anoxic sequence has subsequently been well documented (Peddie et al., (1988a), (1988b), Jenkins, (1988)).

Matsuda et al., (1988) followed the transformation of nitrogen and phosphorus in the solid and liquid phases, while comparing aerobic-anoxic vs. continuous aerobic sludge digestion. Some interesting profiles were presented; however, their major conclusion was that the reduction rate of sludge solids and the behaviour of nitrogen and phosphorus under intermittent aeration (controlled by a D.O. criteria) was substantially equivalent to that undergoing continuous aeration. Therefore, intermittent aeration could be considered a viable method of sludge digestion with its attendant economic benefits.

Jenkins and Mavinic (1989a) investigated the solids degradation obtained using three different sludge digestion operating strategies (aerobic/anoxic (2.5 air-on/ 3.5 air-off), aerobic with lime addition and straight aerobic). Further to this, when operating the digesters at 3 different SRTs (10, 15 and 20 days) and two different temperatures (10 ^{o}C and 20 ^{o}C), it appeared that cycling the air flow gave comparable results in terms of percent TVSS reduction, while using only 42 % of the air that continuous aeration would employ. In addition, aerobic/anoxic sludge digestion maintained a neutral mixed liquor pH at almost no extra cost.

They postulated that comparable results were attainable because the bacteria made more efficient use of the air, since prior to initiation of the air, the driving force would be quite high, (enabling greater oxygen transfer efficiency once air resupply commenced). Furthermore, during the anoxic portion of the cycle, endogenous respiration would still be in effect (with nitrates as the terminal electron acceptor), so that some reduction in solids would continue to occur. Microbial degradation by nitrates and more efficient oxygen transfer efficiency was essentially the same rationale offered earlier by Ip et al., (1987), who investigated the savings in aeration energy costs encountered when air was cycled on and off (controlled by a D.O. probe) to a normal continuous flow activated sludge system.

In a subsequent paper, Jenkins and Mavinic, (1989b) detailed the benefits accrued from the AASD operating strategy in terms of improved supernatant quality (ex. reduction of nitrates through denitrification during the anoxic portion of the cycle). They also used ORP as a tool to monitor the aerobic/anoxic sludge digesters and clearly showed that the ORP profile with time was reproducible from cycle to cycle. Moreover, in developing an overall rating system to evaluate the performance of the three digestion modes, the potential for automation, based upon ORP, resulted in AASD receiving the highest ranking in this category (Jenkins 1988).

Finally, Kim and Hao (1990) investigated aerobic-anoxic sludge digestion, specifically focusing in on the kinetics of the anoxic phase and how it related VSS degradation to the endogenous nitrogen respiration (ENR) rate. They recognize that the <u>in situ</u> placement of an NO_3^- probe could modify the duration of the cycle period in a SBR to accommodate the required nitrate consumption pattern. This is a very similar concept to the one explored in this research.

2.4 Biological Phosphorus (Bio-P) Removal and ORP

Perhaps of most significance in terms of rekindling interest in ORP, was the development of bio-nutrient removal processes (Koch and Oldham, 1985). These designs incorporate a non-aerated regime in the process train, a domain in which the dissolved oxygen probe is rendered inadequate but the ORP probe remains useful.

In conventional activated sludge systems, the typical phosphorus content (based on dry weight) is 1.5 to 2.0 percent (U.S. EPA, 1987). This is primarily composed of the phosphorus taken up by microbes for use in biomass synthesis (i.e. phospholipids, nucleotides, and nucleic acids etc.). In the late fifties and early sixties, researchers such as Levin and Shapiro, (1965) and Shapiro et al., (1967) reported that up to 80 % of the phosphorus in activated sludge could be removed by vigourous aeration, while much of this was re-released at the bottom of the secondary clarifier, under conditions of low or zero dissolved oxygen. It was apparent, therefore, that some microbes could take up phosphorus in excess of normal metabolic requirements, a phenomenon that eventually became known as excess biological phosphorus (Bio-P) removal.

As mentioned, the Bio-P process modifies the activated sludge process by including a non-aerated zone prior to the aerobic reactor. Addition of simple short-chain carbon substrates to this zone, (ex. volatile fatty acids such as acetate or propionate) result in a phosphorus release to the liquid, accompanied by a corresponding microbial carbon storage in the form of either poly-β-hydroxybutyrate (PHB) or poly-β-hydroxyvalerate (PHV). Together, these carbon storage compounds are known generically as poly-β-hydroxyalkanoates (PHA) (Comeau et al., 1987b).

When the biomass is subsequently subjected to carbon-limiting, aerobic conditions, those bacteria which have previously sequestered carbon in reserves, seem to evidence a competitive advantage over other organisms. In fact, in the aerobic zone, the competition is restricted to that fraction of carbon which is not so readily biodegradable; thus, Bio-P organisms, drawing upon their exclusive access to the stored carbon, proliferate in greater numbers and, in doing so, take up not only the phosphorus they initially released in the anaerobic zone, but also much more than normal metabolism would dictate. A typical biological phosphorus removal plant might have up to 6-10 percent P in the sludge (U.S. EPA, 1987). This P seems to be complexed into polyphosphate reserves which the bacteria can break down and utilize for "maintenance/survival" energy, when again subjected to conditions in which there are no usable terminal electron acceptors available (i.e. anaerobic conditions).

In the early stages of Bio-P research, Shapiro et al., (1967) considered ORP significant enough to monitor and suggested it as a possible factor governing phosphate release. He observed that the rapid release of phosphorus in the anaerobic zone appeared to occur around an ORP value of -150 millivolts. However, Randall et al., (1970) concluded that phosphate release was not a function of, nor dependent upon, ORP since release often occurred before any significant change in the ORP level.

Countering this, Barnard (1976) proposed that ORP had potential in characterizing the degree of anaerobiosis at the front end of a Bio-P plant. He stated this because it appeared that a certain minimum level of ORP had to be reached to ensure good P removal. Barnard eventually developed a modification of his Bardenpho (Barnard Denitrification Phosphorus) nutrient removal process, titled the Phoredox process, because of the lower redox potentials that could be achieved in the anaerobic zone. However, Barnard later abandoned the theory of a minimum anaerobic stress level in favour of the availability of simple carbon substrates as being the prerequisite for good P release.

In a series of batch experiments Koch and Oldham, (1985) traced the ORP-time profile, in essence temporally modelling the spatial progress of a biomass/organic waste through a Bio-P plant. One important discovery was the existence of a reproducible nitrate breakpoint (or knee) in the ORP-time profile, corresponding to the transformation between respiratory and non-respiratory processes. This breakpoint also correlated to the onset of anaerobic phosphate release, a key phenomenon in biological phosphorus removal.

Koch and Oldham's experiments acted both to dispel some of the theoretical ambiguity in interpreting the ORP measurement and to counter the lack of enthusiasm which had plagued the use of ORP over the last several years. Further to these experiments, routine monitoring and visual inspection of ORP levels has become an integral part of recent biological nutrient removal research carried out at the University of British Columbia (Comeau et al., 1987a, 1987b, Zhou (1991)).

Additional work by Koch et al., (1988) sought correlations between ORP values and nitrate, ortho-phosphate and dissolved oxygen concentrations, in several biological regimes particular to the bio-nutrient removal process. Several equations were derived relating ORP to dissolved oxygen, nitrate and phosphate concentrations. Since these equations are all sludge specific, no attempt has been made to verify them in this research.

Furthermore, the sludge specificity of the equations makes the applicability of such equations questionable. The authors of the above research do acknowledge observed shifts over the course of the experiment, in the coefficients for regressions; therefore, there is certain to be variation in this research, done a few years later with a totally different sludge. This research, therefore, has elected to avoid regressions of this nature, abandoning them in favour of highlighting general behavioral trends, not only for the Bio-P experiments (Chapter 5) but also for the AASD set of experiments (Chapter 4).

2.5 Sequencing Batch Reactors (SBRs)

2.5.1 Overview of Operation

Sequencing batch reactors are in essence, modern day versions of the draw-and-fill systems used in the early days of sewage treatment (U.S. EPA, 1986). The original systems were fairly time intensive in nature, since they required an operator to manually feed and draw the reactors at appropriate times, and initiate the various sequences during the day. The use of draw-and-fill reactors tended to fade naturally with the advent of modern continuous flow through systems (CFS); however, since the SBR system merely provides in time what the CFS provides in space, these latter systems were adopted primarily from operational considerations and not from any process-related weaknesses of the batch system (Arora et al., 1985).

Recent advances in technology such as the use of timer controlled pumps, solenoids, level sensors and microprocessors etc. have obviated the need for operator controlled functions and revived interest in SBR technology.

Following the convention adopted by the studies done at the University of Notre Dame, Indiana (Irvine and Busch, 1979) the operation of an SBR can be divided into 5 discrete operating periods entitled...

(i) FILL - the receiving of the raw waste;

(ii) REACT - the time to complete the desired reaction(s);

(iii) SETTLE - the time to separate the organisms from the treated effluent;

(iv) DRAW - the discharge of both the treated effluent and waste solids (if necessary) and;

(v) IDLE - the time after the effluent is discharged and before refilling.

One or more of these periods may be omitted depending upon the control strategy desired, however at the very least all tanks must contain the FILL and DRAW periods (as for example in an equalization tank). A sketch of the 5 periods during one cycle is shown in Figure 2.3.

Advantages of an SBR system are numerous and make it ideal for small communities which experience wide variations in influent flows and strength. Some of the more obvious benefits include (Arora et al., (1985)...

(i) Acting as an equalization tank during FILL it has an ability to balance peak flows and absorb shock loads;

(ii) The effluent may be held until it meets specific objectives;

(iii) The MLVSS cannot be washed out by hydraulic surges;

(iv) There is no need for return activated sludge (RAS) pumping since the mixed liquor is always in the tank and;

(v) Solid-liquid separation occurs under near ideal quiescent conditions since short circuiting is non-existent during the settle period. Furthermore there is no need for an extra tank for clarification since the same tank can serve as both a biological reactor and a clarifier.

Probably the most readily apparent advantage is the SBR's flexibility of operation. Easy adjustment of the microprocessor timer settings, allows timed intervals to be changed to permit different modes of operation. For example, a portion of the REACT period can be reserved for aeration to allow for nitrification while another portion can be dedicated to the denitrification process. Biological phosphorus removal

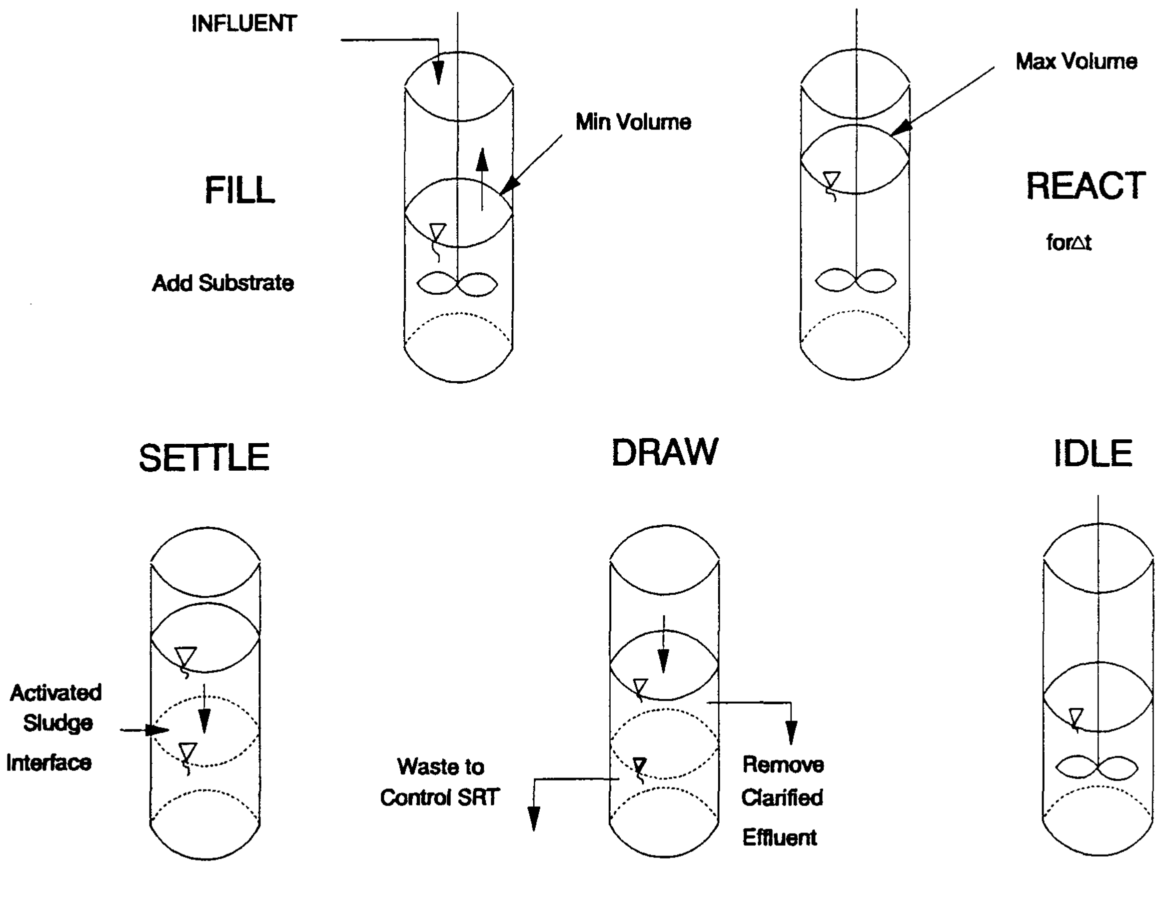


Figure 2.3 Diagram of 5 Operating Periods of Bio-P SBRs

strategies can also be implemented in this way. Furthermore, a liquid level sensor could be adjusted to allow only a fraction of the tank capacity to be used during the early years of the design life, without wasting power through overaeration. Finally, if more than one tank is used in series, tanks can be put on or offline to allow for seasonal variation.

2.5.2 SBR Applications in Wastewater Treatment

Several recent studies at the University of Notre Dame (Alleman and Irvine (1980a, 1980b), Palis and Irvine (1985)), the University of California, Davis (Silverstein and Schroeder (1983), Abufayed and Schroeder (1986a, 1986b), and the University of Manitoba (Oleszkiewicz and Berquist (1988), McCartney and Oleszkiewicz (1988, 1990)) have investigated nitrification and denitrification in sequencing batch reactors. Primarily monitoring several SBR performance characteristics, most of the studies were able to consistently remove a very high percentage of the organic carbon and nitrogen in the wastewater.

Sequencing Batch reactors have also be used to remove phosphorus both chemically (Ketchum and Ping-Chao Liao (1979), Ketchum et al. (1987)) and biologically (Manning and Irvine (1985), Vlekke et al., (1988)). Again the inherent flexibility of an SBR system allows the proper mix of anoxic, anaerobic and aerobic conditions necessary for Bio-P removal. In particular a control strategy must be selected which at a minimum eliminates oxidized nitrogen and dissolved oxygen during the FILL (anaerobic) period and allows for aeration during the REACT period (Manning and Irvine, 1985).

The increased interest in SBRs has been reflected in the number of studies done on full scale applications in recent years. Irvine et al., (1983, 1985, and 1987) have examined the operational performance of full scale SBRs at Culver, Indiana and Grundy Centre, Iowa under high and low loaded conditions and depending on the study have reported excellent effluent quality in terms of BOD_5, SS, N and P removal despite varying influent conditions. Melcer et al., (1987) examined the conversion of small municipal wastewater treatment plants in Manitoba to sequencing batch reactors and reported that it was technically and economically feasible to convert the existing small-scale package plants and septic tanks to SBRs over the flow ranges studied (4 to 227 m^3/d).

CHAPTER 3

EXPERIMENTAL METHODS AND ANALYTICAL TECHNIQUES

3.1 Source of Feed Sewage and Sludge

The University of British Columbia's Environmental Engineering Group manages a pilot-scale sewage treatment plant located about 2 kilometres south of the UBC campus. The facility, housed in a renovated tractor trailer unit, generally operates in a biological phosphorus removal mode. More specifically, it is a modified version of the well known University of Cape Town (UCT) process (Figure 3.1), routinely depicted in papers published by South African researchers (eg. Seibritz et al., 1983). This modified configuration will henceforth be referred to as the UBC version (Figure 3.2) to distinguish it from its UCT predecessor.

The process, treating primarily campus wastewater (and a small fraction of household domestic waste) is designed so that the operator can choose (by way of baffle insertion) the proper mix of alternating aerobic, anoxic and anaerobic sequences necessary to ensure good biological phosphorus removal. The sludge age is usually maintained at an average age of 20 days; however, flexibility in piping, valves and pumps, allows SRT variations as desired.

The pilot-plant facility has two process trains, labelled side "A" (the control) and side "B" (the experimental). Either raw sludge or raw sewage was collected from the pilot plant as the needs of the experiment dictated. For the AASD experiments, sludge was collected from the aeration basin of the control

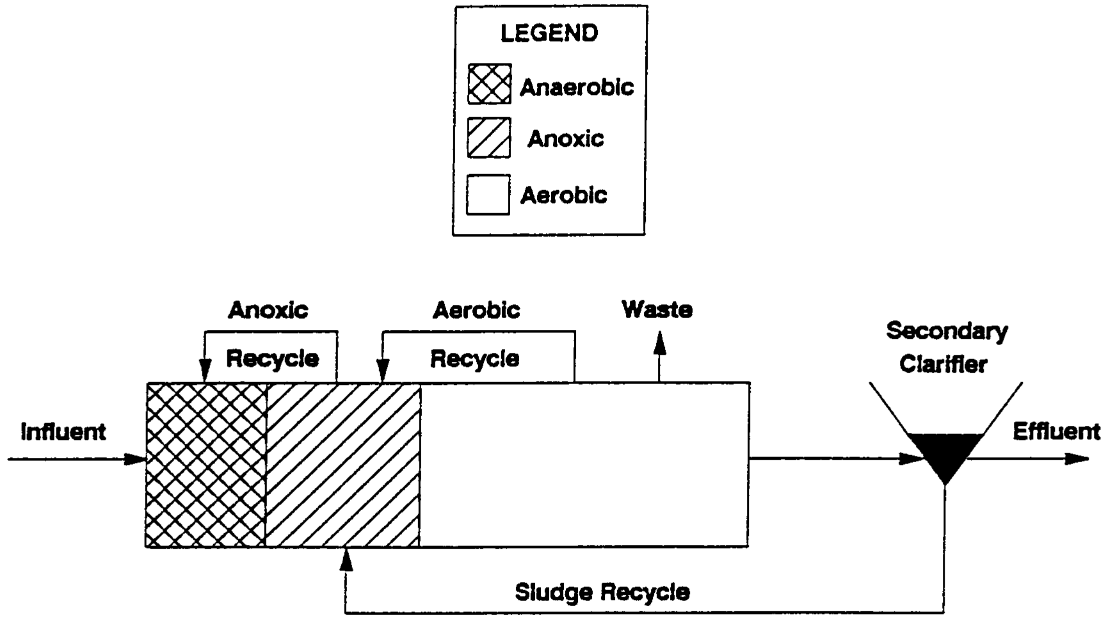


Figure 3.1 UCT Bio-P Process

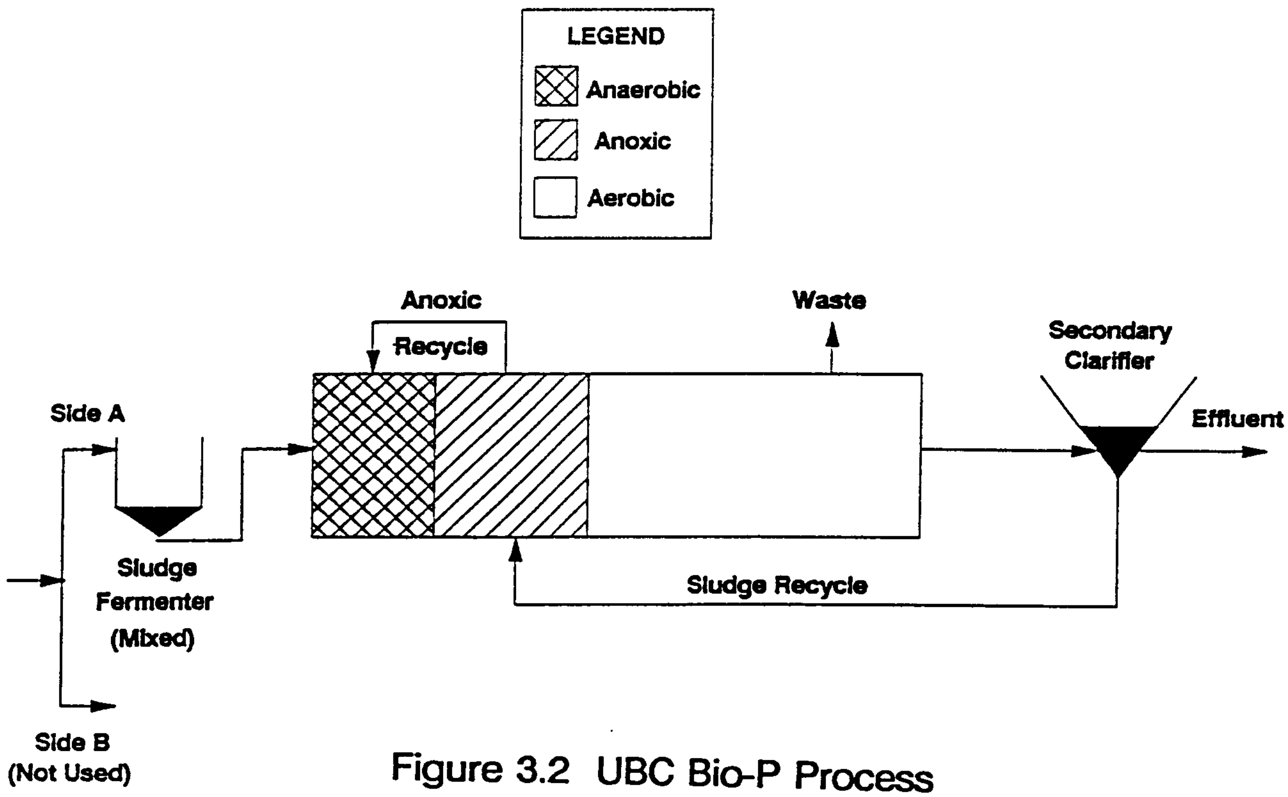


Figure 3.2 UBC Bio-P Process

("A") side in the manner which will be described in Section 3.3. The side "A" configuration includes a primary sludge fermenter to generate volatile fatty acids for later addition to the anaerobic portion of the process.

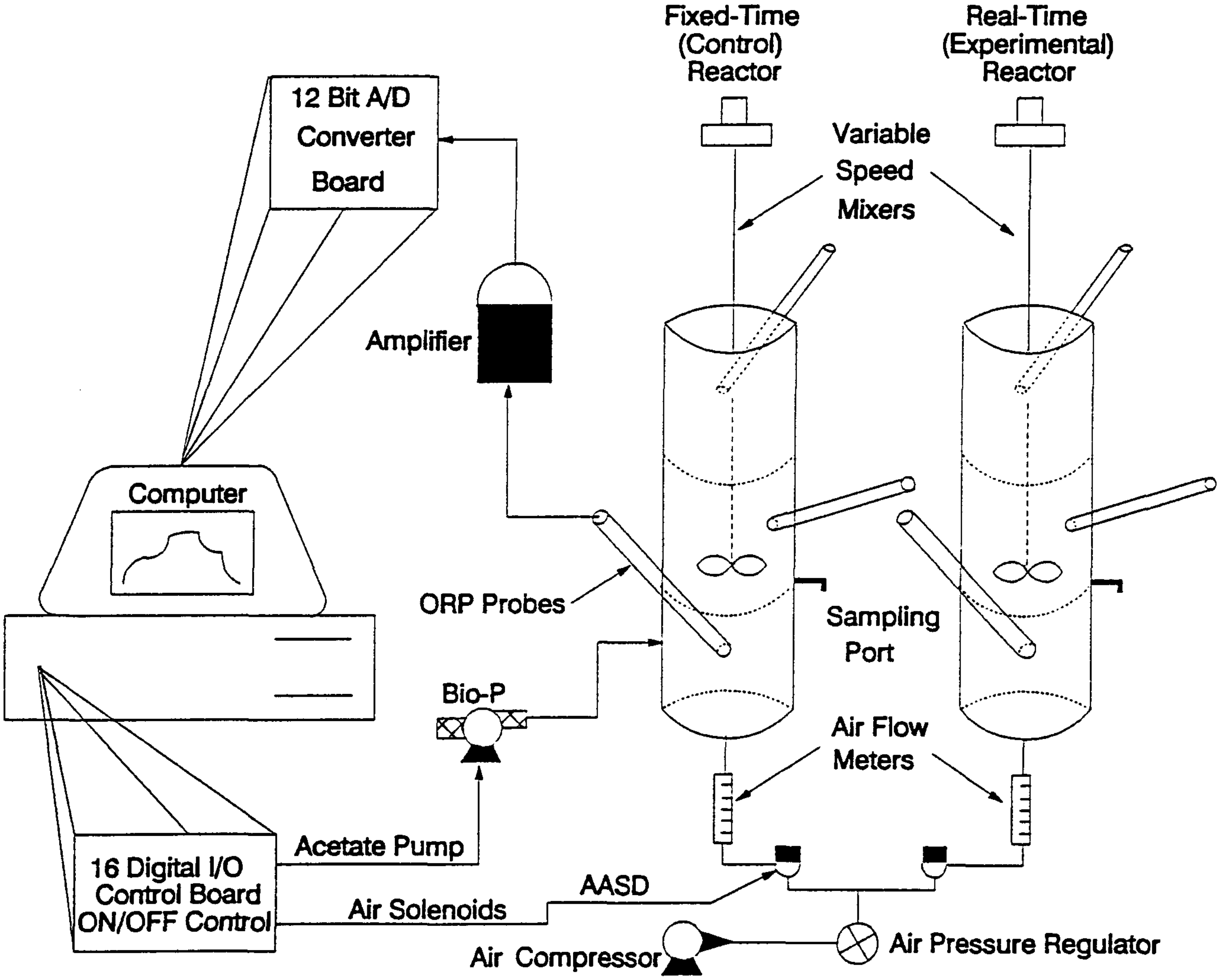
In addition, external equalization tanks, plus a primary clarifier, are merged into the process train so that the aerated sludge is fairly "clean" in the sense of being uniform in nature and having very little, if any, of the organic and inorganic "problem" materials that sometimes create difficulties for a sewage treatment plant. Thus, no pre-treatment of waste sludge was required. For the Bio-P set of experiments, raw sewage was obtained from the equalization tanks in the manner also described in Section 3.3.

3.2 Experimental Set-Up and Design

3.2.1 General Structural Configuration

A block diagram highlighting the major components of the research apparatus, is shown in Figure 3.3. Slightly different structural arrangements of the Sequencing Batch Reactors (SBRs) were used for the AASD and Bio-P experiments respectively, and these are illustrated in the schematic of Figure 3.4. Table 3.1 itemizes the particular model numbers of many of the experimental components.

In general, the reactors were made of plexiglass (Diameter = 12 cm., Volume = 5.4 litres) and filled to the 4.8 litre mark with either activated sludge and/or raw sewage depending upon the experiment. Spigots for sampling and solenoids for decanting etc. were placed at strategic heights



Note: In actual reactor all 6 probes (i.e 3/reactor) connect to computer

Figure 3.3 Schematic of Experimental System

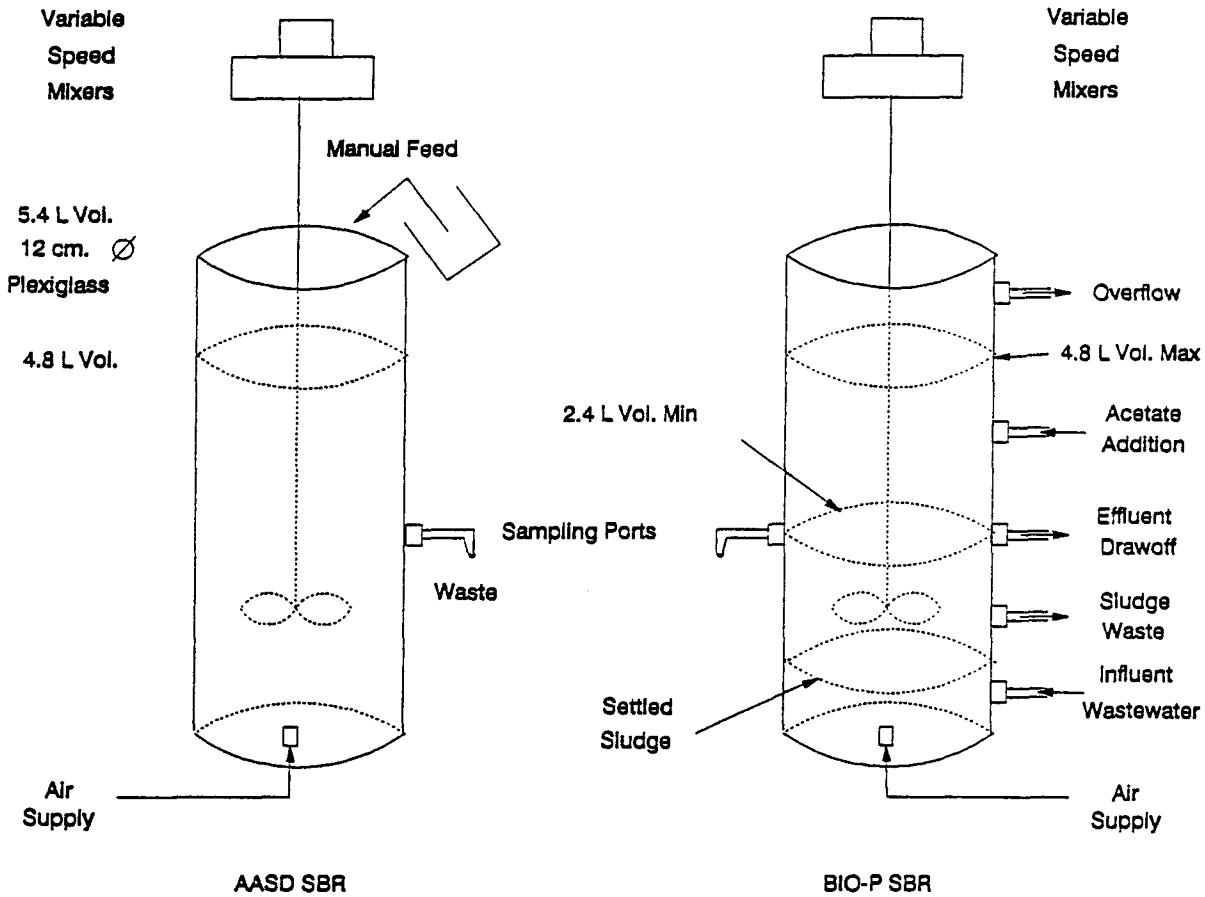


Figure 3.4 Schematic of AASD and Bio-P Sequencing Batch Reactors

Table 3.1 Components of Experimental Apparatus

EXPERIMENTAL COMPONENT	DESCRIPTION OF ITEM
Air Pressure Regulators - 2	Parker Model # 07R218AB
Air Solenoids - 2	MAC 113B-112CCAA
Air Flow Meters - 2	Cole-Parmer PR0034-FM32-15ST
Mixing Motors - 2	Dayton DC Model #47539A
ORP Probes - 3/Reactor	Broadley-James #P114101-10BC
Computer	Morse Shuttle 386-SX AT
Analog-to-Digital Card	Data Translation DT2814
Input/Output Control Card	Metrabyte Model PIO12
Standby Power Supply	American Power Conv. UPS-SX

and utilized according to the operating strategy. Wasting and feeding of the sludge in the AASD experiments was done manually, while for the Bio-P experiments the liquids were pumped automatically, entering and exiting the reactors at appropriate levels.

Air for both experimental sets was supplied by an in-house compressor at 410 - 550 kPa (60 - 80 psi). Two pressure regulators, connected in series at the air supply outlet, subsequently reduced this pressure to approximately 100 kPa (15 psi). The airline was then split into two separate lines, with each line passing through an air solenoid (ON/OFF regulation controlled by computer) before continuing on through an adjustable air flow meter (rated range 55-165 mL/min). The lines then looped around below the reactor underside to flow through a diffusing stone before entering the reactor.

The AASD digesters (and Bio-P reactors when in non-quiescent conditions) were completely mixed by a stainless steel shaft with an appropriate blade design. Visually, complete horizontal and vertical mixing appeared to be achieved.

At three strategic points Broadley-James Corporation combination oxidation-reduction potential probes were inserted into each reactor. These probes use a Ag/AgCl reference electrode with a platinum band as the noble metal. The probes were affixed physically to one end of a piece of rigid plastic tubing which subsequently slid, with minimum resistance inside the sleeve of yet another plastic tube. This latter tube opened up through a ball valve into the interior of the reactor, acting as a conduit to allow the ORP probe to slide, with some degree of ease, into and out of the reactor. An O-ring seal sandwiched between the two cylinder walls prevented liquid being forced by back-pressure from the reactor.

The three probes were labelled a, b, and c to denote the front, side and back of the reactor from the perspective of facing the experiment on the computer side of the research bench. Thus, in referring to the ORP probe in the front of the right reactor (labelled RCTR#2 - Section 3.4.1) the nomenclature ORP2a would be used.

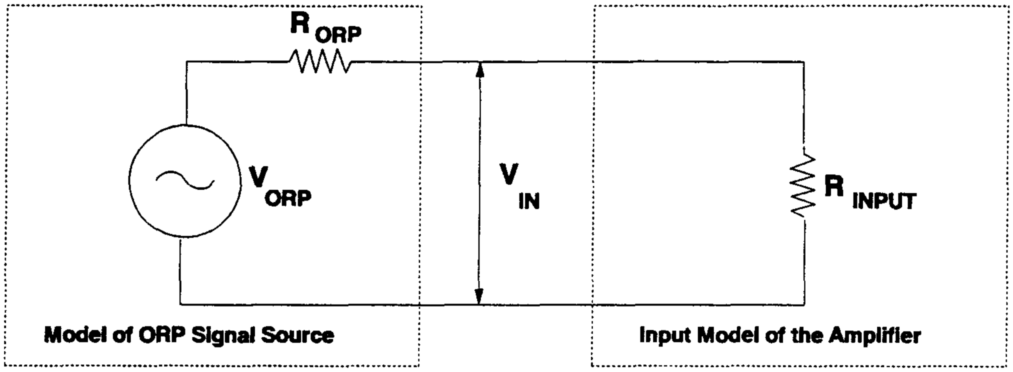
3.2.2 Electronic Hardware

In the experimental environs used in this research, the ORP probes generate a low-level voltage electrical signal in the range of -300 to +300 mV. Furthermore, the total electrode resistance is generally in the order of 10 Kohms (Petersen, 1966), thus an application of Ohm's law reveals that the current is quite small (around 30 microamps). Moreover, due to the physical construction of the probe, even larger resistances (in the order of Mohms) are possible. These subsequently produce extremely small currents, thus coaxial shielded cable was used from the probe to the computer to protect the signal from induced currents. Magnetic stirrers and water baths are among the commonest sources of noisy readings (Midgley and Torrence, 1978); however, all electric motors and any ancillary apparatus containing relay switches (ex. ovens and hotplates) were suspect.

The source impedance of the probe was measured and observed to be greater than 15 Mohms (Milligan, 1989). The probes were therefore connected to a custom-built amplifier (having a large input impedance (100 Mohms)) in order to more accurately measure the voltage. Figure 3.5 indicates the theory behind this, by replacing the ORP probe with an ideal voltage source (0 internal resistance) in series with a resistor having the corresponding source impedance. The largest value of V_{in} will occur when the input impedance of the amplifier is much larger than the internal resistance of the source (Weber and Maclean, 1979).

Sporadic results (documented in Section 4.2.1) were initially obtained due to the lack of a common ground between the coaxial shield of the probe cable (left floating) and the amplifier chassis, whose differential inputs were also both floating. Furthermore, unshielded wire inside the amplifier resulted in rampant pick-up of electrical noise. Modifications to the amplifier and elimination of ground loops eventually corrected these problems, leading to reasonably stable ORP measurements.

As shown previously (Figure 3.3), the amplifier output connected to a junction box which relayed the signal through an electronic cable into the back of the computer. Inside the computer, an analog to digital (A/D) card (16 single-ended input channels) converted the signal (via a 12-bit monolithic converter) into binary code which could be processed by the host computer. Working with a range of -500 mV to +500 mV (1 Volt) an ORP resolution (change) of 1000 mV/2^{12} = 0.25 mV



V_{ORP} = Voltage of the ORP Source

R_{ORP} = Internal Resistance of the ORP Probe

R_{INPUT} = Input Impedance of the Amplifier

I = Current

V_{IN} = The Voltage across the Amplifier = $I R_{INPUT}$

Now:

$$V_{ORP} = I R_{ORP} + I R_{INPUT} = I (R_{ORP} + R_{INPUT}) \quad \text{thus} \quad I = \frac{V_{ORP}}{(R_{ORP} + R_{INPUT})}$$

Thus:

$$V_{IN} = \left[\frac{V_{ORP}}{(R_{ORP} + R_{INPUT})} \right] (R_{INPUT}) = \frac{V_{ORP}}{\dfrac{R_{ORP}}{R_{INPUT}} + 1}$$

Thus:

IF $R_{INPUT} >>> R_{ORP}$ then $V_{IN} = V_{ORP}$

Figure 3.5 Impedance Diagram of ORP-Amplifier Circuit difference was obtainable.

At various stages in the research, different computers were dedicated to the project; however, most of the preliminary work was performed on a Laser Turbo XT-2 computer operating at various times with a Central Point Software, Juko ST and finally Phoenix, BIOS on its motherboard. For the majority of the control runs a Morse 386-SX AT computer was used. To provide protection from brown-outs and power failures, an uninterruptible power supply (UPS) was purchased into which the computer and all power cords were plugged. When the input power line voltage dropped below an acceptable level (15 % below nominal), the UPS automatically transferred to battery operation (in less than 3 milliseconds) providing an output wave in the form of a sinewave approximation. During the course of this research, several momentary blackouts occurred and in all cases the UPS performed admirably and kept the process operating.

For control purposes, a commercial I/O control card was purchased which fitted into an expansion slot in the computer's motherboard. The interface card provided 24 TTL/DTL compatible digital I/O lines, split into three 8 bit ports (Metrabyte Corporation, 1989). The I/O lines were linked to a bank of solid state relays (16) mounted on the inside of the box housing the computer. These, in turn, were wired to two socket power bars (mounted on the outside of the computer box) which were modified so that each outlet could be controlled independently by a single solid state relay. The pumps and solenoids were plugged into this latter bank of sockets and thus control, originating from software switching bits (1 = ON, 0 = OFF), was finally established.

3.2.3 Computer Software

The successful implementation of a computer controlled system is very much an "evolutionary" process. This is most evident in the development of the computer software. For example, the AASD#1 control software (Section 3.4.1), underwent 7 major structural modifications (not including numerous small adaptive measures taken to refine the program) before arriving at its "final version" form.

The software was written using QUICKBASIC 4.5, a mature form of the original BASIC language developed at Dartmouth College over 25 years ago. Not only is it very popular (Shammas, 1988), it is much more powerful than its earlier predecessors due to the advent of callable subroutines, numeric and alpha-numeric labels (used to direct program flow), and powerful new decision making constructs (Microsoft, 1987a, 1987b, 1987c). The lone exception to the QUICKBASIC 4.5 language was the software used to access the A/D board which was written for expediency in Microsoft Assembler Language by an in-house UBC computer technician.

The prime advantage of QUICKBASIC 4.5 is that it can be written in a modular fashion. That is, a function or subroutine can be written, debugged and then installed as a separate module into any main program, written at various times and for different needs. Thus, the majority of subroutines and functions written for this research are common to both the AASD experiments and the Bio-P experiments, with subtle differences reflected in the structural flow of the main control program and occasionally the order in which common subroutines are invoked. The Bio-P experiments also use separate controllers to operate some of the pumps and solenoids, in order to minimize the complexity of the main Bio-P control program. Table 3.2 catalogues the main control and subroutine/function modules incorporated into all three operating strategy programs.

Flowcharts of all subroutines, functions and main control programs have been relegated to Appendix C, while the associated software code can be found in Appendix D. A detailed description of the mechanics of the program is not necessary here; however, some general comments are offered below.

The structure of the main control programs (i.e. one for each AASD operating control strategy and one for the Bio-P experiment) is fairly sequential with the majority of control actions dictated by flag switches; these are set and reset to TRUE and FALSE respectively, in order to activate or deactivate specific relays. ORP data files are written to the hard disk with a nomenclature specifying the type of reactor (Fixed-Time (FT) or Real-Time (RT)) appended to the date (ex. 90-04-21.RT). Message files for both reactors coexist under an appropriately dated file (ex. 90-04-21.msg).

Due to some initial incompatibilities between the software and hardware, the programs are designed to alternate between graphics and text mode, rather than operating in continuous graphics mode. Thus, the user can periodically

Table 3.2 Subroutines and Functions in Each Experiment

Main Programs	AASD#1 AASD#2 BIO-P
Functions	Global.bi Typrobe$ Jinkey% Getscan1%
Subroutines	Inform Filename Initrelays Relayswitch Refresh ORPscreen Axes Paxis Scans Diff Writing Transfer Plot Breakpt Layout Update

interact with the computer to graphically access recent historical plots of the ORP-time profile. When a plot is requested, the computer transfers the ORP data of the probe selected, to a common array, and after refreshing the screen, uses the PLOT subroutine to lay out the profile.

The ORP probes are scanned by accessing the ON TIMER (Scantime) event-trapping Quickbasic 4.5 feature, which directs program flow (every number of seconds equal to Scantime) to a READPROBE subroutine which further invokes a function GETSCAN1%. After a certain number of scans have elapsed, the computer interrupts this loop to "drop" through the rest of the program where it calculates first-differences, writes data to disk files, checks flags according to externally-timed conditions, searches for the breakpoint (if in the appropriate phase of the cycle), and scans the keyboard buffer for user requests.

The subroutine BREAKPT requires a more detailed explanation, since it is the cornerstone upon which control is based. BREAKPT operates as a "Linear Ring-Buffer", a term coined to describe the effect of a moving window along the slope of the ORP curve. BREAKPT is invoked when the computer registers (by way of a flag) that the air supply has ceased. After an initial delay to acquire stability (as air bleeds from the line), the computer begins to load the first Ring (5 points wide) with ORP first-difference points (i.e. the first-difference or slope between two adjacent ORP values) until the Ring is complete. When the Ring is complete, an average of all five first-differences in the Ring is calculated and assigned to Ring(1) which also receives the title "FirstRing" in the Ring-Buffer. (Note: The actual software variable names have the appropriate letter appendages, corresponding to the probe in question, ex. Ring2a(1) and FirstRing2A etc.)

The next first difference point drawn into the Ring-Buffer (i.e. Pt 6) becomes the last point of (i.e. completes) Ring(2), while Ring(2)'s first point corresponds to the second point already in the Buffer. An average first-difference for Ring(2) is now calculated based on points 2 to 6. In other words each succeeding point is admitted into the Buffer to complete the Ring formed by abandoning the point occurring 6 points earlier. Finally, the terminal Ring in the Ring-Buffer (Ring(5)) is reached and is assigned the title "LastRing" (Figure 3.6).

The value of LastRing is then compared to FirstRing and if it is substantially more negative (in this case DELTA is set to -1.25) the breakpoint is assumed to have occurred. The slope difference limit is somewhat arbitrary and is a function of the probe responsiveness. Preliminary testing, consisting of alternately tightening and loosening the knee constraint, indicated that a value of -1.25 for all probes was sufficient to detect the knee in the majority of cases (Figure 3.7).

In the event that the slope change between LastRing (Ring(5)) and FirstRing (Ring(1)) is less than DELTA (i.e. more positive), the entire Ring-Buffer shifts, with the next first-difference point flowing in to complete Ring(6) (which now becomes LastRing). Concurrently, Ring(2) now receives the title FirstRing. The new slope difference is calculated and compared

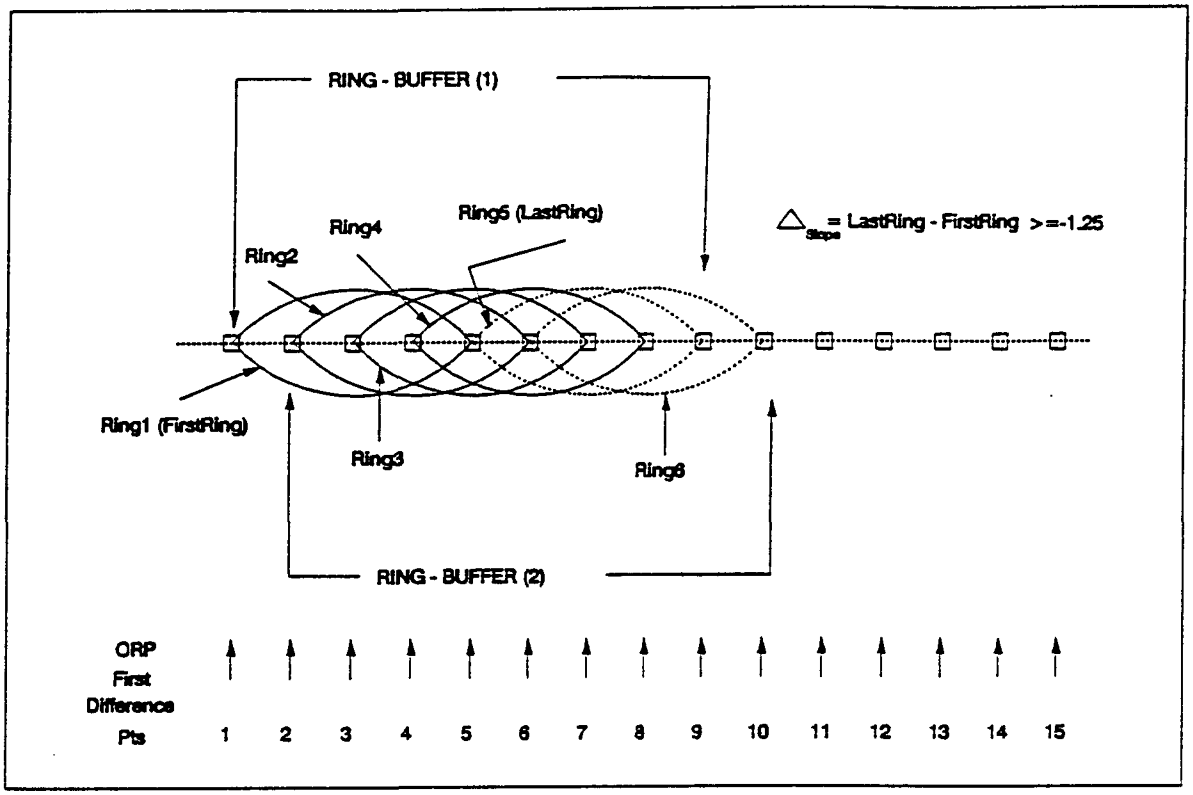


Figure 3.6 Illustration of Linear Ring-Buffer Concept

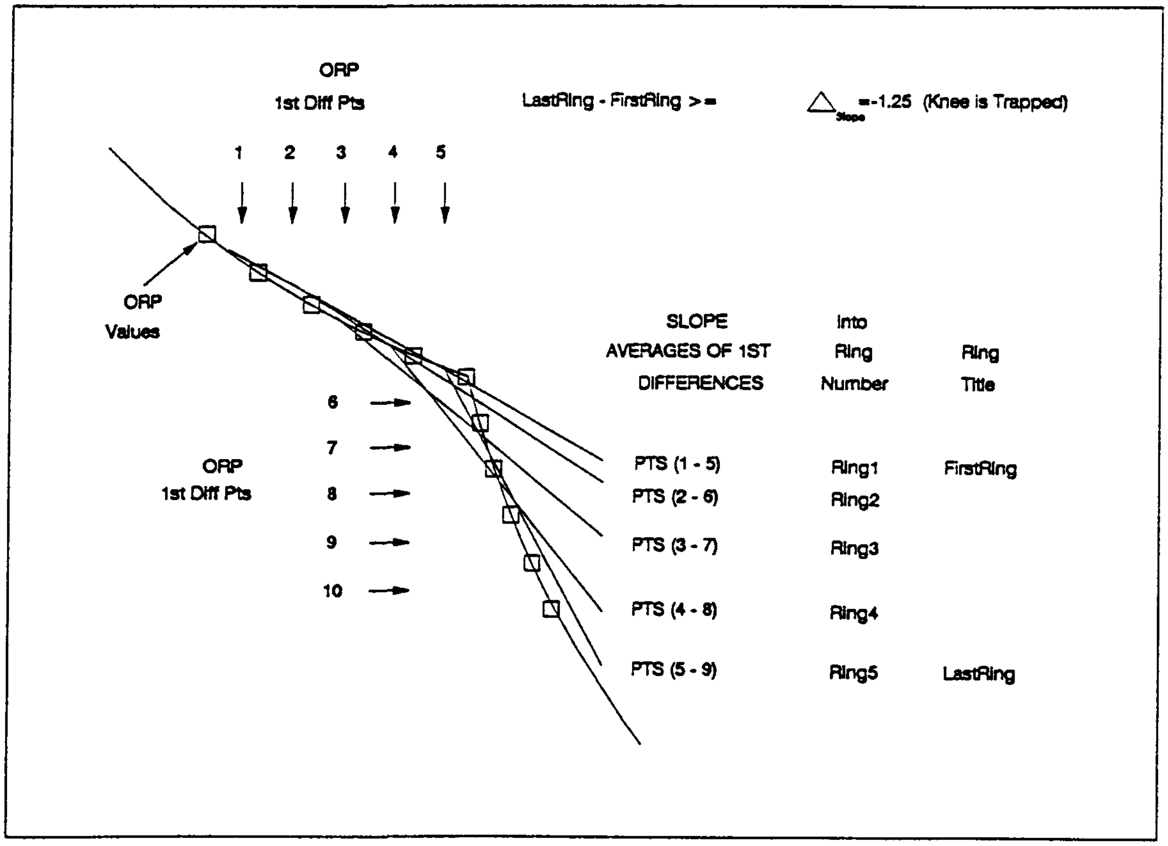


Figure 3.7 Illustration of BREAKPT Capture of Nitrate Knee

to DELTA and again, if it is less (i.e. more positive), the Ring-Buffer continues to move in sequence. In this way, the Ring-Buffer functions as a moving window across the ORP profile until the knee is trapped by a difference in slope greater than DELTA (Figure 3.7).

It should be noted that there is a requirement that only two of the three probes detect a knee in order for control to be initiated. This serves as a protective measure should one probe suddenly become inoperative. It also permits the withdrawal (and disconnection from the amplifier) of one probe for cleaning purposes. Experience has shown that it is best to withdraw the probe during the aerobic portion of the cycle, since the computer during this time is merely recording values, rather than actively searching for a control-based feature. Moreover, reinsertion allows some time for the probe to acclimate to reactor conditions before measurements again become critical for control purposes.

The program also utilizes global variables in an INCLUDE file, so that both the size of the ring (RINGSIZE, currently set to 5), the width of the Ring-Buffer (NUMRINGS, currently set to 5) and the individual knee constraints (DELTA2A, DELTA2b, and DELTA2C, currently all set to -1.25) can be varied as a function of the operator experience with the ORP probes and the type of waste. Finally, should the knee not be detected for whatever reason (ex. all probes foul (become less responsive) to the point where the knee constraint becomes too severe) some intelligence in terms of a time-base is built into the program to initiate air resupply (in the AASD experiments) or to initiate acetate additions (in the Bio-P experiments), in order to keep the process respiring.

3.3 Raw Feed Collection Procedures

During the AASD set of experiments, the SBRs were operated in a semi-continuous mode, in the sense that they manually received feed in a batch manner (once/day). Thus, activated sludge was wasted diurnally from the pilot-plant aeration basin, by routing it to the sludge thickener, where after 20-30 minutes of gravity settling, the sludge blanket interface, (initially at a level of 100-110 litres (a function of the system SRT)) usually reached the 40-50 litre mark. The sludge was then drawn off by means of a control valve or pump and collected in a 4 litre milk container for transport to the UBC lab. Once there, it was allowed to gravity settle a second time where a visual inspection of the sludge consistency and settling characteristics, usually meant that about half the clarified supernatant would be decanted off and disposed of down the drain.

By systematically adhering to this two stage thickening process, the raw feed sludge consistently had a MLSS concentration roughly 3 times the aerobic basin of the pilot plant. Furthermore, for the most part, the feed MLSS was greater than that in the laboratory reactors. After wasting an appropriate amount from the reactors (Section 3.4.1) the feed sludge was then added (after shaking to ensure a uniform MLSS concentration) into the top of the reactor to maintain a constant reactor volume.

The remaining feed sludge was stored in a Bell-Par Industries environment chamber held at a constant temperature of 4 °C. For the most part this volume was stored purely for contingency purposes should fresh feed from the pilot plant suddenly become unavailable.

In the Biological Phosphorus (Bio-P) Removal experiments, raw sewage was obtained directly from the external equalization tanks located outside the pilot plant facility. After collection, it was transported in carboys to the lab to be stored at 4 °C, for up to a maximum of 12 days.

3.4 Operating Control Strategies

3.4.1 Aerobic-Anoxic Sludge Digestion #1 (AASD#1)

As mentioned in Section 1.2, the main objective of this research was to demonstrate the potential ORP has to control sequencing batch reactor wastewater treatment systems. Thus, operating strategies were formulated both to demonstrate control and to evaluate the effectiveness of ORP as a process control parameter.

The first such strategy involved aerobic-anoxic digestion of waste activated sludge. It was structured such that the Control Reactor (RCTR#1) was known as the Fixed-Time Control (FT) reactor, since the ON/OFF sequence was "fixed" at 3 hours of air-on and 3 hours of air-off. The ratio of air-on to air-off was arbitrary and other reasonable ratios consistent with the literature review comments (Section 2.3) could have been used.

In contrast, the Experimental Reactor (RCTR#2) was labelled as the Real-Time Control (RT) reactor, since the on/off sequence consisted of a 3 hour air-on period (as before) but a variable length of time for air-off, contingent upon detection of the nitrate breakpoint. Reactor #2 exhibited Real-Time behaviour in the sense that it operated in an instantaneous on-line self-adjusting fashion. The rationale for adopting this control strategy is that theoretically, the Real-Time Control reactor should provide better treatment (in terms of solids degradation) since the bacteria are always ensured a ready supply of highly efficient electron acceptors (be they oxygen or nitrate). Thus, the different sequences of the reactor allow for effective organic carbon removal, and alternating nitrification and denitrification.

Both digesters were controlled on the basis of solids retention time (SRT), as this was convenient to use, has significant merits (Smith 1978), and can be related to solids loadings when variations in feed and digester TVSS are recorded as part of the daily solids inventory. Since the reactor volumes are constant (4.8 litres) and there is no recycle, the SRT equals the hydraulic retention time (HRT). The SRT chosen for the AASD#1 experimental runs (10 days) was admittedly on the low end of the scale (Metcalf and Eddy, (1979) recommends 10-20 days); however, a shorter SRT translates to a larger volume wasted according to the equation below.

$$SRT = \frac{\text{volume of digester}}{\text{volume wasted per day}} \qquad (3.1)$$

On track-study sampling days, larger volumes were necessary in order to accurately track parameters (such as NO_x and NH_3) which theoretically range from 0 to 100 % of their full value, throughout the course of one aerobic-anoxic cycle (assuming complete nitrification-denitrification). Thus, with a 4.8 litre liquid volume and a 10 day SRT, 480 mL of sludge was wasted on a daily basis and in due compensation, 480 mL of feed sludge was added to keep the reactor volume constant.

Other operational nuances included occasional scraping of the digester walls to return biomass accumulations to the system. Distilled water was also added on a sporadic basis to compensate for evaporative losses. Evaporation was not perceived to be a problem, as there was seldom an observable discrepancy between the liquid level in the reactors and the 4.8 litre reference mark on the cylinder walls.

Prior to start-up, the digester solids concentration was increased significantly by wasting (after a brief settling period), a clarified volume of supernatant (low MLSS) equal to that required to keep a constant SRT. The feed sludge (with a relatively high MLSS) was then added to artificially increase the solids level in the reactors, in an attempt to more closely simulate field digester conditions (> 30,000 mg/L).

Before each run, the reactors were drained, thoroughly cleaned and some of the tubing (most often the sampling ports and air supply lines) was replaced. The diffusing stones were also acid washed to remove accumulated microbial growth tending to blind off the air pores. The ORP probes were also cleaned as will be described in Section 3.5.4. The sludge from both reactors was then mixed, split into two, and reintroduced into the reactors, so that both reactors ostensibly had identical starting conditions in terms of biomass characteristics and concentrations.

Both reactors were then operated on a Fixed-Time basis for at least two days. If the ORP profile with time consistently produced the characteristic features described in Section 4.2.2. (i.e. In both reactors nitrate knees were present and dissolved oxygen levels during the plateau region of the ORP curve were between 2-4 mg/L (and roughly equivalent)), the decision to switch to Real-Time control of Reactor #2 was implemented. It must be noted however, that if the user requested real-time control, it was not until the next anoxic cycle that the computer switched over to this form of control. This circumvented the possibility that the user request could come during an anoxic sequence, in which the knee had already occurred.

In order to assess the ability of ORP to effectively maintain control under duress, and to evaluate ORP as a process control parameter, perturbations to the operating strategies were investigated. The first and most natural disturbance to the system involved interrupting the daily wastage and feed pattern, simulating a breakdown in supply (i.e. the waste pumps from the aeration basin). As available carbon for the denitrification reaction was exhausted, the time necessary to complete denitrification became elongated; thus, this strategy sought to demonstrate the flexibility of control based upon actual rather than fixed denitrification times.

Other aggravations included additions of strong oxidants (hydrogen peroxide and sodium nitrate), and ammonia chloride spikes, all designed to observe the stability of ORP under transient influent conditions. After each disturbance a recovery time period was allotted to allow conditions to normalize.

3.4.2 Aerobic-Anoxic Sludge Digestion #2 (AASD#2)

Much of the preceding discussion is applicable to the second sludge digestion experiment. It should be noted however that AASD#2 was operated at an SRT of 20 days. The control reactor again operated in a Fixed-Time fashion (3 hours air-on, 3 hours air-off), a practice which can also be described as operating in a 50/50 air on/off manner. In contrast to AASD#1, the Real-Time reactor also operated in a 50/50 fashion, by matching its length of aeration period to the previous time for denitrification. In otherwords, the preceding cycle's total time to eliminate the nitrates (as calculated from the moment the air supply terminated, to the nitrate breakpoint (assuming near instantaneous disappearance of D.O.)) was recalled from memory and allocated to be the length for the following cycle's aeration period. In this way a 50/50 strategy was maintained.

As mentioned in Chapter 1, it was suspected that an ORP-driven, 50/50 strategy might prove stressful for the organisms; in the sense that the strategy might collapse in on itself, with very rapid air on/off periods. However, if the bacteria seemed to readily accommodate this strategy, it might provide grounds for further investigating a control strategy which alternated extremely rapidly between denitrification and nitrification, as determined by the features on the ORP-time curve (Section 4.1). Such a strategy might induce considerably savings, through the discontinuing of overaeration during the nitrification portion of the curve.

3.4.3 Biological Phosphorus (Bio-P) Removal

In Bio-P removal , the SBRs model in time the plug-flow treatment of a waste subjected to the right mix and sequence of aerobic, anoxic and anaerobic conditions. The operation of the two reactors differed in one aspect, that being, the timing for the addition to the reactor of volatile fatty acids (in this research acetate). The Fixed-Time reactor had the addition scheduled at 1 hour and 25 minutes (modelled after Comeau, 1989) into the anoxic period, while the Real-Time reactor had its timing triggered by the nitrate breakpoint.

The SBR operation during the Bio-P experiments was somewhat more complex and thus commercially-purchased Chrontrol timers were used to initiate and control most of the sequences during the cycle. For both reactors, the period lengths (Table 3.3) were modelled after Comeau (1989), with each cycle having a total length of 8 hours. During the FILL phase (10 minutes), raw wastewater was pumped from an influent feed bucket to the reactor, where it underwent the first REACT (unaerated) period for 2 hours and 50 minutes. As indicated, approximately in the middle of the unaerated REACT period (after anoxic conditions had ended) acetate (30 mg per litre of raw influent) was pumped

Table 3.3 Timing of Phases in a Bio-P SBR

SBR PHASE	CONTROL ACTION TIME ON (Hrs:Min)	TIME DIAGRAM
FILL Period	Feed Pump (0:10)	0:00
REACT (Unaerated)	(2:50)	0:10
Anoxic Period	(1:25)	
	Acetate Pump (0:06)	
Anaerobic Period	(1:19)	
REACT (Aerated)		3:00
	Air Solenoids (4:00)	
	Waste Pump (0:10)	
SETTLE Period	(1:00)	7:00
	Wastewater Mixers (Off)	
DRAW/IDLE Period	Effluent Solenoids (0:10)	7:50
		8:00

for 6 minutes into the reactors. Subsequently, the following REACT (aerated) period lasted for 4 hours while the SETTLE period lasted for 1 hour and included a 10 minute DRAW/IDLE period.

Wasting normally occurs during the DRAW period, however, since the sludge settled well below the half-way decanting port, it was not possible to waste at this time. Thus, once/day, in the middle of the REACT (aerated) period, mixed liquor was wasted to control the sludge retention time at 20 days (a typical SRT for Bio-P plants). The practice of decanting one half of the reactor contents every 8 hours (i.e. clarified effluent only) made for a 16 hour hydraulic retention time.

3.5 Analytical and Sampling Techniques

3.5.1 General Procedures

As mentioned previously, the volume for a particular test was deducted from the total volume wasted. In all cases before extracting a sample, the sampling port was opened and allowed to run briefly, clearing the line of residual material not fully exposed to REACT conditions. This volume was returned to the reactor before reopening the port to obtain a representative sample. In addition, an appropriate volume of feed sludge or sewage was set-aside and reserved for later analysis.

Sampling, handling and preservation time before analysis was kept to a minimum, with the majority of tests conducted in accordance with Standard Methods, 15th Edition

(A.P.H.A. et al., 1980). Exceptions and non-standard testing procedures are discussed in the following sections.

3.5.2 Suspended Solids Measurements

Due to the elevated concentration of suspended solids in both the AASD digesters and feed sludge (>5000 mg/L), the Gooch crucible method of solids determination was deemed impractical, as discussed by Anderson (1989). Instead, daily solids were determined by taking duplicate 25 mL aliquots of well mixed sludge or feed (measured in a graduated cylinder) and transferring them to 50 mL centrifuge tubes. These were then spun down at 2500 rpm in an IEC Clinical Centrifuge until solids capture was judged complete (about 10 minutes). The supernatant fraction was vacuum-filtered through a previously tare-weighted, Whatman 934AH glass microfibre filter (5.5 cm diameter), which had been removed from its aluminium storage dish. The sludge residual at the bottom of the centrifuge tube was then scraped out and washed on to the filter paper.

The aluminium dish (with the filter paper replaced inside) was then transferred to a Fisher Isotemp forced draft oven (Model 350), operating at a constant temperature of 104 °C, where it was left to dry overnight. Reweighing with a Mettler AC 100-S2 balance allowed calculation of the Total Suspended Solids (TSS) concentrations, with an average of the duplicate samples assumed to be representative. Total Volatile Suspended Solids (TVSS) was determined by weighing the cooled residue remaining after igniting the dish to 550 °C (for one hour) in a Lindberg muffle furnace (Type 51828).

3.5.3 pH, Alkalinity, Dissolved Oxygen and Temperature

All pH measurements used a Beckman Φ 44 pH meter with automatic temperature compensation (ATC). Several different probes were used throughout the research; however, the meter was routinely calibrated using twin standard buffers (4.0 and 7.0 or 7.0 and 10.0) before being placed into 25 mL of unfiltered reactor and feed samples. Temperature measurements were made with a mercury thermometer. When dissolved oxygen readings were of interest a Yellow Springs Instrument (YSI) DO meter (model 54ARC) was used in combination with a YSI 5739 submersible probe. The membrane was changed on a regular basis to ensure effective D.O. transfer across the membrane. Samples for total alkalinity were titrated to an end point of pH of 4.5 with 0.02 N H_2SO_4 acid.

3.5.4 ORP Measurements

In keeping with the focus of this research, ORP measurements were recorded continuously using the probes described in Section 3.2.1. Probe responsiveness was tested prior to each run by immersion in a quinhydrone solution. Quinhydrone, an organic acid, sets up a well-defined equilibrium potential particular to a given pH and temperature.

Accordingly, 2 grams of quinhydrone were dissolved into 200 mL of pH = 4 and pH = 7 buffer solutions (ASTM (1983)) and each probe in turn was inserted into the solution. At a pH = 4 (T = 18 °C), an ORP probe (with a Ag/AgCl reference electrode) is expected to yield an ORP measurement of 270 millivolts. The corresponding value for a pH = 7 solution is 92 millivolts. In all cases, the ORP probes responded to within 5 to 20 millivolts of the expected value, although with varying degrees of speed (usually 2-15 minutes).

During this research it was seldom necessary to resort to some of the harsher cleaning methods described in the American Society for Testing Materials (ASTM) handbook. The relatively clean waste and the frequency of aerobic conditions seemed to prohibit the build-up of slime films on the platinum ring which sometimes impede the rate of electron transfer across the surface. Normally all that was necessary was a distilled water rinse followed by a perfunctory wipe with a kleenex tissue. If visual discoloration of the noble metal persisted, the probes were dipped into either a dilute HCl or chromic acid (1 g $K_2Cr_2O_7$ in 100 mL of concentrated H_2SO_4) cleaning solution, as recommended by the ASTM.

In some probes there was a slow movement of microbial growth (resembling a wetting front) up the ceramic porous plug which could have possibly reduced the ion transfer necessary to maintain electroneutrality. As this plug could not be physically accessed for cleaning, no remedial action was taken.

3.5.5 Nitrogen Analysis

Nitrate and ammonia samples were first filtered through Whatman No. 4 filters prior to analysis. Nitrate was analyzed in triplicate by the colorimetric automated cadmium reduction method (A.P.H.A., 1980), using a Technicon

AutoAnalyzer II Continuous Flow Analytical System (Industrial Method No. 100-70W). The cadmium granules advocated in this method were replaced with a cadmium wire. The strip chart recorder peak heights were compared with the heights from a series of standards of known concentrations. Ammonia Nitrogen was measured using the automated phenate method, with the intensity of the colour complex formed, determined by Industrial Method No. 98-70W on the AutoAnalyzer II.

Total Kjeldahl Nitrogen (TKN) (in the AASD experiments) was determined by digesting 2 mL of the sample (and an appropriate volume of the standard) on a BD-40 block digester (in the presence of concentrated H_2SO_4 and K_2SO_4) in order to liberate all organically bound nitrogen. Samples and standards were then analyzed colorimetrically in triplicate on the AutoAnalyzer II (Technicon Industrial Method No. 376-75W). Percent N in the Bio-P experiments was measured exactly the same way except, instead of a liquid sample, approximately .025 grams of dried solids sample was used.

3.5.6 Phosphorus Analysis

Ortho-phosphate (in the form of $PO_4^{-3)}$ was determined on filtered samples using the automated ascorbic acid reduction method (Technicon Industrial Method No. 327-74W). In this method, ammonium molybdate and potassium antimonyl tartrate react with orthophosphate, to form an antimony-phosphomolybdate complex which yields an intense blue colour suitable for photometric measurement after reduction with ascorbic acid.

Samples for total Phosphorus (TP) and/or % P were prepared and measured in the same way as TKN, with digestion on the block liberating all organically bound phosphorus. During the process, liberated phosphorus is oxidized to orthophosphate, the concentration of which can be determined by comparison to peak heights of known standards in the automated ascorbic acid reduction method described above.

3.5.7 Estimates of Carbon Content

In order to characterize the sludge (i.e. determine a C:N:P: ratio) particulate samples for COD analysis were analyzed using the dichromate reflux method outlined in Standard Methods (A.P.H.A., 1980). Fifty mL of the sludge was diluted to 500 mL (i.e. a 1/10 dilution) with 10 mL duplicate volumes withdrawn by wide mouth pipette and transferred to the reflux flasks.

Total Organic Carbon (TOC) was performed on the soluble fraction of the sludge using a 10 mL sample volume. The samples were run automatically on a Shimadzu Total Organic Carbon Analyzer (Model TOC-500) using a series of low and high standards. Combustion of the sample resulted in the production of a quantity of CO_2 proportionately equal to the amount of carbon in the sample.

3.6. Sample Preservation and Storage Techniques

Whenever possible, samples were analyzed promptly after collection and preparation. Table 3.4 summarizes sample preservation and storage techniques when expediency dictated later analysis.

Table 3.4 Sample Preservation, Analysis and Detection Limits

Chemical Parameter	Sample Volume Preservative Storage Period	Analyzed by
COD	50 mL Frozen Indefinite	Dichromate Reflux Method
TOC	10 mL Frozen Indefinite	Shimadzu TOC-500
NO_x-N	3 mL Phenol Mercuric Acetate 3 weeks @ 4°C	Autoanalyzer Colorimetric Automated Cadmium Reduction
NH_3-N	3 mL Conc. H_2SO_4 3 weeks @ 4°C	Autoanalyzer Colorimetric Method
TKN %N	3 mL (TKN) 0.025 g (%N) Conc. H_2SO_4 3 weeks @ 4°C	Autoanalyzer Colorimetric Method
TP %P	3 mL (TP) 0.025 g (%P) Conc. H_2SO_4 3 weeks @ 4°C	Autoanalyzer Colorimetric Method
Ortho-P	3 mL Phenol Mercuric Acetate 3 weeks @ 4°C	Autoanalyzer Colorimetric Ascorbic Acid Reduction

3.7 Statistical Techniques

Averages, standard deviations, maximum and minimum values were calculated using the software program Symphony (release 1.2) of Lotus Development Corporation (Cambridge MA).

CHAPTER 4

AEROBIC-ANOXIC SLUDGE DIGESTION EXPERIMENTS

4.1 Review of Special Features of ORP Curves

Before highlighting some of the mechanical and biological nuances particular to this research, it is necessary to describe in greater detail, the expected shape of an ORP-time profile, generated when activated sludge is subjected to alternating aerobic-anoxic conditions. Although the main feature of interest is the nitrate breakpoint (or knee (which it superficially resembles)), several other distinctive features exist, some of which may offer potential for control in later research. Since other investigators (Peddie et al., 1988, Jenkins and Mavinic, 1989b) have described these features in detail, only a brief review is presented here.

Figure 4.1 displays the classical form of an ORP-time curve produced from an AASD reactor experiencing Fixed-Time conditions (3 hours of air-on, 3 hours of air-off). It can be seen that the ORP probe responds to the influx of oxygen by rising rapidly (as air is supplied to the reactor), even though the dissolved oxygen curve (the dotted line) shows no measurable response. During this initial period it is presumed that oxygen is being consumed (as soon as it becomes available) by nitrifiers, oxidizing the ammonia built-up from the previous anoxic portion of the cycle. This is shown by a decrease in NH_3 (diamond marker) and an attendant increase in the nitrate concentration (triangular marker).

Once the majority of this reserve has been transformed to

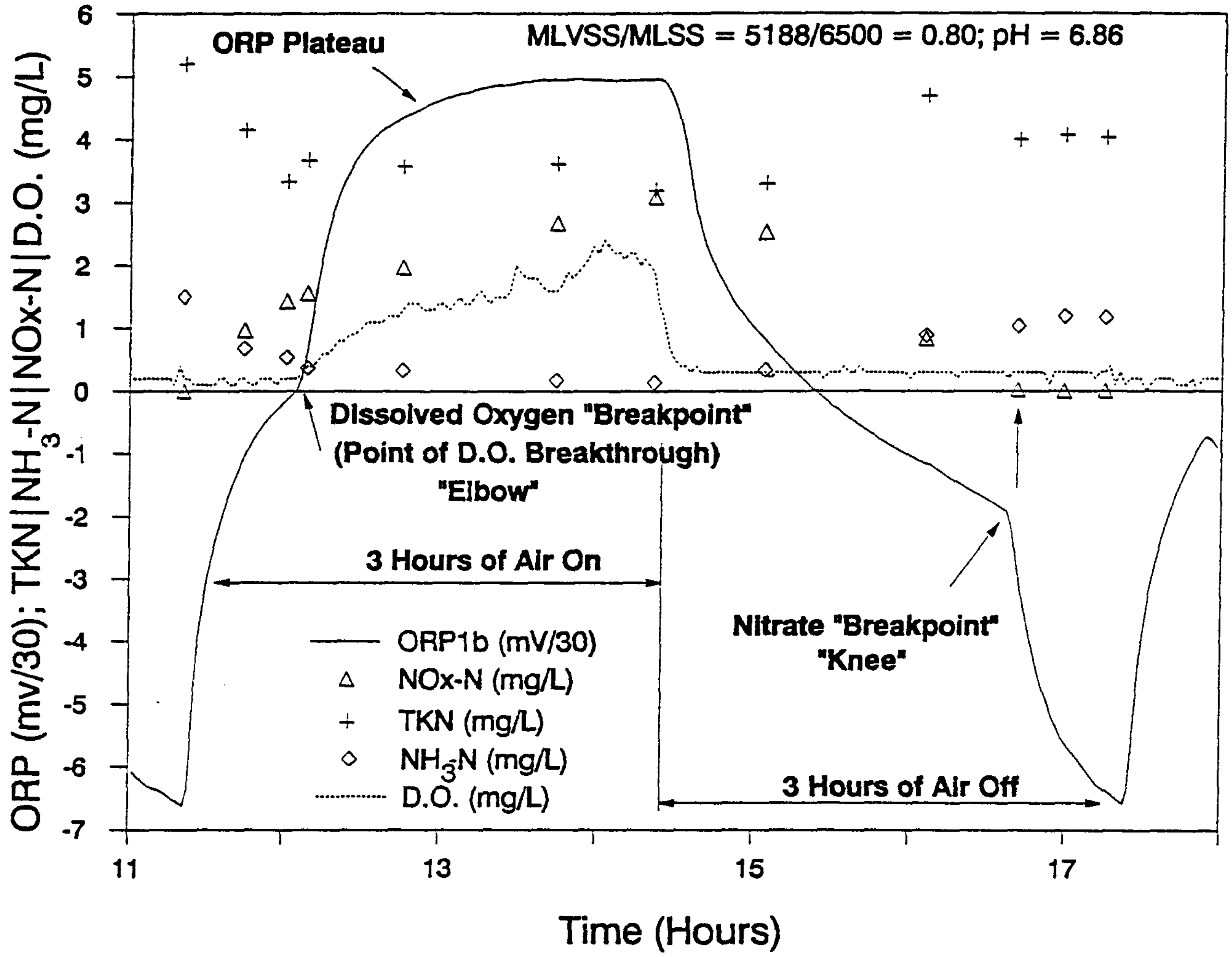


Figure 4.1 Fixed-Time ORP Profile Under AASD Conditions

nitrates, the oxygen "breaks through" and becomes residual oxygen, measurable by a dissolved oxygen probe (the sudden jump in the dashed (D.O.) line). The ORP-time curve follows suit, making a sudden bend which due to its angular shape, is colloquially known as the "elbow" since it is reminiscent of the human equivalent. It is not yet clear whether this inflection point/elbow actually corresponds to a concentration of zero NH_3 or rather a point where the oxidation of NH_3 by O_2 is at equilibrium (in balance with) the production of NH_3 through hydrolysis of organic nitrogen. The latter explanation seems more likely since the NH_3 seems to be "levelling out" at some minimum (plateau) value, which may mean that beyond this inflection point, as fast as it is produced by hydrolysis, it is being converted into nitrates. It can be seen that the nitrate concentration continues to increase beyond this point for the remainder of the aeration period.

Eventually the ORP probe mimics the D.O. response, by reaching a plateau value, seemingly a function of numerous variables such as probe sensitivity, the rate of airflow and the biological dynamics involved. This plateau reflects an equilibrium relationship between the rate of air supply and the rate of air utilization by the biomass; again however, the specifics are not well understood at the present time.

Upon cessation of air and as free oxygen is quickly exhausted from the system, there comes a time when those bacteria whom are able to, switch over and use nitrates as a terminal electron acceptor in the electron transport chain. Some of the researchers mentioned previously have documented an inflection point related to the disappearance of oxygen; however, this has never been definitively observed during this research.

As nitrate respiration continues and the nitrate concentration declines, eventually the point of zero nitrate concentration (the inflection point in the ORP-time curve) is reached. As mentioned this point is known as the "nitrate knee" and it is this feature which is the focus of this research. Beyond this, as more negative potentials are established, a corresponding "anaerobic plateau" begins to develop and presumably it is here that less efficient solids degradation processes (such as sulfate reduction, methane production and fermentation) predominate.

Sampling at the very limit of anaerobiosis however (2 hours and 45 minutes of air off) yielded no production of sulfides. Moreover, even in the feed sludge which may have been stored for up to 8 hours, no measurable sulfides (detection limit of 0.1 ppm) were detected. It would seem that insufficient time is available for any anaerobic organisms (that managed to survive the aerobic phase of the cycle), to develop into a significant population. Thus, after the nitrate breakpoint, in theory, very little if any solids degradation is occurring because of the lack of highly efficient electron acceptors and the failure of other organisms to establish a significant presence.

For comparative purposes, Figure 4.2 portrays an ORP-time profile indigenous to the Real-Time Control (RT) reactor (3

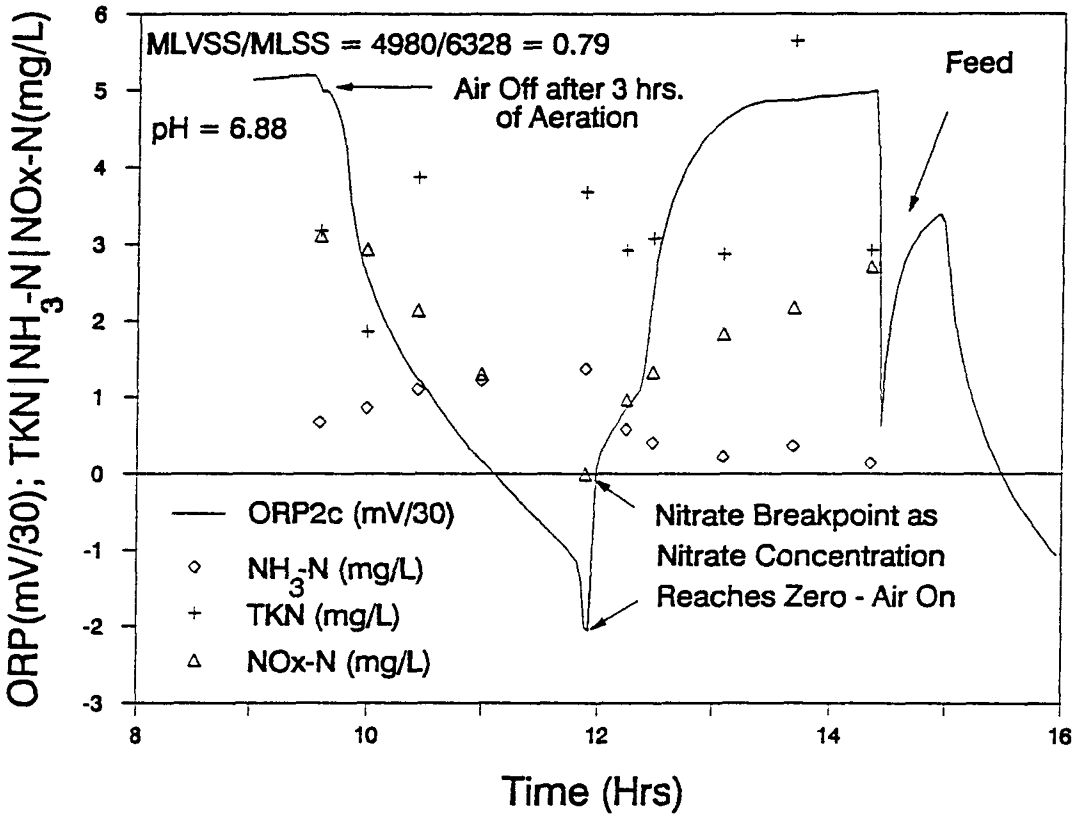


Figure 4.2 Real-Time ORP Profile Under AASD#1 Conditions

hours of air-on, a variable length of time for the air-off). Again, clearly evident is the intersection between the ORP knee and the point of zero nitrate concentration. Consistent with the objectives of the Real-Time operating strategy, the profile does not proceed beyond this point; instead, it rises rapidly, as the ORP probe responds to the presence of oxygen immediately available after the computer detects the breakpoint and re-initiates the air supply.

Figure 4.2 shows a sharp drop in the ORP value (at approximately 2:30 pm) corresponding to the input of daily feed. Due to the daily mechanics involved in sludge collection, transport, and routine laboratory analyses, the feed sludge was frequently in a highly reduced state, at the time of feeding, as compared to the reactor contents. Thus, feeding in these circumstances was equivalent to suddenly increasing the concentration of reductants in the reactor, (an increase in the concentration of the reduced form of NAD^+). Depending upon the relative difference between the feed and reactor ORPs, an ORP drop of up to 100 mV (depending upon the probe sensitivity) could occur. Of course, as the feed experienced oxidization, the ORP would begin to return to its prior value.

Since the addition of feed created the potential for a false knee to be induced in the Real-Time (RT) reactor curve, the practice of feeding the Real-Time reactor approximately half-way through the aeration cycle (after the D.O. measurement) was adopted. However, the reactors would frequently be out of phase; therefore, it was quite possible that the Fixed-Time (FT)

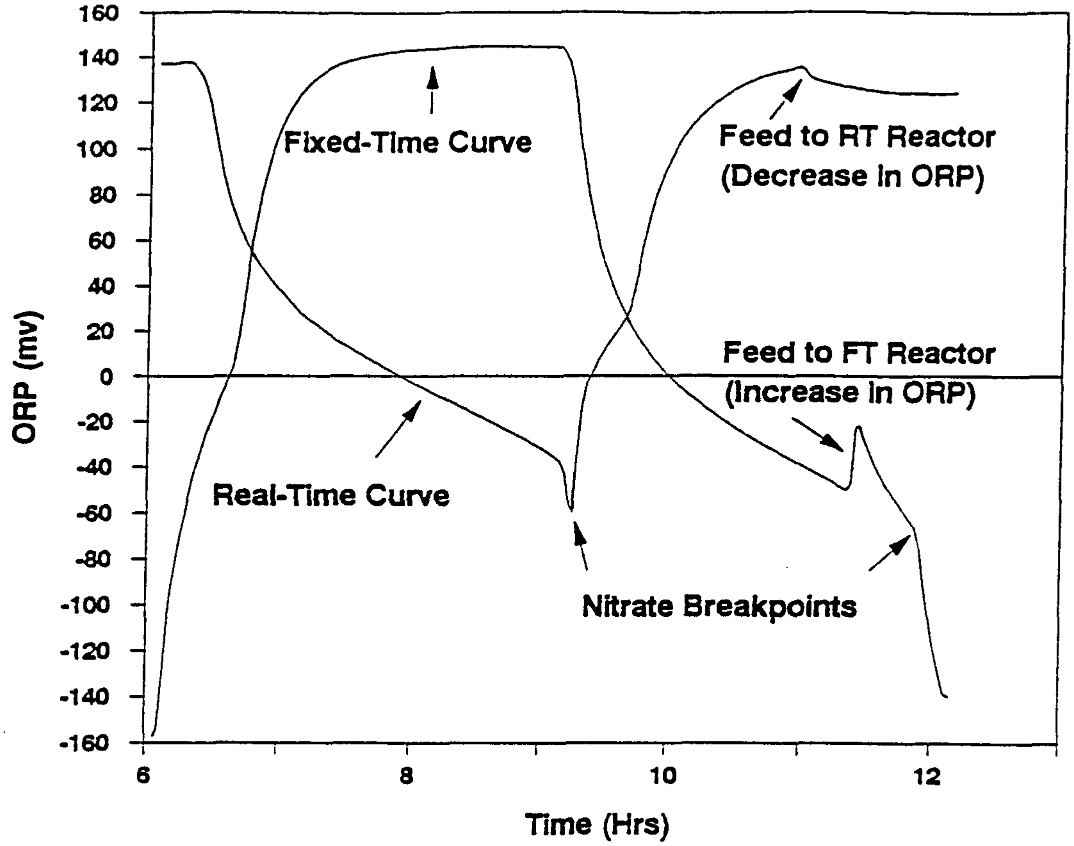


Figure 4.3 Effect of Relatively Fresh Feed on Reactor ORP Curves

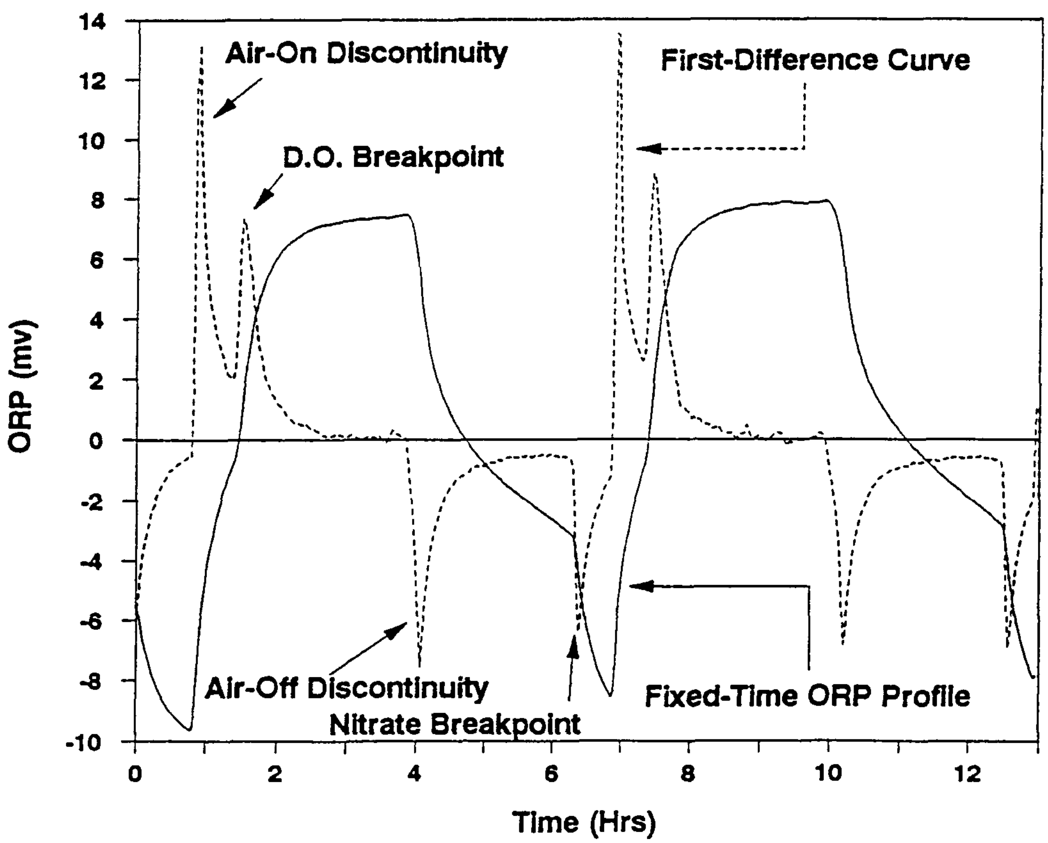


Figure 4.4 Overlay of First-Difference and ORP-Time Profiles

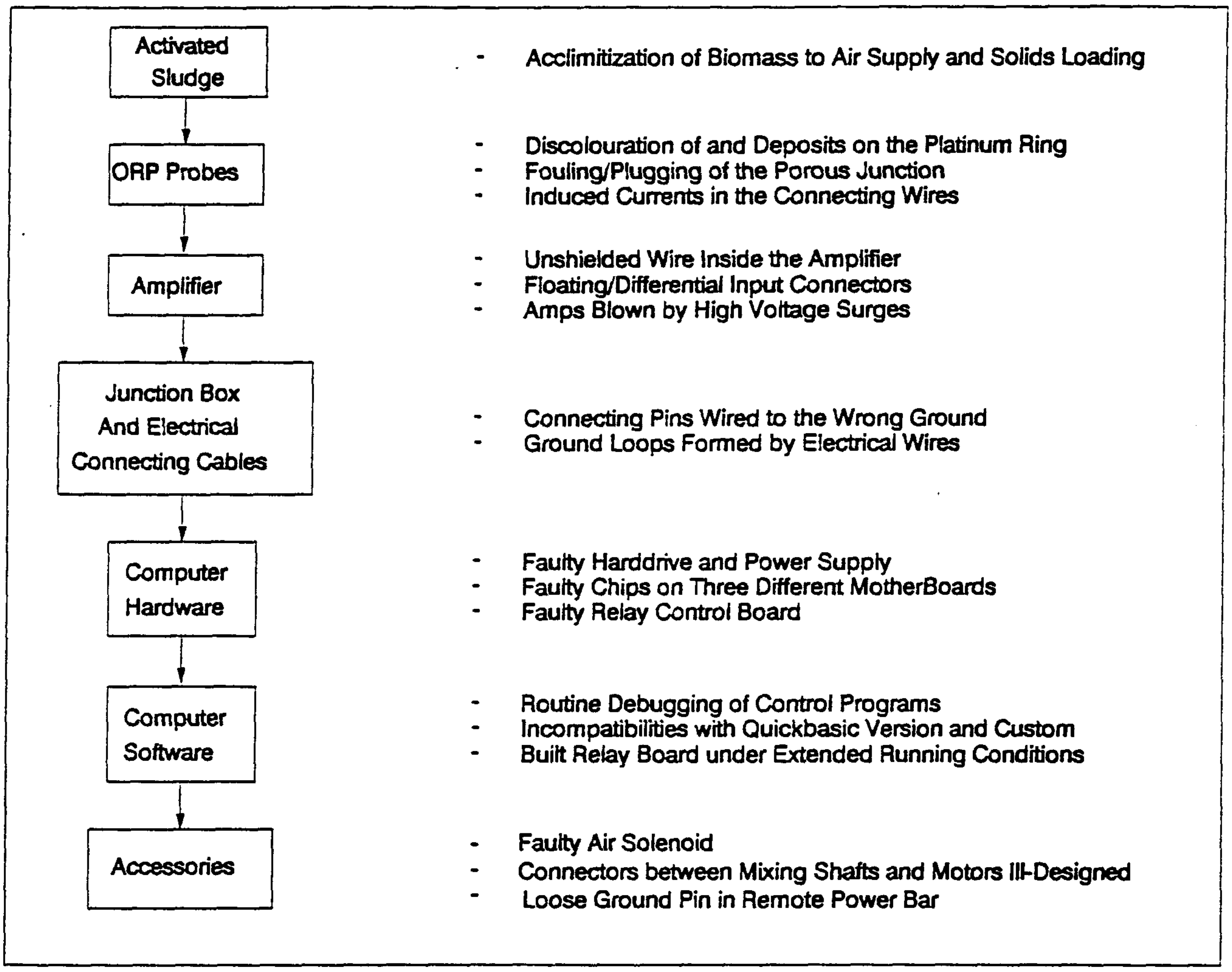


Figure 4.5 Linear Diagram of Components Identifying Problem Areas

Many of the mechanical problems were isolated and remedied in a diagnostic fashion, by sequentially disconnecting the system elements and linking them in various and tandem combinations until identification of the offending component(s). It is worthwhile to mention that a large portion of the difficulty was surmounted, when the experiment was redesigned with adequate knowledge of proper grounding techniques. For example, during one phase, all electrical components were connected (and apparently functioning properly); however, the ORP probes behaved erratically when immersed in the reactor solutions, despite near perfect readings when submerged in quinhydrone test solutions. An oscilloscope detected a stray current travelling down the motor armature, through the mixing shafts and into the reactor solutions, thereby swamping any biologically-induced signals. To remedy this problem, teflon connecters were designed in order to isolate the motors from the mixing shafts/biological liquids.

The existence of ground loops further complicated matters by producing an interaction effect between the two reactors, surfacing primarily when one reactor switched on (or off) an air solenoid. The effect manifested itself in the form of a sudden spike in the ORP profile of one reactor, when the air to the other reactor clicked on or off (and vice versa). This became critical in the Real-Time control reactor, since if the spike conformed to a sudden drop in the ORP profile, it quite realistically simulated a nitrate breakpoint, thus causing the computer to prematurely initiate air resupply. Figure 4.6

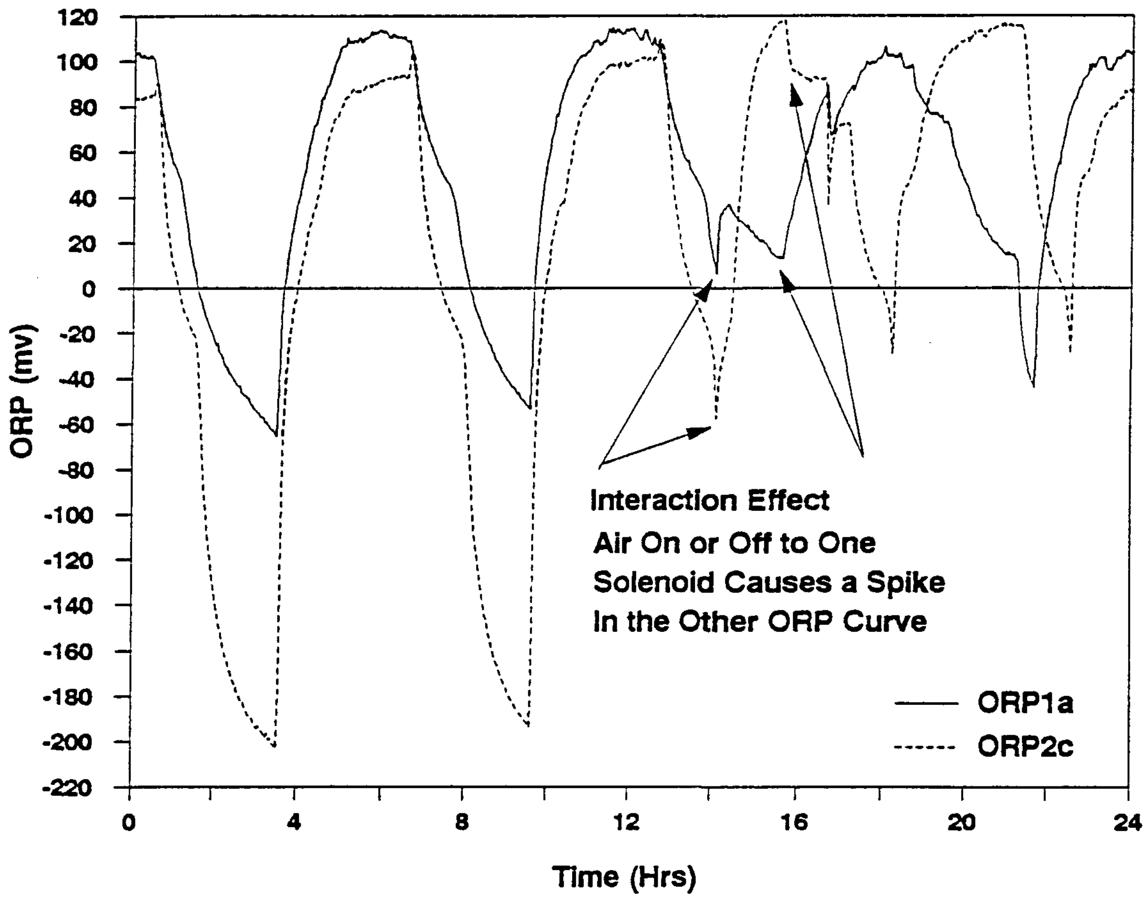


Figure 4.6 Reactor Interaction Effects Due to Improper Grounding

illustrates a typical example of the interaction effect between the two reactors.

Many of the problems were trivial in nature but quite time consuming to detect. For example, a loose ground pin in an electrical socket on a remote power bar, produced an intermittent problem whereby the curve form would be smooth for a period of time (Figure 4.7) and then suddenly degenerate into electrical noise. Eventually this problem worsened to the point where the ORP curves resembled a seismograph waveform (Figure 4.8).

An even more time consuming problem was the suspected existence of an interaction effect between the Quickbasic 4.5 language itself and the custom-built relay control board originally installed in the computer. In this case, the computer would run perfectly, from anywhere from 2 to 9 days, before suddenly "locking up" to the extent of requiring a power-down/ power-up reboot of the system. The locked condition of the computer usually meant that one reactor received air overnight while the other reactor went unaerated, a condition presumed to be highly detrimental to bacterial cultures having a life-span of 20-30 minutes. Moreover, after such a disturbance, any serious comparison between the two reactors was highly questionable. The purchase of a commercial relay-control board solved this problem.

Despite many such difficulties, only a few of which have been recounted here, it can be concluded that, provided sufficient attention to detail is observed, a robust design will

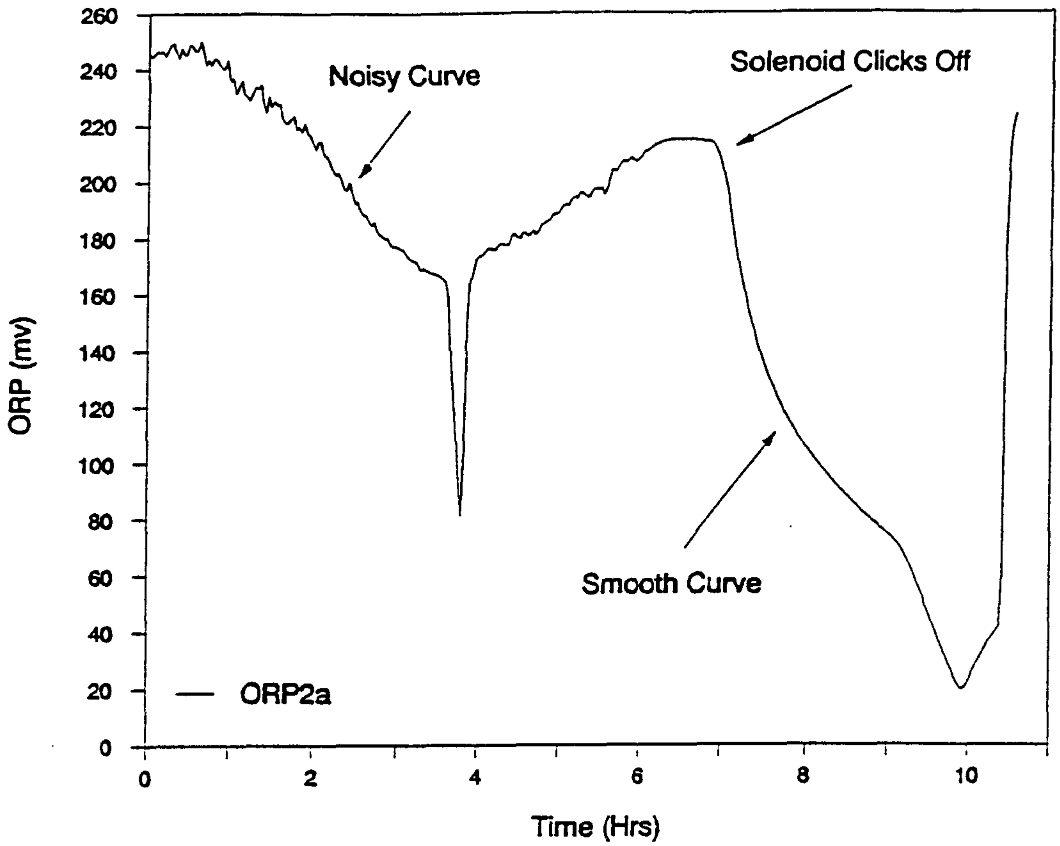


Figure 4.7 ORP Profile Affected by Intermittent Electrical Noise

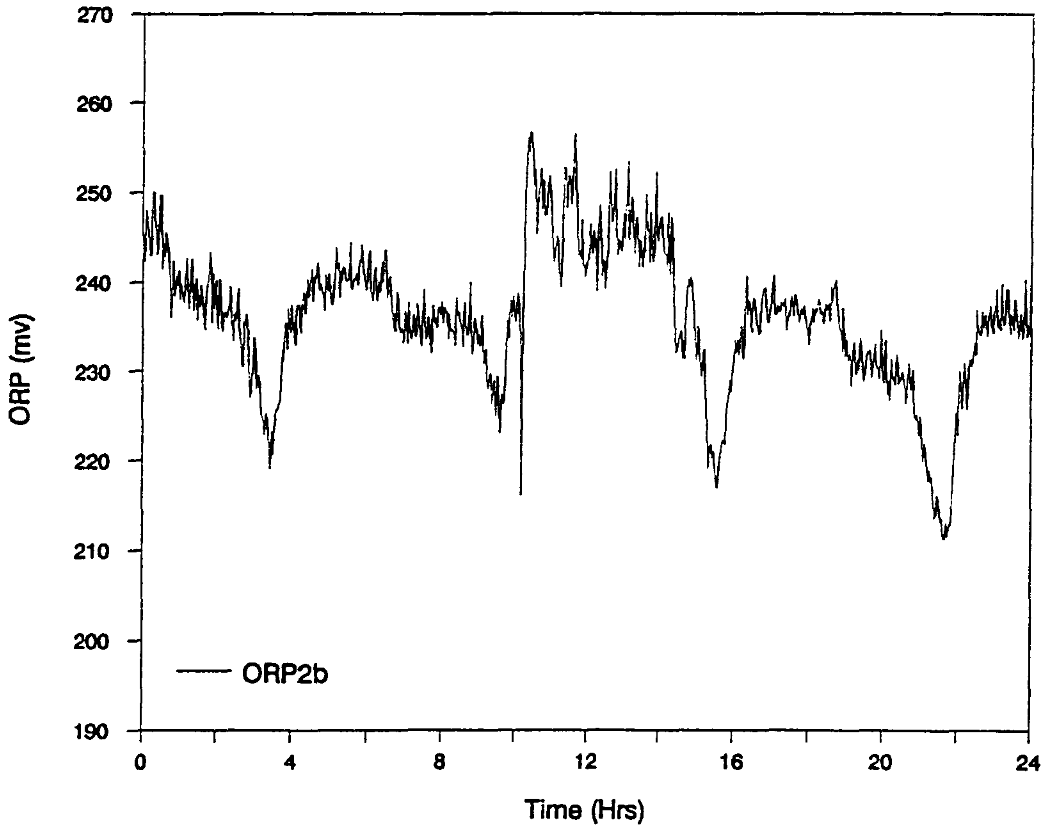


Figure 4.8 Complete Deterioration of ORP Profile

eventually prevail. This attention to detail would be paramount in full-scale applications, where numerous electrical and other similar interferences would be commonplace readily negating any meaningful data monitoring and process control.

4.2.2 Experimental Pre-Run Conditions

Once the hardware and software irregularities were eliminated, attention could be focused on the biological conditions in the reactor. "Adequate running conditions" could be obtained by harmonizing readily adjustable parameters, such as air supply and solids concentrations. In certain cases, this would take several days as the biological elements within the reactor became accustomed to the dynamic interplay between solids levels and air supply.

Experimenting, until the right combination of these two parameters was achieved, led to the development of conditions deemed suitable for the commencement of an AASD run. These conditions consisted of "equivalency" in terms of ...

(i) Both reactors operating on a Fixed-Time basis,

(ii) The consistent occurrence of the characteristic curve shape of the ORP profile under Fixed-Time conditions (with all attendant features);

(iii) A good range (at least -200 mV to +200 mV) between the minimum and maximum ORP values; and

(iv) A D.O. measurement during the plateau portion of the cycle between 2 and 4 mg/L.

Figures 4.9 and 4.10 consist of extreme examples of curves obtained during sporadic periods when the experiment

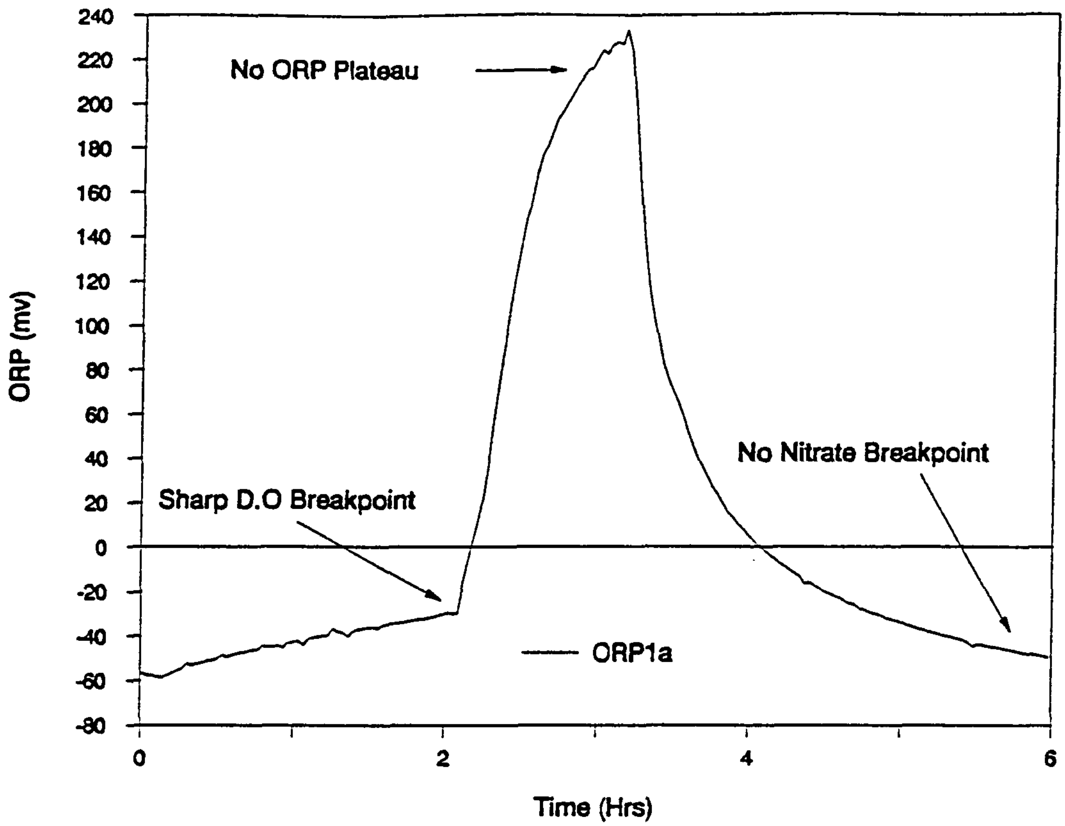


Figure 4.9 Unusual Response Pattern: No Nitrate Breakpoint

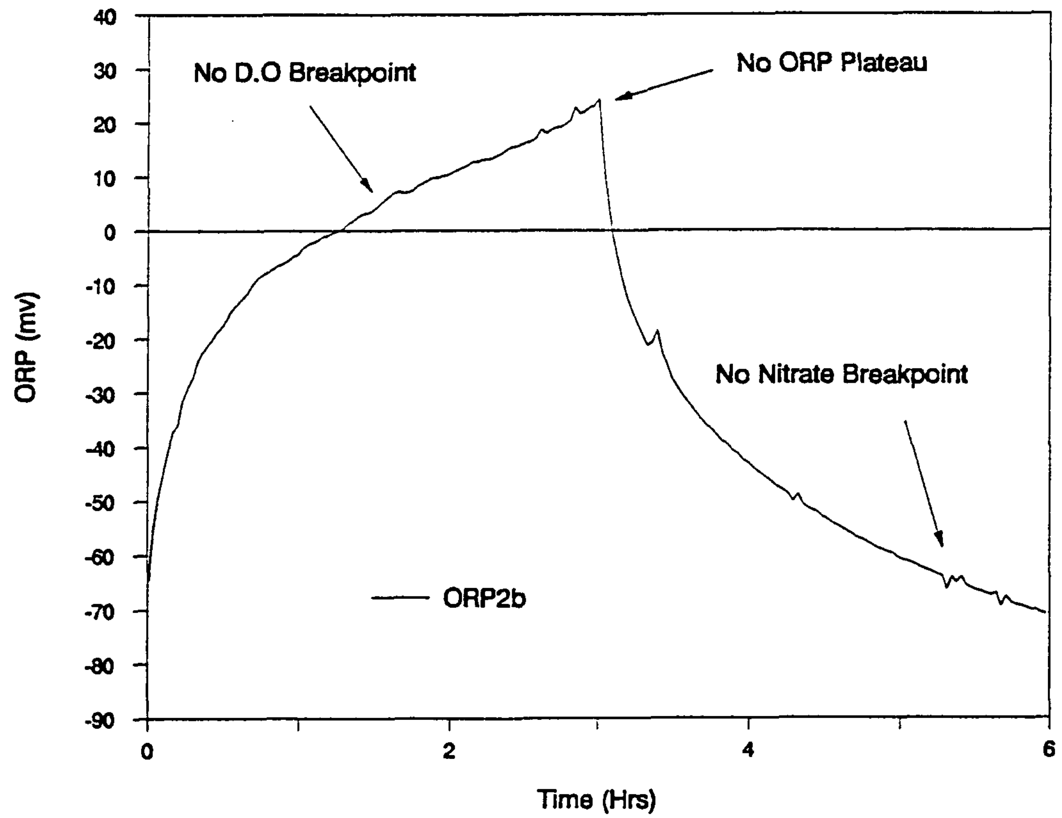


Figure 4.10 Unusual Response Pattern: No Diss. Oxygen Breakpoint

seemed to be mechanically sound but experiencing difficulties, as biological conditions inside the reactor adjusted to the balance between air supply and solids level. In the majority of cases, curves much less extreme were observed; however, whenever the micro-organisms were acclimating to pre-run conditions, the ORP curves took a few days to consistently arrive at all of the distinctive features of the "classic" ORP-time curve indigenous to Fixed-Time AASD conditions (Figure 4.1).

Once "equivalency" was achieved, the command to "switch over" to Real-Time control was issued (Figure 4.11). From then on the air was activated in the Real-Time reactor by the breakpoint occurring in the anoxic cycle.

4.3 Behavioral Trends: AASD#1 Experimental Conditions

4.3.1 Operating Characteristics and ORP Profiles

Several general observations can be made regarding the pattern of ORP curves generated during the first set of AASD experiments. Under this operating strategy, at least 4 cycles/day of aerobic-anoxic sequences (6 hours total for the air-on, air- off time period) occurred in the Fixed-Time reactor. The Real-Time reactor however would frequently be into its 5^{th} cycle, since denitrification often occurred within 3 hours, making the total cycle length of the Real-Time reactor less than 6 hours. Over the course of a 24 hour period however, all probes in both reactors showed a remarkable consistency in the curve shape, from cycle to cycle as illustrated in Figure 4.12.

As mentioned earlier, critics of ORP often decry the

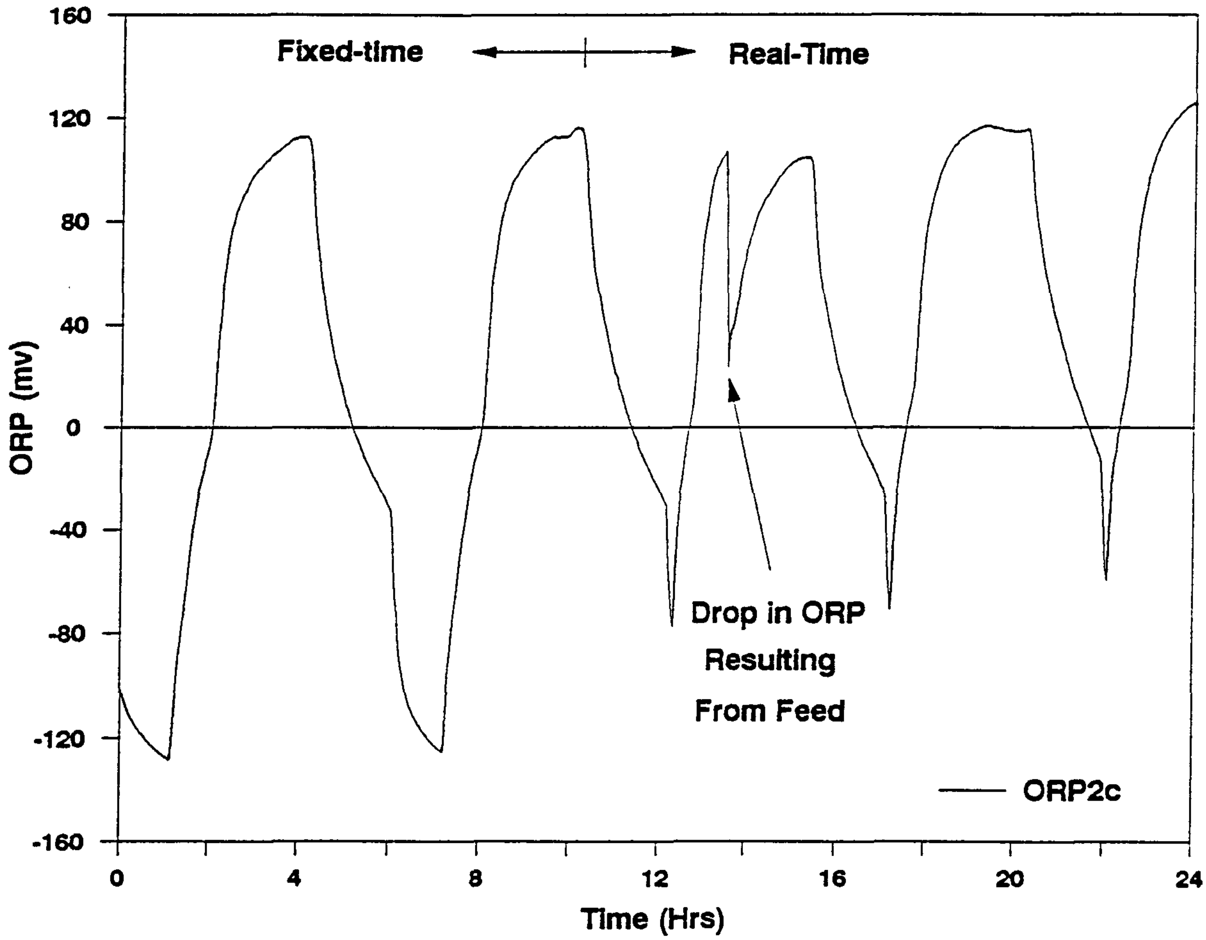


Figure 4.11 "Switch Over Day": FT to RT Control - AASD#1

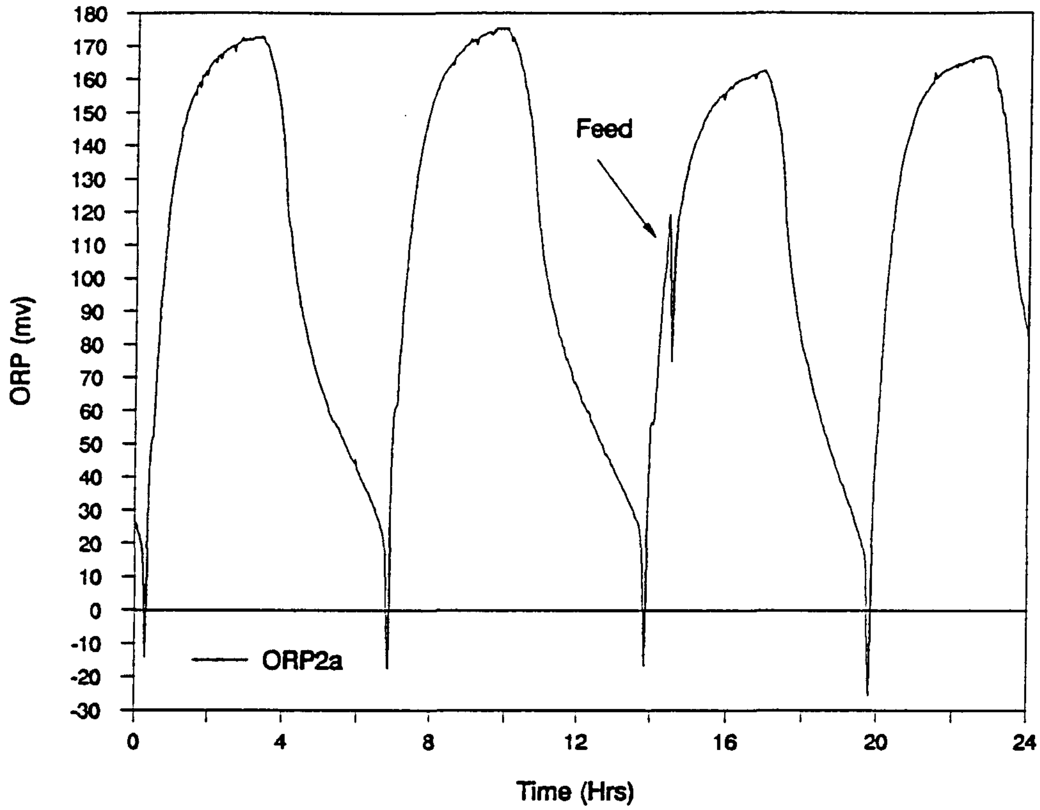


Figure 4.12 Temporal Reproducibility of ORP Curves in RT Reactor

fact that ORP probes in the same sewage, frequently yield widely divergent results. This research, however, emphasized the relative change in ORP with time, with Figure 4.13 illustrating that all 3 probes in the same reactor simultaneously detected the breakpoints, despite widely diverging absolute values. Minor discrepancies in detection times are ascribed to differences in the individual probe sensitivities. Moreover, the particular example selected is an extreme example of differences in the absolute ORP values and is presented solely for clarity of illustration with regard to detection times. In the vast majority of cases, the actual absolute difference between probes in the same reactor was less than 20 millivolts.

The most distinctive characteristic evident in reactors operating under Real-Time AASD conditions, is the self-adjusting ability of the reactor to dynamically meet zero-nitrate effluent guidelines. This is due to the reactor's ability to delay switching on the air until denitrification is complete. On a 24 hour basis (after feeding which raises the carbon level in the reactor), the overall available carbon level decreases, necessitating longer and longer denitrification times (i.e. There is an increase in the total elapsed time between the cessation of air and the nitrate breakpoint). The advent of feeding on the following day immediately shortens the denitrification time and the sequence repeats itself. Operating the reactors in this way generates the cyclical pattern illustrated in Figure 4.14 and 4.15, with the length of the anoxic zone a reflection of the amount of carbon available in

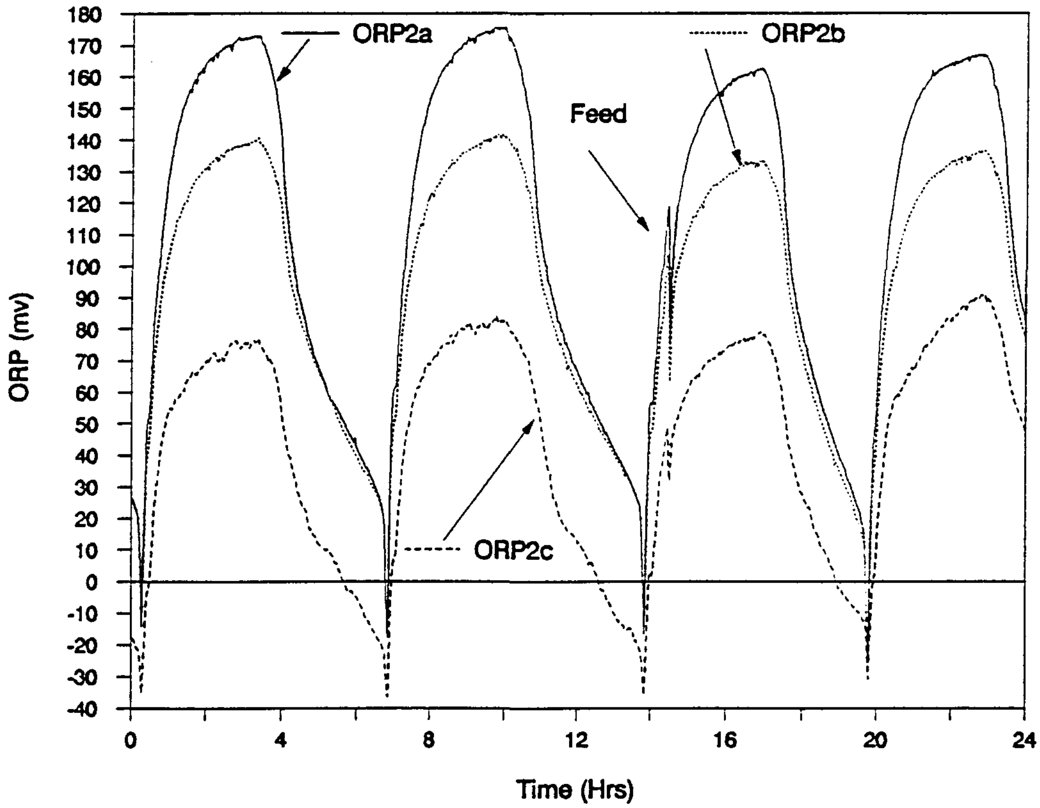


Figure 4.13 Spatial Reproducibility of 3 ORP Electrodes in Same Reactor

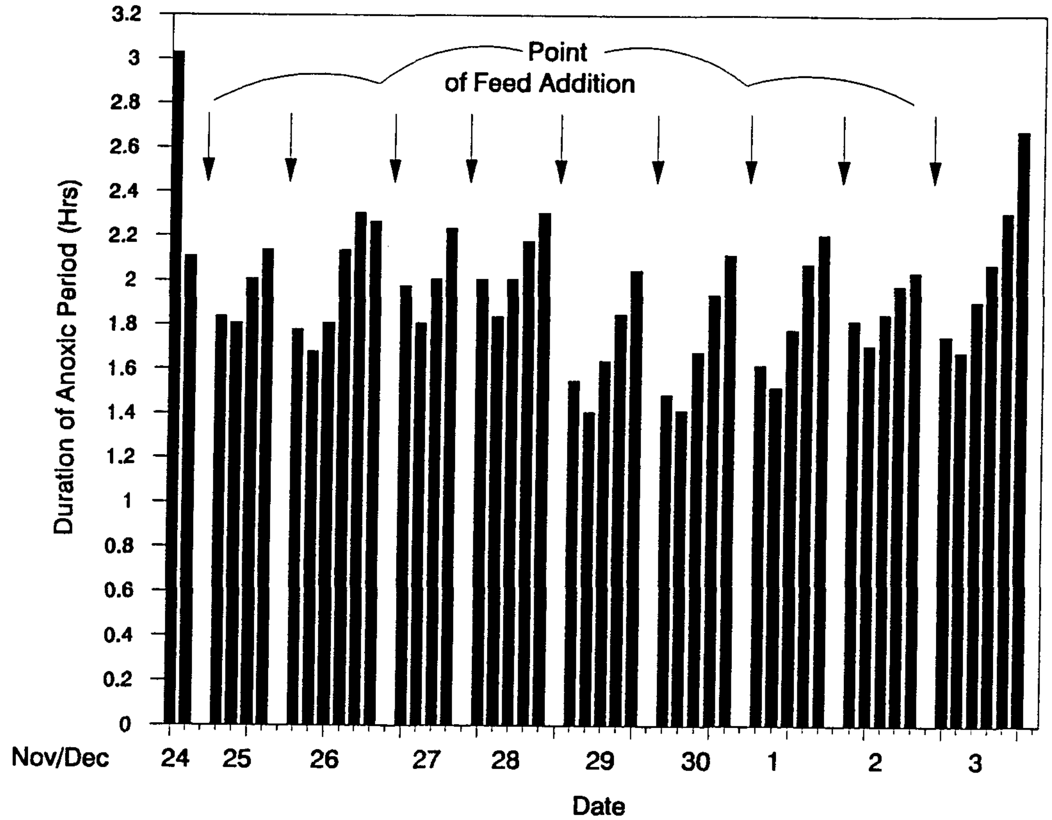


Figure 4.14 Anoxic-Zone-Length: Cyclical Pattern Due to Daily Feed

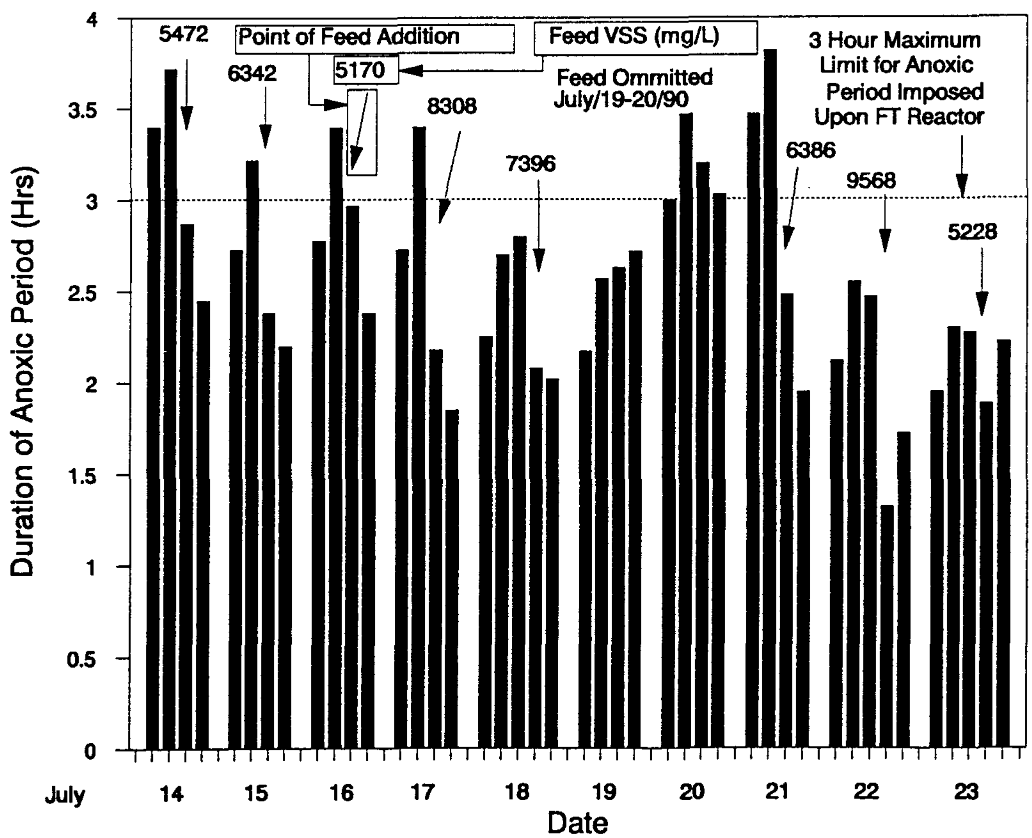


Figure 4.15 Anoxic Periods Greater Than the 3 Hour Fixed-Time Limit

the system.

Further to this, Figure 4.15 illustrates the power of this approach since, in this snapshot, many of the anoxic periods extend beyond the 3 hour anoxic-limit constraint (time available for denitrification) arbitrarily imposed upon the Fixed-Time reactor. Especially noticeable are the two days in which the feeding process was omitted. On these days, the dearth of carbon available for denitrification would result (if decanting had occurred) in a release to the environment (from the Fixed-Time reactor) of an effluent containing nitrates. Again, if a water body had as a priority a ban on nitrates, these instances would represent periods of non-compliance with the stated objectives. In contrast, it can be seen that the Real-Time reactor ensured that all the nitrates were eliminated before release of the effluent.

4.3.2 General Observations: Chemical Parameters

Table 4.1 summarizes some selected chemical statistics of daily measurements performed on the Feed, Fixed-Time, and Real-Time reactors during AASD#1. A complete listing of chemical data for the entire 60 day run can be found in Appendix E.

Since no effort was made to regulate the solids loading to the digesters (other than maintaining a reasonably consistent sludge collection procedure), the daily variation in feed solids concentrations was quite large and is reflected in the large standard deviation (Table 4.1) relative to the means (i.e Std. Dev. approximately 20 % of the mean value) of the TSS

Table 4.1 Selected List of Chemical Statistics: AASD#1

Chemical Parameter	Statistic	FEED	Fixed-Time Reactor	Real-Time Reactor
TSS (mg/L)	Maximum	13550	7472	7404
	Mean	7841	6569	6511
	Minimum	5188	5336	5288
	Std.Dev.	1626	600	610
VSS (mg/L)	Maximum	10794	5812	5712
	Mean	6174	5080	5005
	Minimum	4158	4154	4116
	Std.Dev.	1306	442	432
TKN (mg/L)	Maximum	953	493	500
	Mean	546	436	428
	Minimum	331	265	323
	Std.Dev.	111	47	44
NOx-N (mg/L)	Maximum	7.68	4.66	4.18
	Mean	1.89	1.64	1.80
	Minimum	0.13	0.08	0.04
	Std.Dev.	2.05	0.86	0.73
NH_3-N (mg/L)	Maximum	16.60	0.99	0.92
	Mean	3.00	0.23	0.16
	Minimum	0.06	0.04	0.07
	Std.Dev.	4.27	0.29	0.18
TP (mg/L)	Maximum	472	385	385
	Mean	306	300	302
	Minimum	164	164	199
	Std.Dev.	64	49	53
Ortho-P (mg/L)	Maximum	31.70	61.54	56.23
	Mean	8.40	45.85	42.39
	Minimum	0.00	23.82	25.00
	Std.Dev.	9.27	7.59	6.79
Dissolved Oxygen (mg.L)	Maximum	----	5.30	5.20
	Mean	----	3.20	3.31
	Minimum	----	1.40	1.40
	Std.Dev.	----	0.93	0.88
pH	Maximum	7.30	7.36	7.39
	Mean	6.79	6.76	6.77
	Minimum	6.37	6.37	6.39
	Std.Dev.	0.20	0.22	0.21

and VSS feed solids. It can also be seen that the feed solids concentration (both TSS and VSS) was approximately 1000 mg/L greater on average than the reactor solids levels. Less variation was expected in the reactor solids concentrations (Std. Dev. approximately 9 % of the mean). The different extent of these variations are shown in Figure 4.16. It is noted that full-scale digesters operate at much greater solids concentrations (approx. 3 % solids). The pilot plant facility however, is not able to produce this level of solids as influent feed to the laboratory digesters. The average ratios of VSS/TSS were 0.79, 0.77, and 0.77 for the Feed, FT, and RT reactors, respectively. The relatively constant nature of all of these ratios is illustrated by parallel plots of VSS and TSS for the feed sludge only (Figure 4.17).

The speciation of nitrogen forms (TKN, NH_3, and NO_x) is very much a function of the sampling time (i.e whether the air is on or off); thus, the standard deviations (Table 4.1) for both the NH_3 and NO_x are quite large. Since the TKN parameter is almost all organic nitrogen, its variation is much less.

Figures 4.18 and 4.19 show the profiles with time of total nitrogen and total phosphorus. The feed nitrogen content fluctuated in accordance with the influent solids concentration; however, inside the reactors, the total nitrogen remained relatively constant. As nitrogen was removed from the system, it should have showed a gradual decrease over the course of digestion. It is suspected that experimental error masked this trend and therefore more precise laboratory techniques (such as

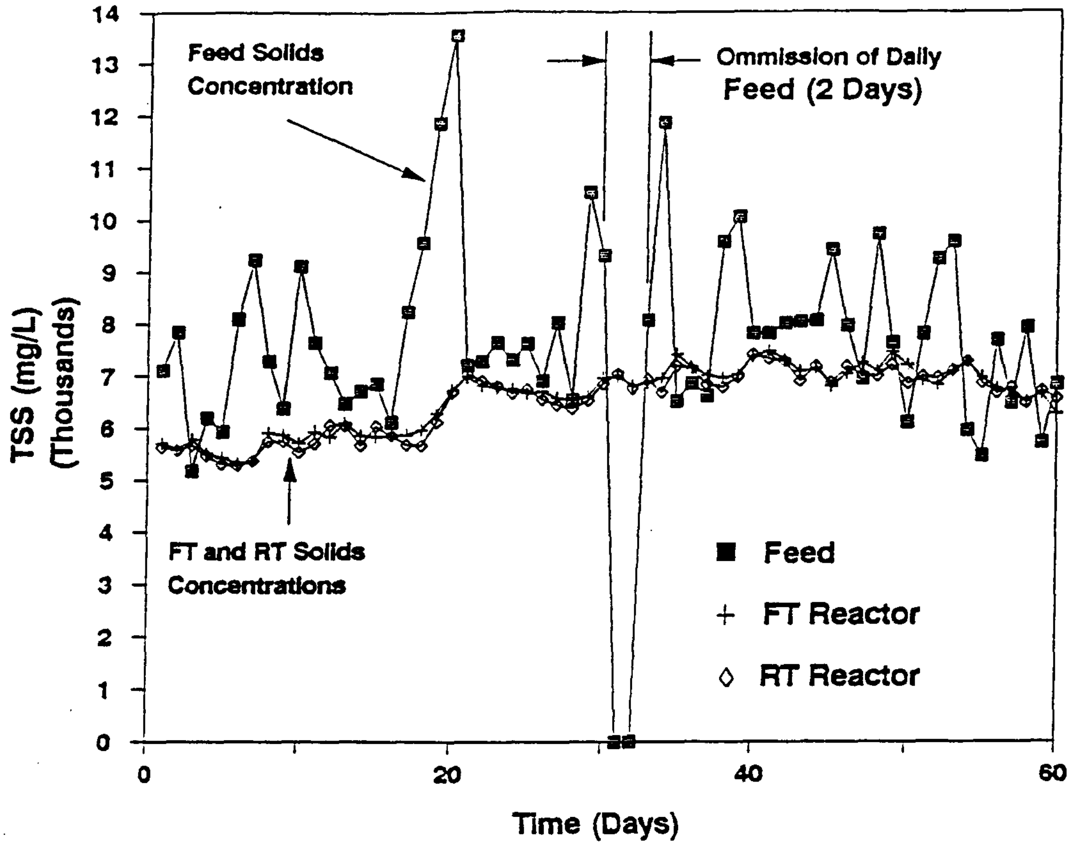


Figure 4.16 Daily Variation in Feed and Reactor TSS: AASD#1

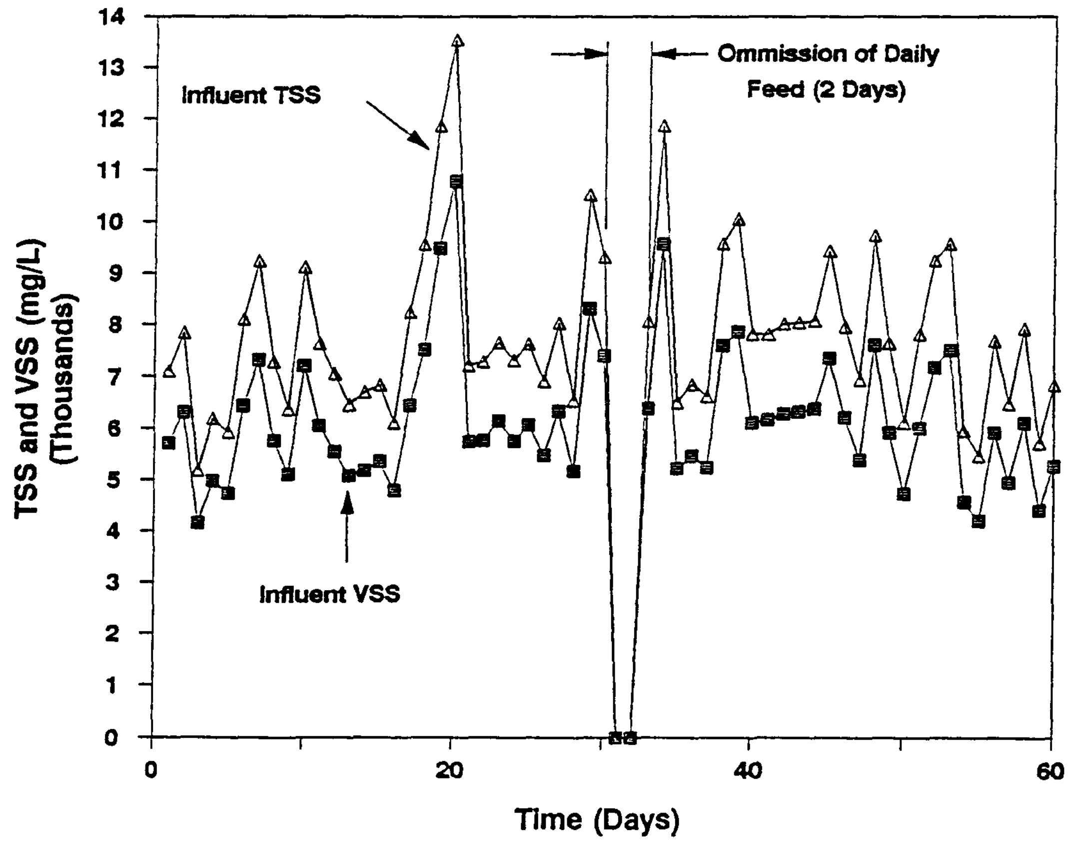


Figure 4.17 Parallel Plot: Feed Sludge AASD#1 TSS/VSS Ratio

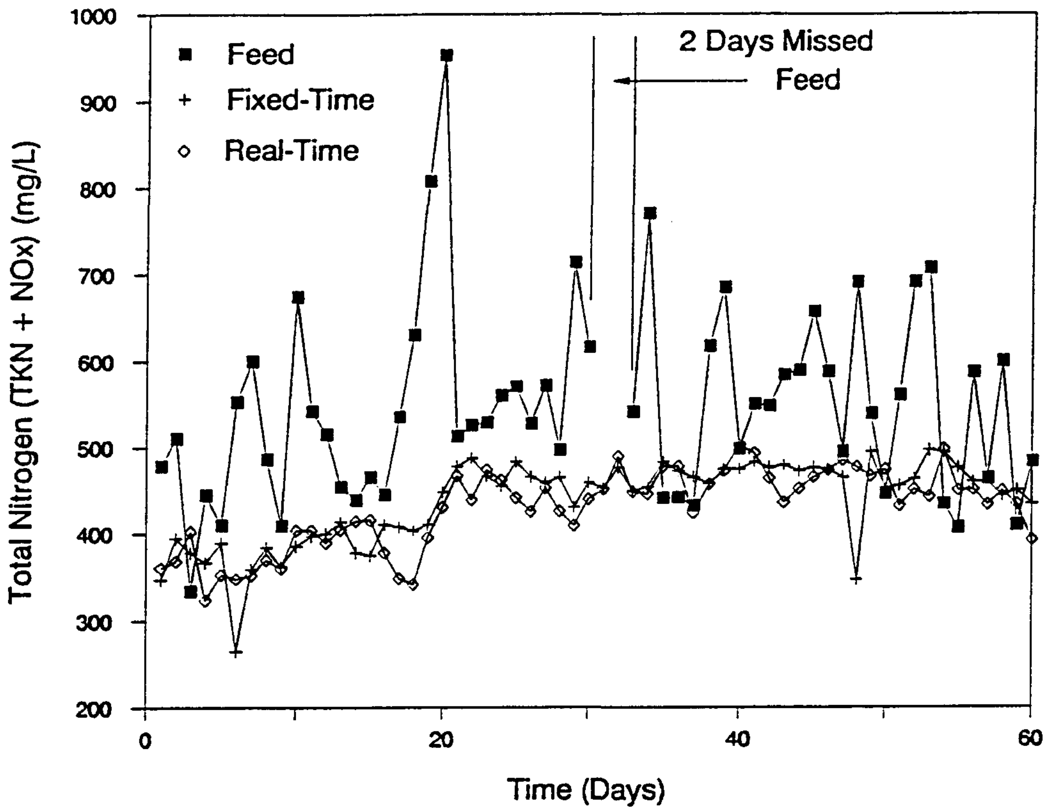


Figure 4.18 Fluctuations in Total Nitrogen Content: AASD#1

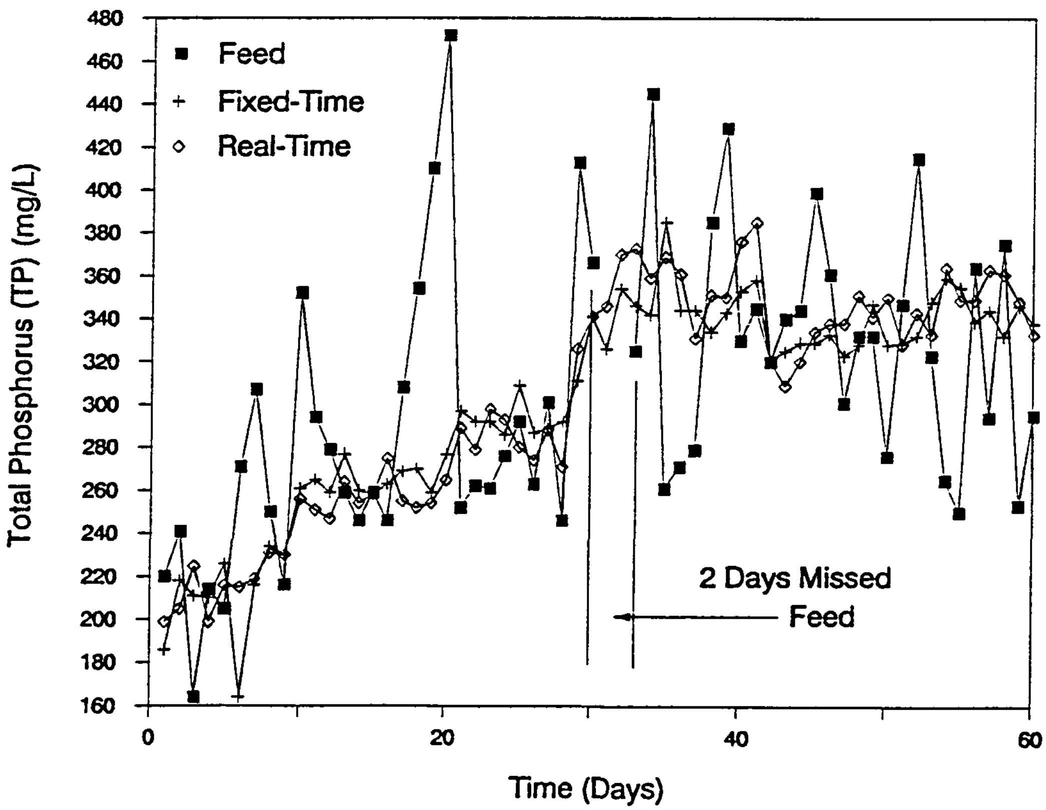


Figure 4.19 Fluctuations in Total Phosphorus Content: AASD#1

pipetted dilutions) were implemented for subsequent runs.

The total phosphorus experienced an increase during the first half of the run, while subsequently levelling off during the latter portion of the run. It is not known why this occurred but it is suspected that the initial rising trend in the influent TP values slowly forced the reactor TP levels to follow suit (since the reactor values represent a trade-off between the relative difference between feed and wastage values).

With regards to soluble phosphorus, the variation in influent ortho-P was directly related to the freshness of feed. If routine operations dictated that the sludge be stored for several hours before being utilized as feed, then anaerobic conditions would prevail, releasing phosphorus into the bulk liquid. Thus, the standard deviation for the influent ortho-P was greater than 100% of the mean. On a cyclical basis, however, inside the reactor, the alternating aerobic-anoxic conditions would have caused an uptake followed by a release of phosphorus to the liquid. Due to an oversight, this trend was not verified.

Total CODs were done on all sludges for the first 20 days. When coupled with daily TKN (minus the ammonia) and TP (minus the ortho-P) measurements, average C:N:P ratios for the sludges could be estimated. They were calculated to be 100:5.1:2.7, 100:5.4:3.4, and 100:5.3:3.4 for the Feed, FT and RT sludges, respectively. In all cases, the ratios were slightly larger than the conventional ratio (100:5:1, Metcalf and Eddy (1979)), especially for the nitrogen to phosphorus proportion.

This is consistent with the pilot plant's operation as a bio-nutrient removal plant, as the sludges were expected to have a higher proportion of nutrients, especially phosphorus.

Sporadic measurements of soluble COD in the reactors revealed averages of 50 mg/L for the FT reactor, and 46 mg/L for the RT reactor, respectively. Both reactors had an average TOC concentration of 14 mg/L. The values for both these measurements are consistent with the sludge digestion process, as little soluble carbon was expected to be available, since the reactors operate with the primary source of carbon generated through endogenous metabolism. Carbon that does become available through cell lysis is immediately consumed by other bacteria.

From the outset of this research, dissolved oxygen measurements were considered less important than ORP, due to reactor dynamics at the lab scale. In other words, it was quickly evident that providing identical airflow rates to the two reactors, often produced different D.O. levels in the bulk liquids. Several possible reasons include;

(i) Irregular pore sizes in the diffusing stones;
(ii) Disparate fouling rates of these pores;
(iii) Possible slight discrepancies in the internal diameters of the air tubing; and
(iv) Variations in the solids levels between the reactors.

The above factors acted in concert to produce visually-discernable differences (in terms of bubble size) between the reactors. This translates directly into oxygen transfer efficiency. Furthermore, since bubble size control was beyond simple modifications to the experiment, it mitigated against using equal air flow rates to control air supply. Instead, air control was based upon preserving a relatively stable D.O. liquid level in the reactor (usually between 2 and 4 mg/L during the D.O. plateau portion of the cycle). As can be seen from Table 4.1, the relatively low standard deviation means that the majority of D.O. measurements fell within the required range.

Routine pH monitoring was incorporated as a matter of principle since pH (acting as a "master variable") often provides the first indication of critical disturbances to a system. In AASD research, pH is especially important, since a prime reason for favouring aerobic-anoxic over continuous-aeration methods of treating sludge, is the fact that the consumption of approximately 7.2 mg/L of alkalinity (as $CaCO_3$) (Barnes and Bliss, (1983)), during the endogenous-respiration nitrification reaction ...

$$C_5H_7NO_2 + 5O_2 \Longrightarrow 5CO_2 + NH_3 + 2H_2O \qquad (4.1)$$

$$2NH_3 + 3O_2 \Longrightarrow 2NO_3^- + 6H^+ \qquad (4.2)$$

$$H^+ + HCO_3^- \Longrightarrow H_2CO_3 \qquad (4.3)$$

is balanced by alkalinity generated through denitrification reactions and reactions involving ammonification of organic nitrogen to NH_3 (Warner et al., (1985)).

Table 4.1 indicates that the pH of both reactors maintained a pH in and around the neutral range of 6.5 to 7.5. This is further shown by a plot of the daily variation in pH for the FT (Figure 4.20) and RT (Figure 4.21) reactors, respectively. There does seem to be a slight decrease with time in the pH of both reactors; however, the fairly small amount of fluctuations in the pH level indicate that the alkalinity produced during the anoxic portion of the cycle, was generally sufficient to balance the alkalinity consumed during the aerated portion of the cycle. As mentioned (Section 2.3), the absence of chemical additives to buffer pH is one of the more attractive cost-related features for considering aerobic-anoxic sludge digestion. If, however, the pH continued to decline, perhaps periodic chemical adjustments could be instituted.

In this research, all experiments were conducted at a relatively constant room temperature of 22 $^{o}C \pm 1$ ^{o}C. The impetus for this originates from the Nernst equation, which includes temperature in the denominator of the term preceding the logarithm. If temperature is held relatively constant, then in theory, a measurable change in the ORP potential can be directly attributed to a specific alteration in the ratio of oxidized to reduced species, rather than to a fluctuation in temperature. In practice, the feed sludge was usually slightly cooler than the reactor sludges; however, there was no discernable temperature drop. Thus a decrease in ORP could be ascribed definitively to a change in the ratio of the oxidized to reduced species (in this case the addition of the reducing feed).

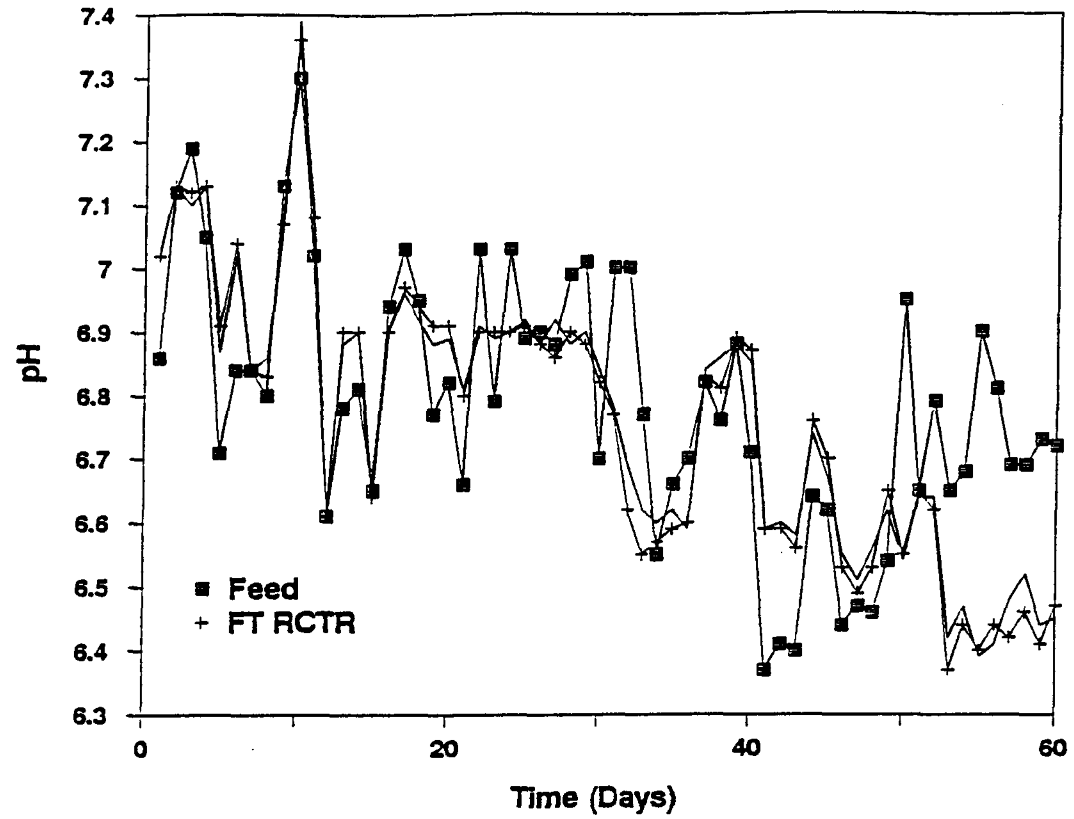


Figure 4.20 Fixed-Time Reactor: pH vs. Time for AASD#1

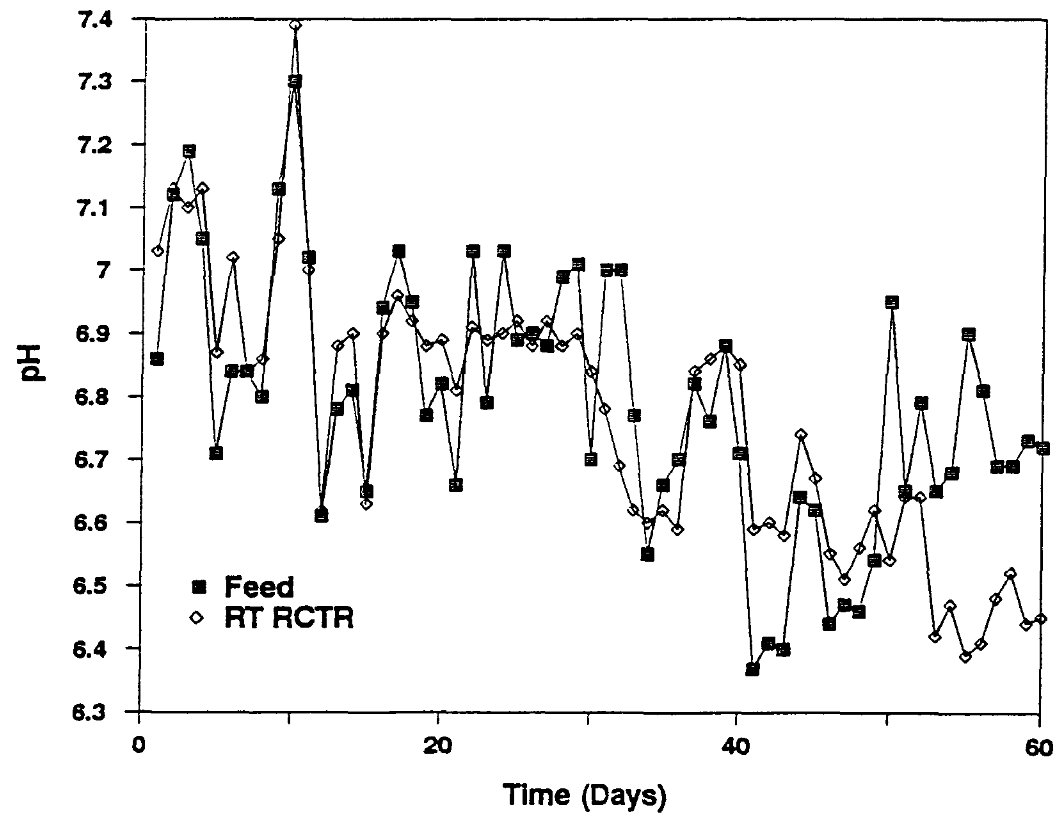


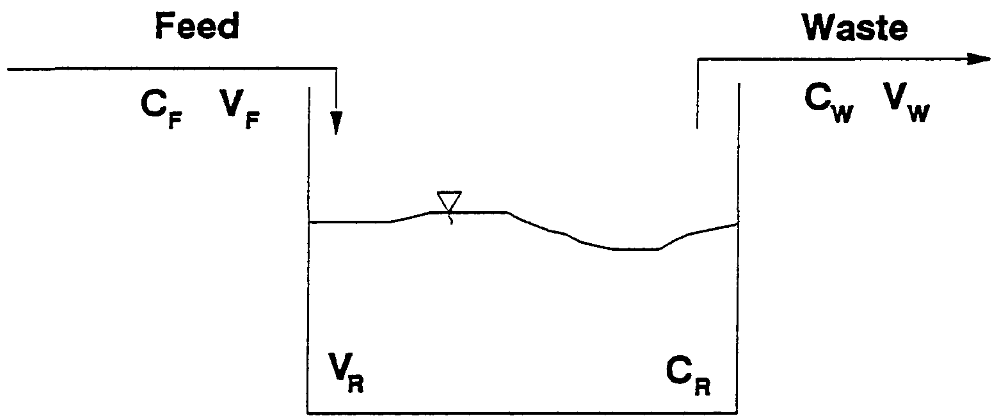
Figure 4.21 Real-Time Reactor: pH vs. Time for AASD#1

4.3.3 Mass Balances: Solids, Nitrogen and Phosphorus

One method of comparing the performance of the two reactors is from a mass balance perspective (Figure 4.22). Both reactors were designed to reduce solids; therefore, since TSS and VSS measurements were made on a daily basis (for both digesters plus feed) any missing solids can be presumed to be degraded by bacterial processes. Similarly, nitrogen (TKN, NO_x, NH_3) was measured daily (with the nitrogen forms both expressed as nitrogen); thus, TKN and NO_x were directly additive and were equal to the total nitrogen entering and exiting the system. Since the pH remained in the neutral range, it is assumed that no stripping of NH_3 occurred and any missing nitrogen is lost solely as nitrogen gas. Phosphorus (TP, Ortho-P) was also measured daily; however, phosphorous should theoretically be conserved since there is no biological mechanism for its removal.

Tables 4.2 and 4.3 summarize the results for each reactor based upon mass balances performed in two distinct manners. The actual calculations have been included in Appendix F. In the tables, the column entitled "Overall Mass Balance" refers to a summation period incorporating days 1 through 60, while the column entitled "Moving Average Balance" involves averaging the results from multiple balance periods, each equivalent in length to one 10-day SRT period (i.e. First SRT - Days 1-10, Second SRT - Days 2-11, etc.). As is evident in both tables, the two methods yield similar results for solids degradation (in terms of TSS and VSS) and nitrogen removal. The

C_F = Concentration of Parameter in Feed Sludge
V_F = Daily Volume of Feed Sludge
C_R = Concentration of Parameter in Reactor
V_R = Volume of Reactor
C_W = Concentration of Parameter in Waste
V_W = Volume Wasted per Day
$\triangle(C_R x V_R)$ = Change in Reactor Parameter Over Sampling Period
(+) ---> Increase ; (-) ---> Decrease



$$\% \text{ Reduction} = \frac{\Sigma[(C_F)(V_F)] - \Sigma[(C_W)(V_W)] - \Delta[(C_R)(C_R)]}{\Sigma[(C_F)(V_F)]} \text{ X } 100$$

Figure 4.22 General Case of Mass-Balance Around Reactor
(Adapted from Koers, (1979))

Table 4.2 Mass Balances for Fixed-Time Reactor: AASD#1

Mass Balance Parameter Percent Reduced	Moving Average Balance Wareham (1991)	Moving Average Balance Jenkins et al. (1989a)	Overall Mass Balance Wareham (1991)	Overall Mass Balance Jenkins et al. (1989a)
TSS	14.7 %	12.5 %	15.8 %	------
VSS	16.8 %	14.0 %	17.7 %	14.6 %
Total N	17.5 %	------	17.9 %	12.5 %
Total P	-6.5 %	------	-6.2 %	1.4 %

Table 4.3 Mass Balances for Real-Time Reactor: AASD#1

Mass Balance Parameter Percent Reduced	Moving Average Balance Wareham (1991)	Moving Average Balance Jenkins et al. (1989a)	Overall Mass Balance Wareham (1991)	Overall Mass Balance Jenkins et al. (1989a)
TSS	15.2 %	------	15.7 %	------
VSS	18.0 %	------	18.3 %	------
Total N	19.5 %	------	21.1 %	------
Total P	-6.9 %	------	-5.8 %	------

relatively low percentage removals for both solids and nitrogen were not unexpected, since the reactors were operated at such a short SRT.

For comparative purposes, the work of Jenkins and Mavinic (1989a) is also presented. In their study (comparing continuously aerated versus aerobic-anoxic digestion), one of the reactors was operated in a Fixed-Time fashion (albeit with a cycle partition of 2.5 hours air-on/3.5 hours air-off). The values quoted in Table 4.2 are those reported for the same SRT (10 days) and an equivalent temperature (20 °C). It is apparent that the removals obtained for both solids and nitrogen in the AASD#1 experiments, compare well with the study by Jenkins and Mavinic (1989a), being a few percentage points higher for both solids and nitrogen.

The phosphorus mass balance for this experiment recorded an apparent increase of 6 percent. The order of magnitude of this error is typical of the TP digestion technique used; since other researchers, (Jenkins (1988), Elefsiniotis (1992)) have reported similar difficulties with closing the phosphorus loop. It should be noted that the relatively small closing error that Jenkins and Mavinic (1989a) report for phosphorus, is more singular than characteristic of their results. As they acknowledge, all the phosphorus can be accounted for within experimental error, with a recovery range of 77-99 %. Thus, although one reactor closed within 1 % (co-incidentally it is the aerobic-anoxic reactor considered in this comparison), the range quoted also means that one reactor closed within 23 percent. In fact, of the 18 phosphorus mass balances presented in the original research (Jenkins 1988), only seven (40 %) closed with less than 6 percent. Thus, an average of all phosphorus mass balances presented in their work reveals a phosphorus closing error of 8.6 percent. This latter number more closely aligns itself with the order-of-magnitude phosphorus error arrived at in this study.

A comparison between Fixed-Time and Real-Time Control reactors indicates that both reactors performed essentially the same in terms of solids degradation (both TSS and VSS). Superficially, it seems that the Real-Time reactor performed slightly better in relation to nitrogen removal (up to 3 % using the overall mass balance method); however, the difference is not thought to be substantial enough to form any non-debatable conclusive statements.

Thus, as a criteria to evaluate the overall performance of the two reactors, the mass balances associated with solids, nitrogen and phosphorous do not convincingly reveal a distinguishable difference between the two reactors. Instead, this method indicates that both reactors were comparable in terms of their removal efficiencies, with the Real-Time Control reactor perhaps (but not definitely) performing marginally better in terms of nitrogen removal.

4.3.4 Evaluation: Unsteady Process Input Conditions

The second method of comparing the performance of the two reactors is to investigate the probe behaviour, when the reactor contents are subjected to transitory stresses. This concurrently evaluates the suitability of the ORP probe as a control parameter. Accordingly, the reactors received (on a mass basis) "low" and "high" spikes of sodium nitrate, ammonium chloride and hydrogen peroxide in order to simulate unsteady process input conditions.

Tables 4.4, 4.5 and 4.6 outline the timing and concentrations of the various spikes. Note that a "high" spike is defined as having 3 times the mass of chemical added as the "low" spike. Samples were removed from the reactors prior to, and immediately following the spikes, after allowing two to five minutes for adequate mixing and dispersion of the chemicals. Figures 4.23 through 4.28 show selected vignettes of the ORP response to the various spikes with some of the more pertinent statistics recorded on each figure.

These figures can best be explained by tabulating for each reactor, the number of deviations (over the entire run) from the ideal curve shapes indigenous to the Fixed-Time (Figure 4.1) and Real-Time (Figure 4.2) control operating strategies. Deviations from the "norm" can then be classified as "failures", since in the majority of instances, they represent a failure to complete a biological reaction.

For example, in this run, 3 major categories of failures exist, most of which can be linked to chemical spikes. The first class refers to "Incomplete Denitrification" and occurs when there is no discernable nitrate breakpoint in the ORP-time profile. No nitrate breakpoint means that insufficient time existed for the micro-organisms to fully eliminate the

Table 4.4 Particulars of Sodium Nitrate Spikes: AASD#1

Reactor Date Day Number	FT July/11/90 23	RT July/11/90 23	FT Aug/6/90 49	RT Aug/6/90 49
Sampled Nitrate Air On (Hr:Min) Concentration[1]	3:10 pm 2:05 2.02 mg/L	5:10 pm 1:30 1.50 mg/L	1:20 pm 1:35 1.68 mg/L	10:00 am 1:30 2.34 mg/L
Time of Spike Amount[2]	3:25 pm 43.2 mg	5:10 pm 43.2 mg	1:20 pm 129.6 mg	10:10 am 129.6 mg
Sampling Time Concentration[1]	3:30 pm 4.09 mg/L	5:15 pm 3.46 mg/L	1:25 pm 7.02 mg/L	10:15 am 8.09 mg/L

[1]Concentration is measured as NO_3-N mg/L
[2]Amount is on a weight basis as Sodium Nitrate

Table 4.5 Particulars of Ammonium Chloride Spikes: AASD#1

Reactor Date Day Number	FT July/13/90 25	RT July/13/90 25	FT Aug/9/90 52	RT Aug/9/90 52
Sampled Ammonia Air Off(Hr:Min) Concentration[1]	5:20 pm 0:55 0.41 mg/L	2:55 pm 0:55 0.39 mg/L	4:35 pm 1:25 0.59 mg/L	2:40 pm 1:25 0.56 mg/L
Time of Spike Amount[2]	5:25 pm 43.2 mg	3:00 pm 43.2 mg	4:40 pm 129.6 mg	2:45 pm 129.6 mg
Sampling Time Concentration[1]	5:30 pm 1.37 mg/L	3:05 pm 1.27 mg/L	4:45 pm 6.68 mg/L	2:50 pm 6.43 mg/L

[1]Concentration is measured as NH_3-N mg/L
[2]Amount is on a weight basis as Ammonium Chloride

Table 4.6 Particulars of Hydrogen Peroxide Spikes: AASD#1

Reactor Date Day Number	FT Aug/12/90 55	RT Aug/12/90 55	FT Aug/15/90 58	RT Aug/15/90 58
Sampled D.O. Air On(Hr:Min) Concentration[1]	2:00 pm 1:30 1.60 mg/L	3:10 pm 1:30 1.40 mg/L	2:15 pm 1:30 2.70 mg/L	3:10 pm 1:30 3.75 mg/L
Feed	2:50 pm	3:40 pm	2:25 pm	3:15 pm
Sampled D.O. Air On(Hr:Min) Concentration[1]	3:15 pm 2:45 0.75 mg/L	3:55 pm 2:15 0.80 mg/L	2:45 pm 2:00 1.50 mg/L	3:35 pm 1:55 2.20 mg/L
Time of Spike Amount[2]	3:15 pm 1 mL	3:55 pm 1 mL	2:45 pm 3 mL	3:35 pm 3 mL
Sampling Time Concentration[1]	3:17 pm 3.80 mg/L	3:57 pm 3.70 mg/L	2:47 pm 10.6 mg/L	3:37 pm 10.8 mg/L

[1]Concentration measured as Dissolved Oxygen (mg/L)
[2]Amount is based on a volume of 3% weight/volume H_2O_2

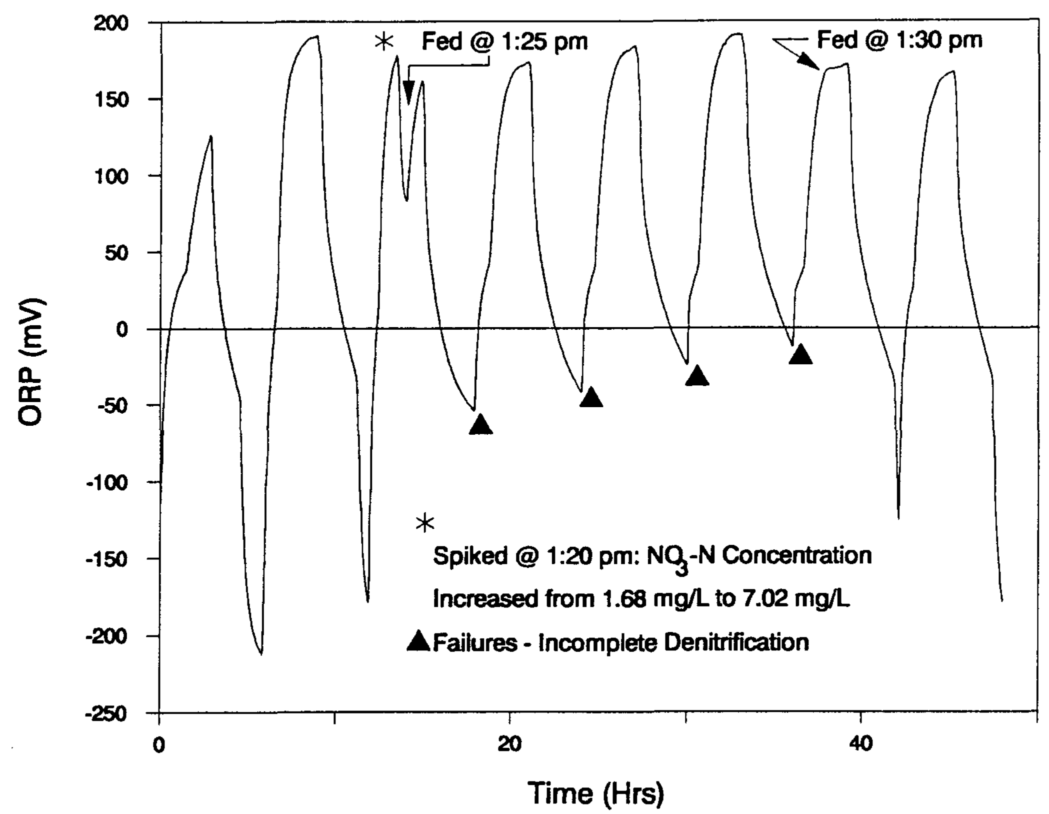


Figure 4.23 High Spike of Sodium Nitrate to FT Reactor: AASD#1

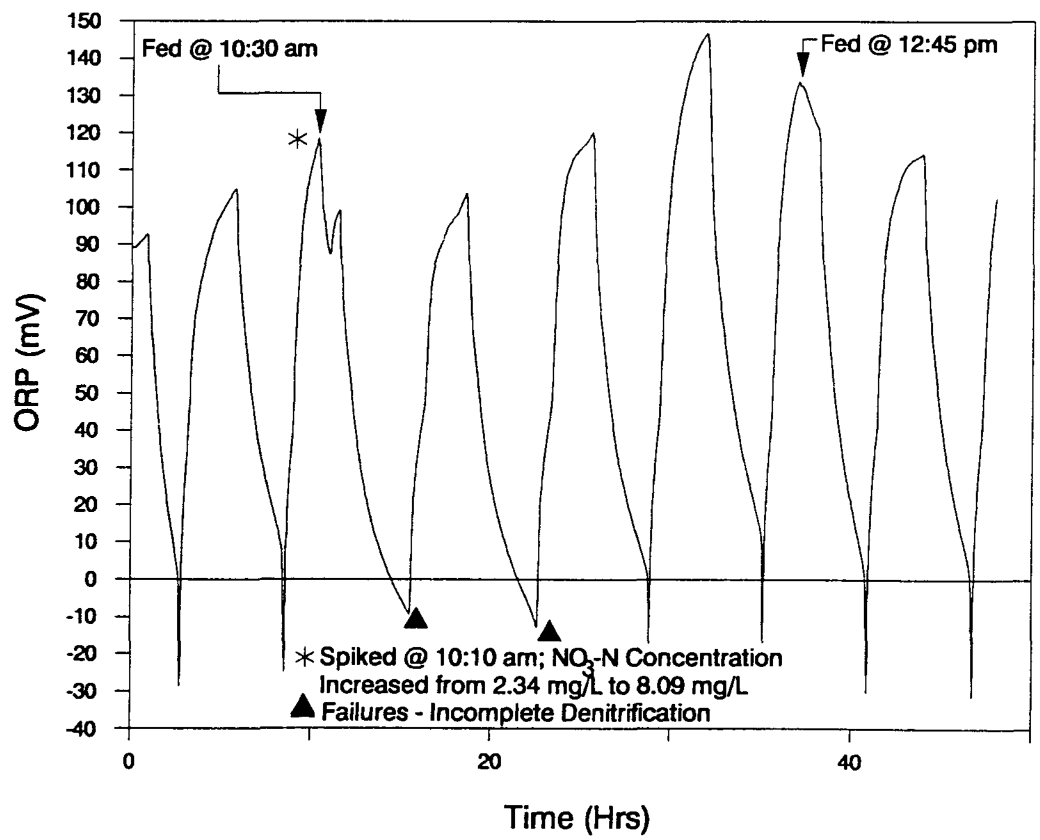


Figure 4.24 High Spike of Sodium Nitrate to RT Reactor: AASD#1

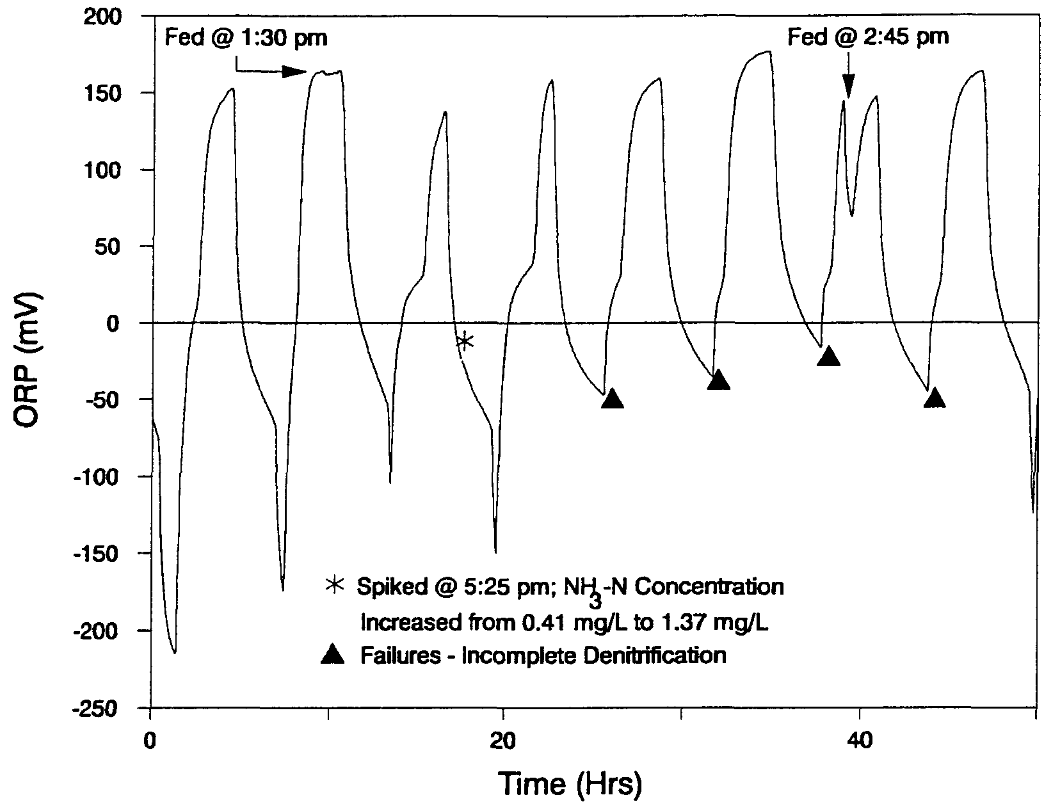


Figure 4.25 Low Spike of Ammonium Chloride to FT Reactor: AASD#1

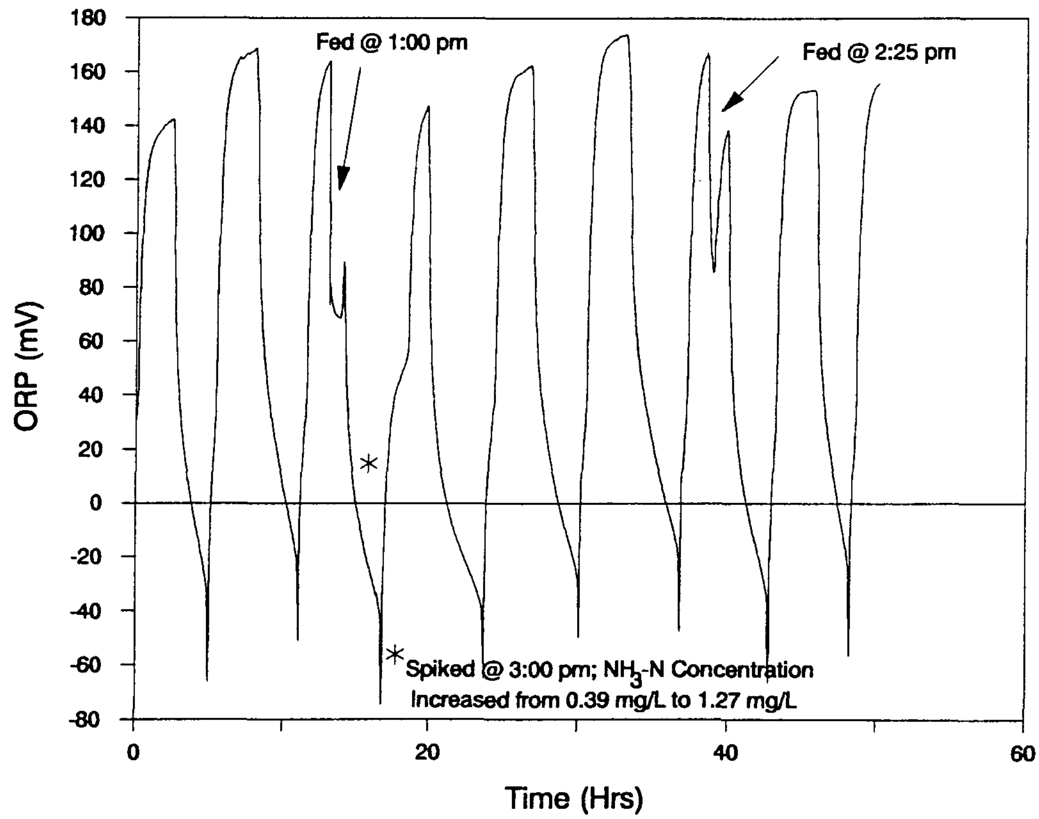


Figure 4.26 Low Spike of Ammonium Chloride to RT Reactor: AASD#1

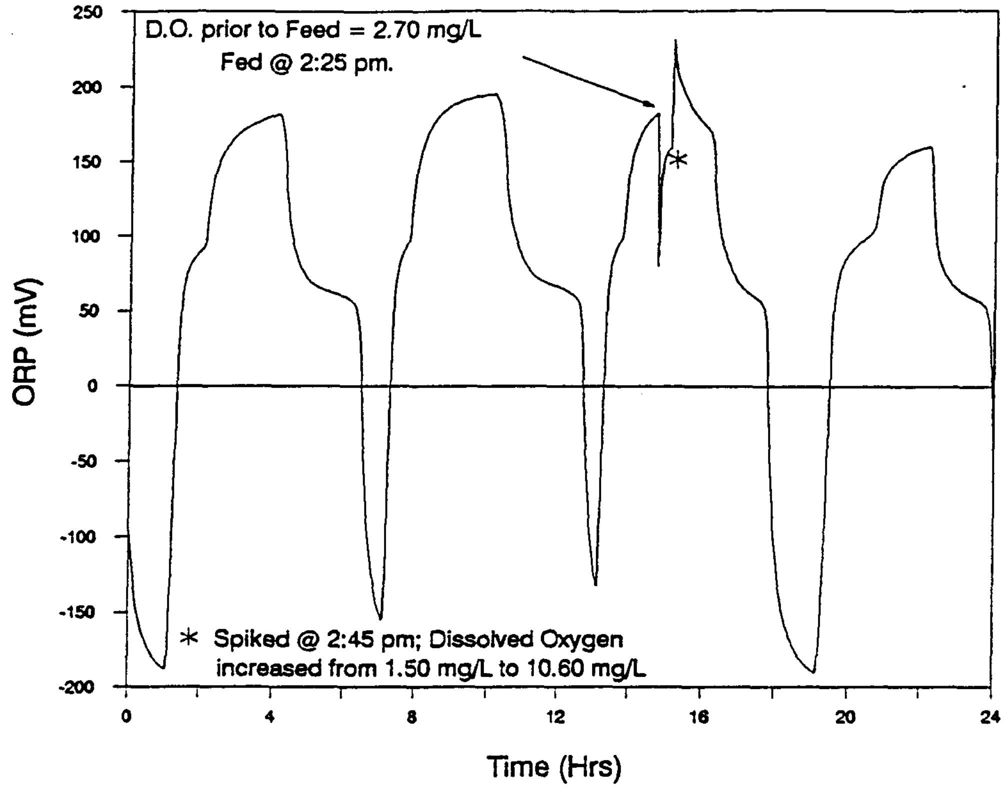


Figure 4.27 High Spike of Hydrogen Peroxide to FT Reactor: AASD#1

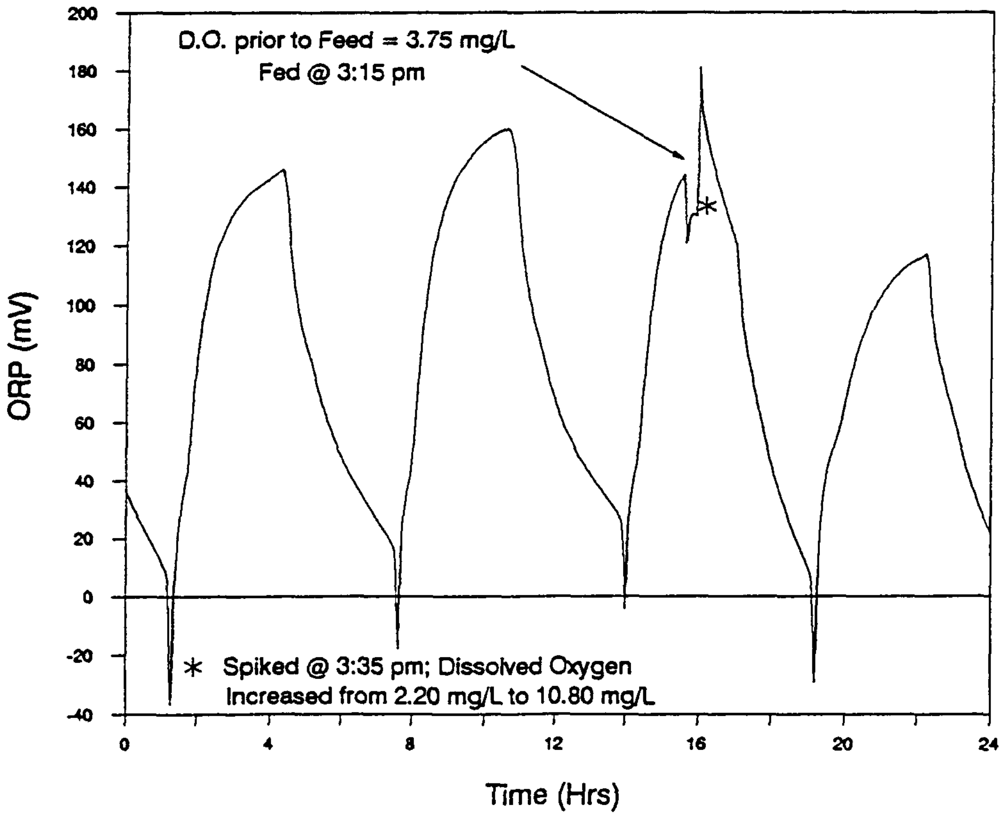


Figure 4.28 High Spike of Hydrogen Peroxide to RT Reactor: AASD#1

nitrates. These failures are characterized by the solid, triangular marks noted on the previous six figures. In Figures 4.23 and 4.24, the failures result from an elevated level of nitrate caused by the disassociation of sodium nitrate. In Figure 4.25, they are caused by the inability of the denitrifiers to eliminate the nitrates generated by nitrification of ammonia originally in the form of ammonium chloride. Note that the addition of a particular spike may cause failures in a number of subsequent cycles, as the reactor seeks to recover from the effect of the stress.

The second category of failure is the converse of the above and is associated with "Incomplete Nitrification" as depicted in Figure 4.29 (solid rectangular mark). This failure, caused by elevated levels of ammonia in the system, is reflected in the absence of the dissolved oxygen breakpoint in the ORP-time curve. There is no "breakthrough" of oxygen because insufficient time exists for the nitrifiers to reduce the ammonia to a low enough level to allow free residual oxygen to become present.

The final failure category (Figure 4.30), is particular to the Real-Time reactor alone and is a failure in the more conventional sense, since the software "failed" by detecting a false nitrate knee (Figure 4.30, solid circular mark). Daily fluctuations in the air supply rate and solids loading, sometimes resulted in excess air entering the system relative to the mass of solids present in the reactor. The resulting over-oxidation of the sludge was reflected in the slow

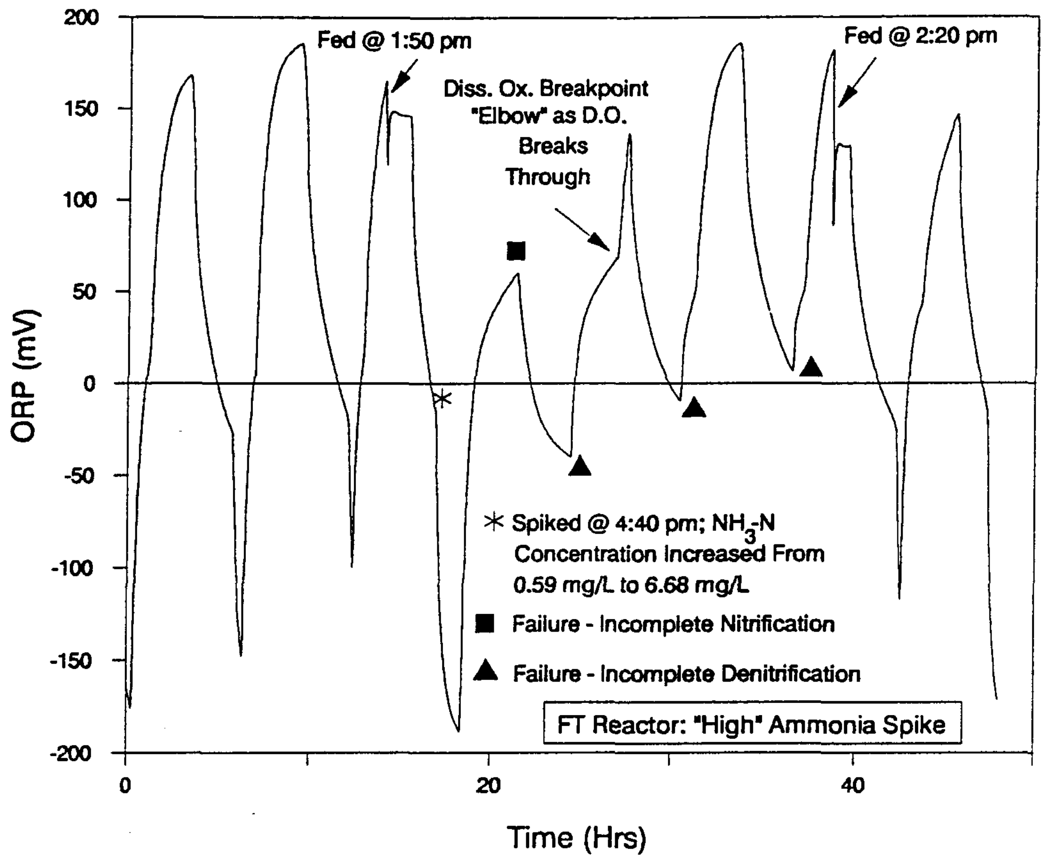


Figure 4.29 Typical "Incomplete Nitrification Failure"

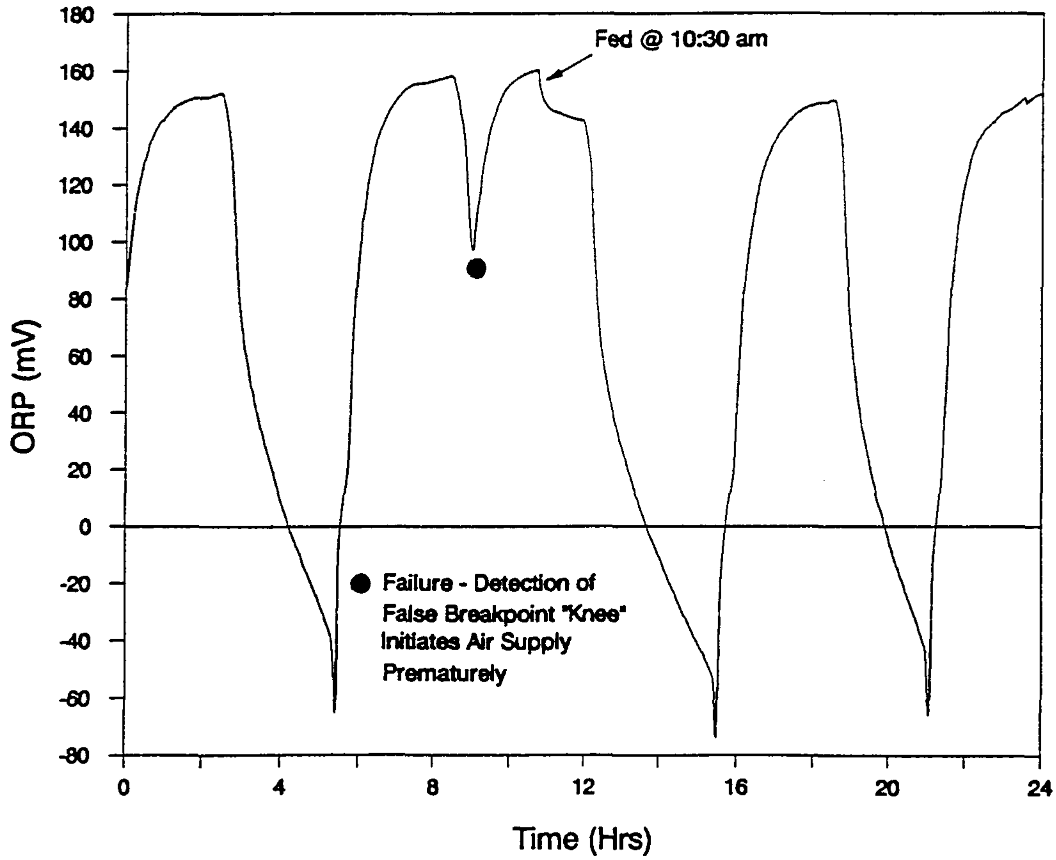


Figure 4.30 "False-Knee" Failure In Real-Time ORP Profile

rate at which the ORP value declined, after the air supply was halted. If the rate was excessively slow, the MAXAVOID window (the variable used to delay the search for the breakpoint until air had bled from the line and stability had been achieved) was in essence, prematurely "used up" by little, if any, changes in the ORP value with time. This was especially common if the probe was dirty and/or unresponsive. Thus, by the time the true decline began, the RingBuffer was often partially filled with horizontal (i.e. zero ORP slope change) values. The sudden change, as the true descent commenced (i.e the reactor truly entered anoxic conditions), sometimes was sufficiently steep enough to exceed the DELTA limit, (registering a knee-like feature) and triggering the air solenoid.

It is evident that there are several ways to remedy this problem, most notably the mechanical methods such as cleaning the probes, attempting to better match the air supply to the solids loading (reduce the air/solids ratio) or deliberately thickening the feed sludge so that the ORP curve declines more rapidly (increasing the solids/air ratio). Controlling the air supply is at the best of times difficult at the lab scale, while increasing the solids loading is somewhat artificial and may not always be possible. Thus, these two methods were not seriously considered. Furthermore, cleaning the probes produced intermittent success depending on how much the fouling actually contributed to the lack of decline in the ORP curve.

The other two ways of reducing these types of failures were software-based and involved tightening the knee constraint and/or expanding the window capacity of the variable MAXAVOID. Of the two options, expanding MAXAVOID represented a more certain means of success, since tightening the knee constraint would ideally involve some experimental trials, being a reactive rather than a proactive method of eliminating the problem. Currently, the program is not flexible enough to interactively shorten the length of the MAXAVOID window; however, the program was quickly recompiled (after the window was expanded from 16 to 30 minutes) and this eliminated the problem.

Regardless of the solution chosen, it is clear that these types of failures could be reduced or even circumvented with more sophisticated programming techniques and/or better detection algorithms.

In terms of some general comments, it is noted that "Incomplete Denitrification" was by far the most common failure. It is also evident that the hydrogen peroxide spikes produced no failures of any kind. Other stresses included the addition of "stale" feed which referred to a period of two consecutive days in which the same sludge was used to feed the reactors thus allowing NH_3 in the feed to build-up through hydrolysis of organic nitrogen. With regards to the period in which the feeding process was omitted (already alluded to in Figure 4.15), Figures 4.31 and 4.32 show the FT and RT reactor responses to this type of stress. The Fixed-Time reactor logged four "Incomplete Denitrification" failures, while the Real-Time

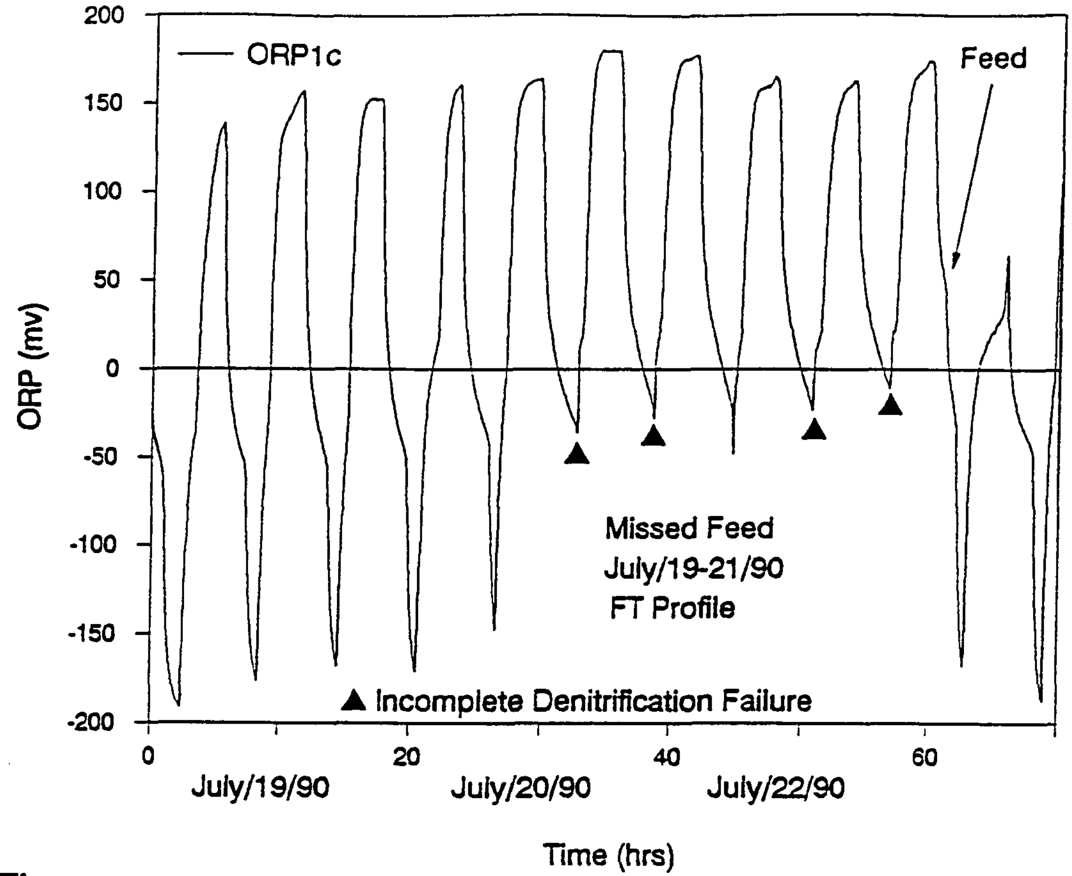


Figure 4.31 Fixed-Time Reactor Response to Missed Feed: AASD#1

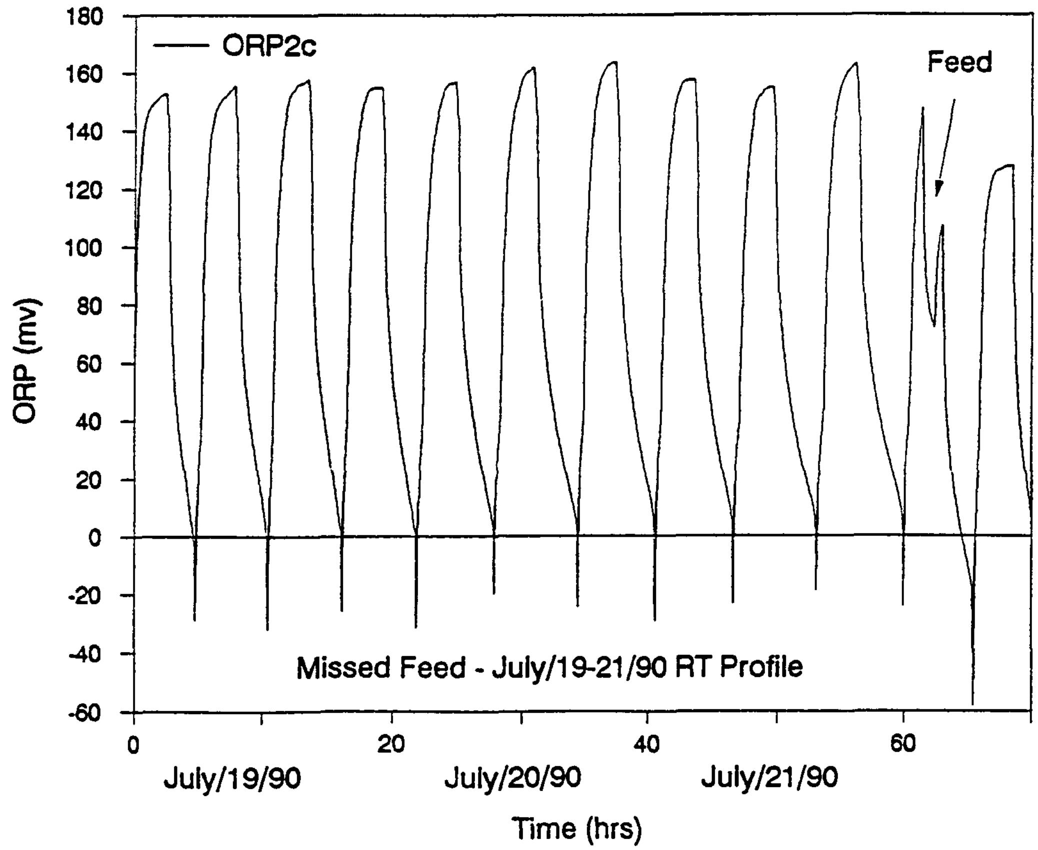


Figure 4.32 Real-Time Reactor Response to Missed Feed: AASD#1

reactor because of its flexibility, easily accommodated this disturbance.

Tables 4.7 and 4.8 summarize the number of occurrences, over the 60 day period, of each of the three categories of failures. The total number of cycles during the run was 231 for the Fixed-Time and 246 for the Real-Time Control reactors respectively. Thus, using the data from Tables 4.7 and 4.8, the Fixed-Time reactor failed 9.5 % of the time (22 failures) while the Real-Time reactor failed only 5.3 % of the time (13 failures). Furthermore as mentioned, many of the Real-Time reactor failures were software-based and could have been circumvented with more sophisticated detection algorithms.

Thus, a comparative evaluation based upon a "failures" criteria, indicates that the Real-Time reactor outperformed the Fixed-Time reactor during AASD#1 by more readily accommodating and recovering from the stresses considered in this research.

4.4 Behaviourial Trends: AASD#2 Experimental Conditions

4.4.1 Operating Characteristics and ORP Profiles

As mentioned in Section 3.4.2, the second AASD operating strategy consisted of comparing two reactors, both operating in a 50/50 air-on/air-off fashion. The Fixed-Time reactor retained its original ratio for each segment (i.e 3 hours for air-on, 3 hours for air-off); thus, there was a total of four, 6 hour cycles/day. Its characteristic profile was identical to that generated under AASD#1 operating conditions (i.e. Figure 4.1).

Table 4.7 Failures Associated with FT Reactor Operation: AASD#1

Type of Stress	Incomplete Denitrification Failure	Incomplete Nitrification Failure	False Nitrate Breakpoint Failure	Total Number
Normal Operation	3	1	0	4
Sodium Nitrate Spikes	4	0	0	4
Ammonia Chloride Spikes	7	1	0	8
Hydrogen Peroxide Spikes	0	0	0	0
Ommission of Daily Feed	4	0	0	4
Addition of Stale Feed	2	0	0	2
Total Number of Failures	20	2	0	22

Table 4.8 Failures Associated with RT Reactor Operation: AASD#1

Type of Stress	Incomplete Denitrification Failure	Incomplete Nitrification Failure	False Nitrate Breakpoint Failure	Total Number
Normal Operation	2	0	5	7
Sodium Nitrate Spikes	2	0	0	2
Ammonia Chloride Spikes	3	1	0	4
Hydrogen Peroxide Spikes	0	0	0	0
Ommission of Daily Feed	0	0	0	0
Addition of Stale Feed	0	0	0	0
Total Number of Failures	7	1	5	13

The Real-Time reactor's operation consisted of matching the time for aeration to the previous anoxic period length, as determined by the detection of the nitrate knee. Figure 4.33 portrays the "switch-over" day from Fixed-Time to Real-Time conditions, and depicts the rapid development of a distinctive pattern, reflecting the tendency of the Real-Time reactor to "collapse" in on itself, with very short on/off times for both the aerated and non-aerated portions of the cycle. Consequently, as Figure 4.34 illustrates, the characteristic profile associated with AASD#2 Real-Time conditions, consists of a vastly reduced total cycle time, (very brief air-on and air-off sequences), with the shortest sequence immediately after feeding, followed by a gradual lengthening throughout the day.

The fluctuations in the cycle length are better illustrated in Figures 4.35 and 4.36. These figures track the cycle over two days in which the feeding process was omitted. Figure 4.35 has 13 complete cycles, while the next day (Figure 4.36), is comprised of only 7 cycles. The expansion in the cycle length over the course of a day is directly attributable to a depletion in readily available carbon in the system. Concurrently, there is a gradual rise in the peak absolute ORP value associated with each cycle, and this is also due to exhaustion of carbon from the system.

The short cycle time made it difficult to accurately distinguish the "classic" features of the ORP-time curve, thus some interpretation has been necessary for this analysis. Moreover, the brevity of the cycle time (after feeding),

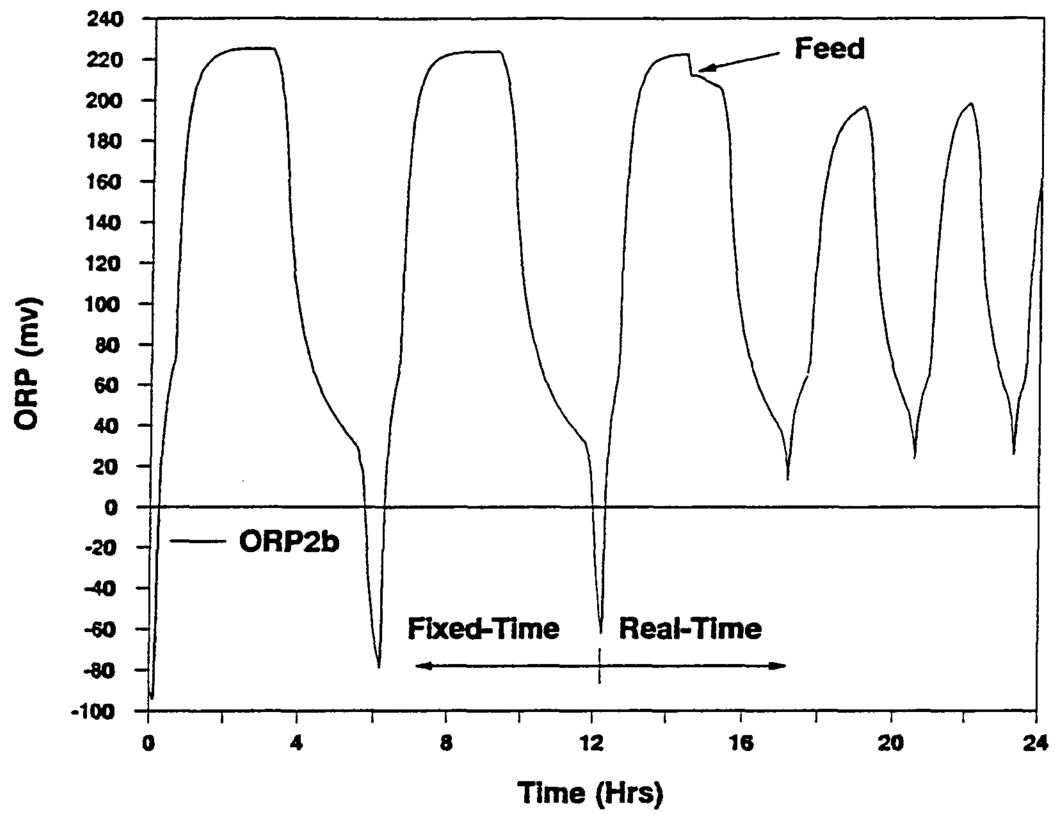


Figure 4.33 "Switch Over Day": FT to RT Control - AASD#2

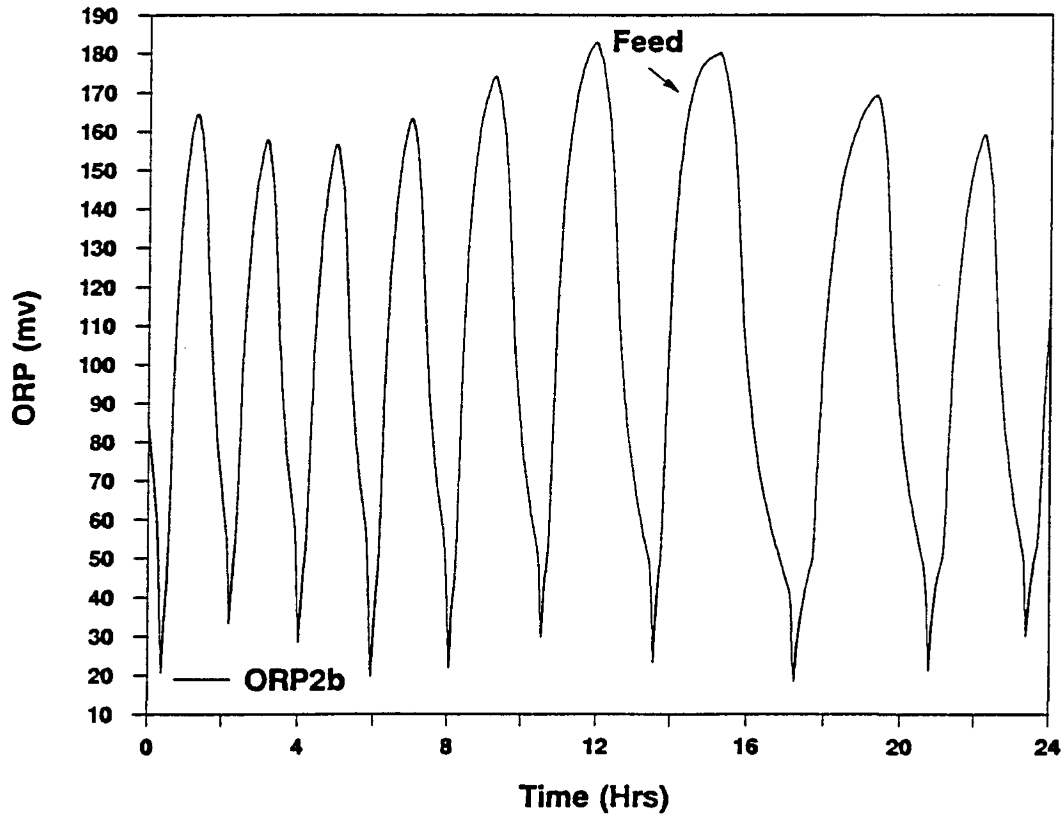


Figure 4.34 Real-Time ORP Profile Under AASD#2 Conditions

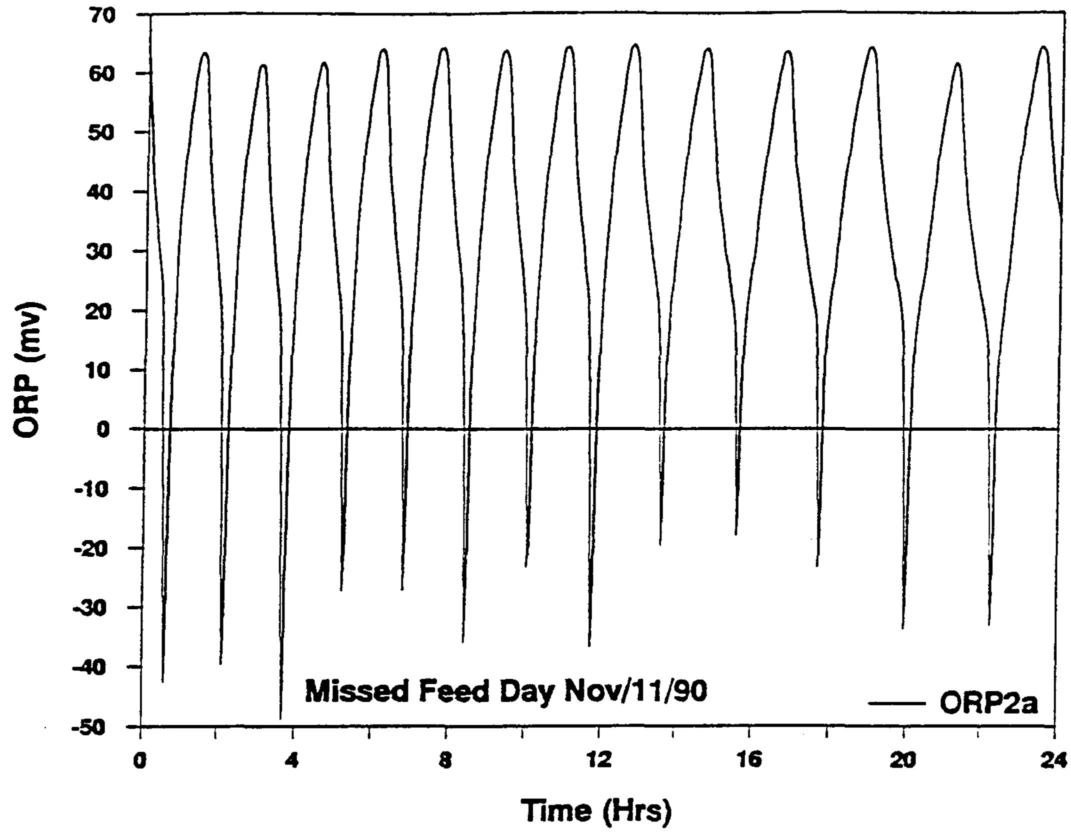


Figure 4.35 RT Profile AASD#2 - Missed Feed Day Nov/11/90

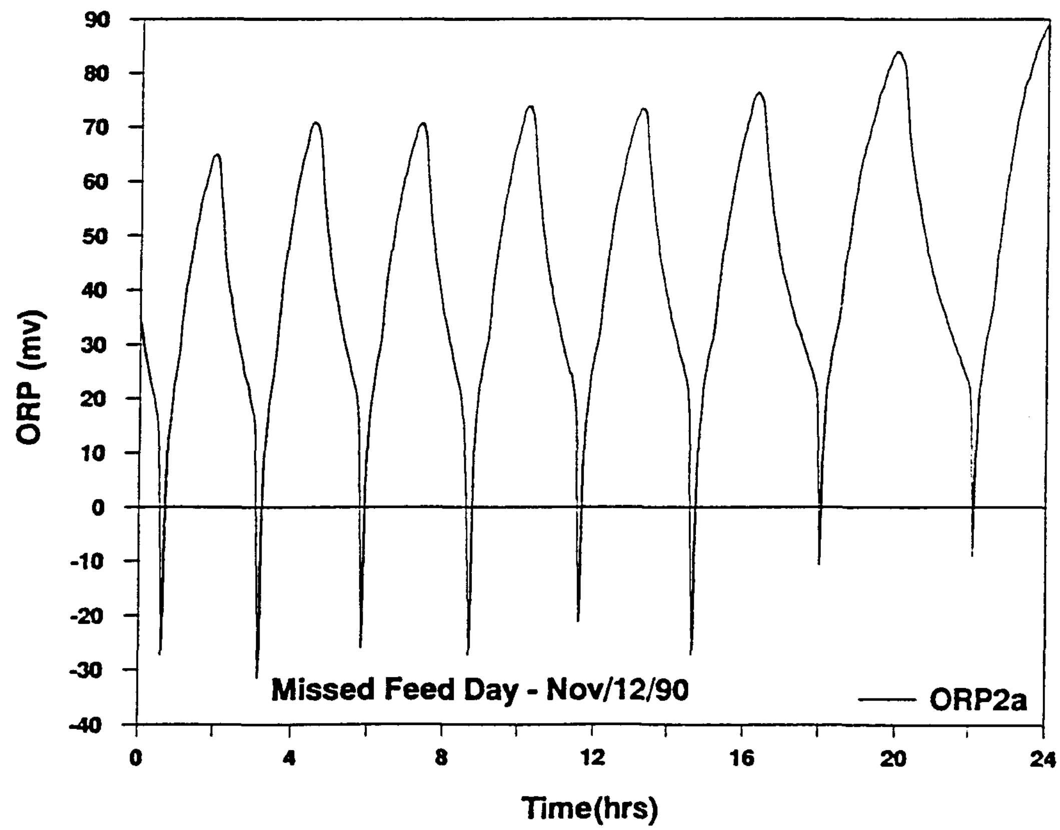


Figure 4.36 RT Profile AASD#2 - Missed Feed Day Nov/12/90

eventually led to a new software-based "failure" category, in which the program "failed" to locate the breakpoint, by actually physically "missing" the nitrate knee (Figure 4.37). This stands in contradistinction to the AASD#1 "False-Knee" failure in which the computer "failed" by detecting a non-existent knee, attributable to the excessively slow decline in the ORP-time curve.

As Figure 4.37 illustrates, during the 6^{th} cycle of the day, the steep gradient of the ORP-time curve means that the knee occurred almost immediately upon cessation of air . The computer therefore "missed" the knee entirely and the reactor proceeded into truly anaerobic conditions. After 4 hours, the "intelligence" built into the program reactivated the air supply, since the computer "assumed" the knee had been missed. Consequently, the next aeration period was also 4 hours as the computer adhered to its 50/50 operating strategy. Subsequent to this, the cycle lengths shortened once again, and eventually, a daily recursive pattern developed revolving around one "Missed-Knee" failure a day, with the occasional two such failures in a single day (Figure 4.38).

The rationale for this failure is the reverse of that proposed for the "False-Knee" failures of AASD#1. The rapid decline in the ORP curve means that the MAXAVOID variable, (which ordinarily is used to delay the search for the knee), is in reality, comprised of points which should be entering the Ring-Buffer for purposes of detecting the nitrate breakpoint. By the time the Ring-Buffer actually starts filling, the breakpoint

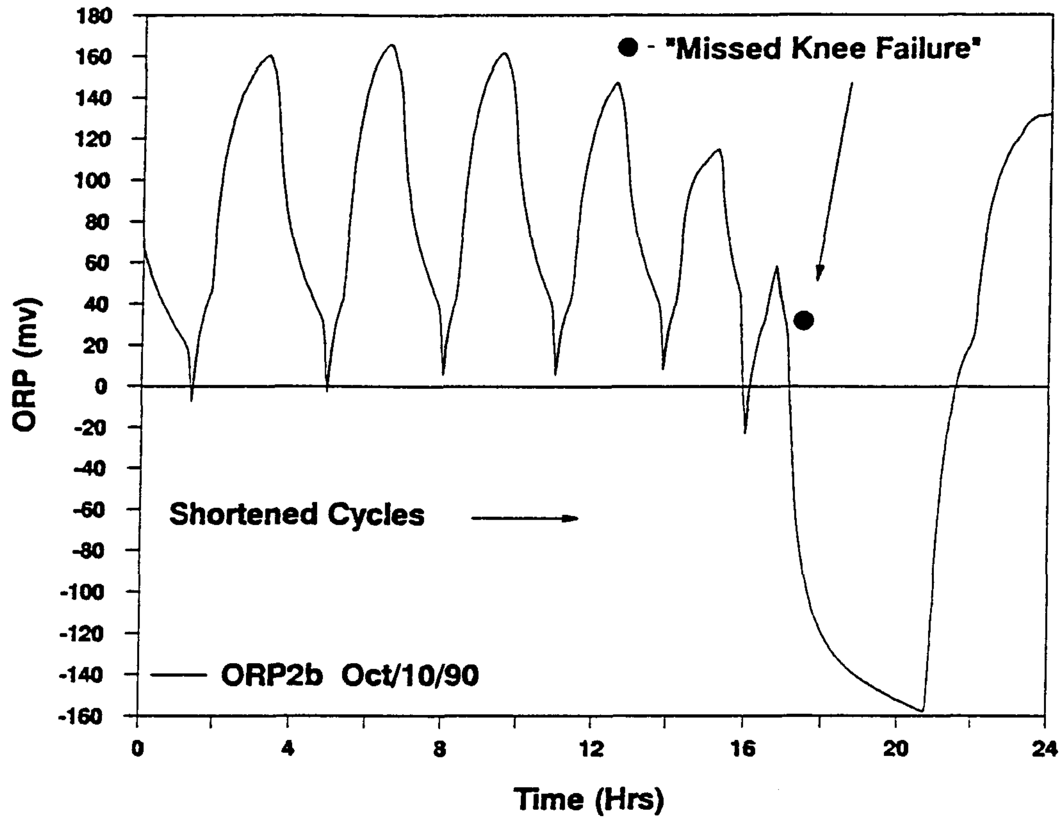


Figure 4.37 "Missed-Knee" Failure in Real-Time ORP Profile

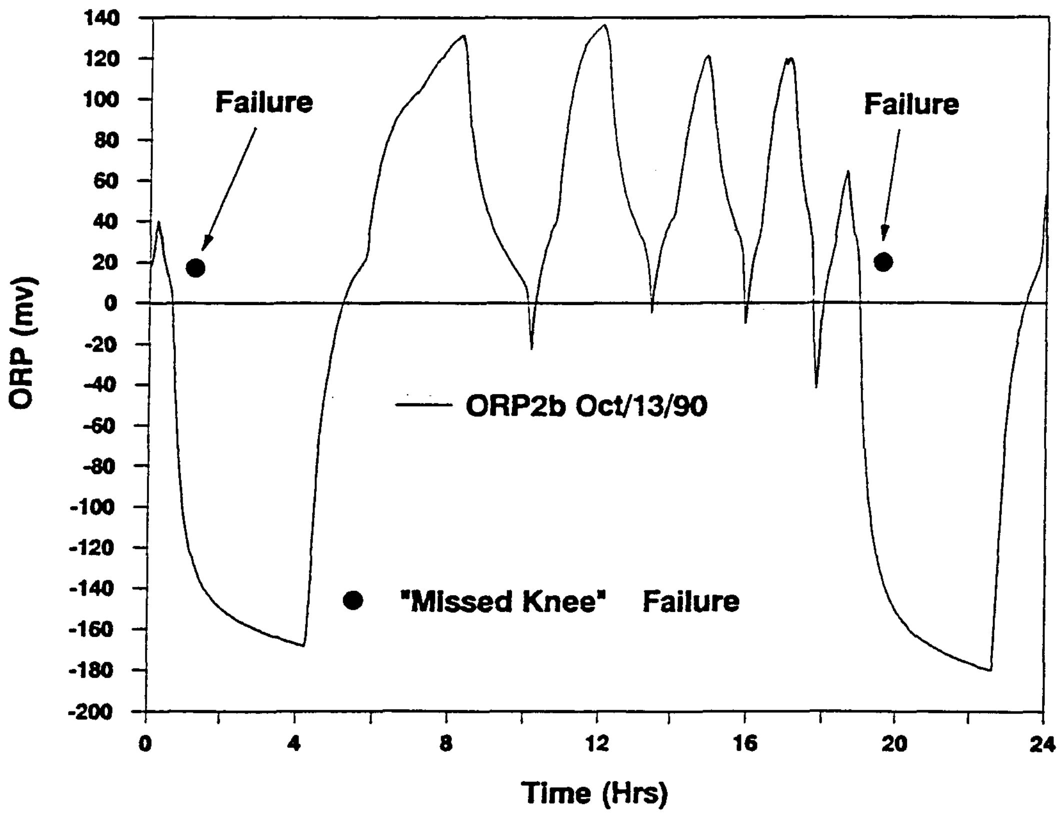


Figure 4.38 Two "Missed-Knee" Failures During Single Day

has already occurred and consequently the computer cannot capture the knee. In order to reduce the number of "Missed-Knee" failures, the variable MAXAVOID was shortened from 30 minutes to 10 minutes (instead of lengthening it, as was done in AASD#1). This remedy, however, was not entirely successful in eliminating all of the failures of this kind, since occasionally denitrification occurred extremely rapidly after cessation of air. Clearly evident however, from both figures, is the ability of the Real-Time reactor to rapidly recover from this kind of failure, in the sense of again developing the short-cycle pattern.

4.4.2 General Observations: Chemical Parameters

The chemical parameters measured during AASD#1 were also recorded for AASD#2 and the data has been relegated to Appendix E with a summary table depicted in Table 4.9. It should be noted that the reactors were spiked with potassium cyanide (56 mg/L) on the third last day of the run (after sampling); thus, the reactor statistics (Table 4.9) do not include the final and penultimate days, since certain variables were unduly influenced by the KCN spike. For example, for both reactors, the ortho-P suddenly increased by approximately 20 mg/L as the cells lysed, while the dissolved oxygen level rose by approximately 3 mg/L, as the demand for oxygen declined.

The majority of observations made about the AASD#1 chemical data set are equally applicable to the data obtained from AASD#2. For example, the stochastic nature of the influent feed TSS and VSS solids (as compared to the relatively stable

Table 4.9 Selected List of Chemical Statistics: AASD#2

Chemical Parameter	Statistic	FEED	Fixed-Time Reactor	Real-Time Reactor
TSS (mg/L)	Maximum	10610	6772	6820
	Mean	6547	6039	5931
	Minimum	4040	4904	4942
	Std.Dev.	1372	362	470
VSS (mg/L)	Maximum	8466	5350	5442
	Mean	5376	4826	4748
	Minimum	3362	4122	3954
	Std.Dev.	1109	281	367
TKN (mg/L)	Maximum	734	528	530
	Mean	480	441	430
	Minimum	294	352	336
	Std.Dev.	92	38	41
NOx-N (mg/L)	Maximum	6.74	4.05	5.05
	Mean	1.29	1.25	0.73
	Minimum	0.07	0.09	0.14
	Std.Dev.	1.55	0.77	0.74
NH_3-N (mg/L)	Maximum	11.20	0.71	0.89
	Mean	1.14	0.26	0.16
	Minimum	0.04	0.00	0.02
	Std.Dev.	2.52	0.23	0.15
TP (mg/L)	Maximum	425	306	317
	Mean	215	260	258
	Minimum	116	216	212
	Std.Dev.	50	25	27
Ortho-P (mg/L)	Maximum	22.26	73.09	75.94
	Mean	3.07	60.15	63.56
	Minimum	0.06	48.41	47.71
	Std.Dev.	4.54	4.63	4.38
Dissolved Oxygen (mg.L)	Maximum	----	5.30	4.60
	Mean	----	3.12	2.49
	Minimum	----	0.70	1.00
	Std.Dev.	----	0.93	0.82
Alkalinity (mg/L) (as $CaCO_3$)	Maximum	256	176	180
	Mean	185	146	146
	Minimum	128	120	110
	Std.Dev.	28	15	15
pH	Maximum	7.37	6.78	6.88
	Mean	6.89	6.56	6.54
	Minimum	6.57	6.36	6.28
	Std.Dev.	0.18	0.11	0.12

reactor values (Figure 4.39 and 4.40)), the constant and parallel nature of the VSS/TSS ratio (averages of 0.82, 0.79, and 0.80, for the Feed, Fixed-Time, and Real-Time reactors were calculated), and the speciation and behaviour of the nitrogen forms (as a function of the air being on or off) were all similar in nature to the AASD#1 run. The C:N:P ratios for the Feed, Fixed-Time and Real-Time sludges were 100:5.66:2.41, 100:5.69:2.50, and 100:5.61:2.48, and again the comments made in discussing the results from AASD#1 are equally valid here.

Figures 4.41 and 4.42 show the profiles with time of total nitrogen, and total phosphorus. Inside the reactors, both parameters (nitrogen and phosphorus) show a decrease with time over the course of the digestion period. The TSS (and VSS by implication of its constant ratio) also exhibited this trend. The decline of the reactor solids and total nitrogen levels is logical in that there are biological mechanisms for removal of both parameters. Moreover, it is readily apparent from Figures 4.39 to 4.41 that the <u>feed</u> values for both solids and nitrogen are on the average consistently <u>larger</u> than the <u>reactor</u> values. This is also shown by the mean values quoted in Table 4.9. The relative difference between the means (i.e. the feed mean is greater than the reactor mean) is reflected by <u>positive</u> removals being calculated for both parameters (solids and nitrogen).

Conversely, as Figure 4.42 indicates, the phosphorus <u>feed</u> levels are consistently <u>lower</u> than the <u>reactor</u> values (on average) (also indicated in Table 4.9). Thus, although no biological mechanism for total phosphorus removal exists, Figure

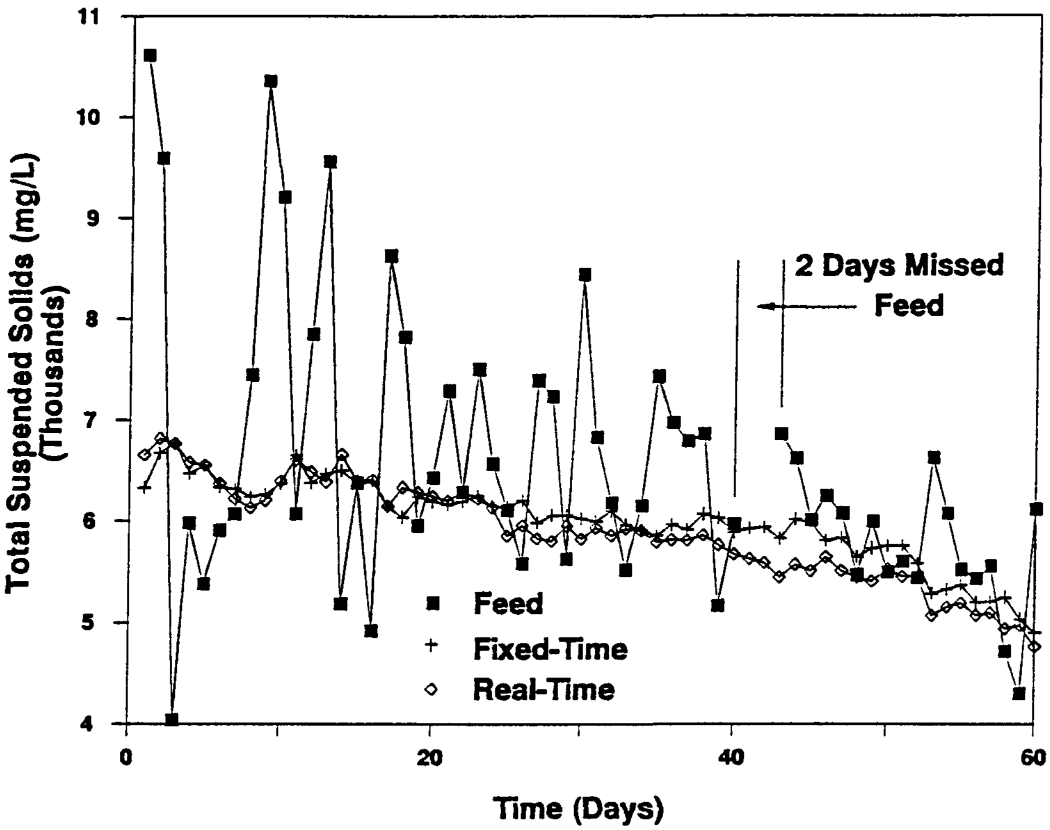


Figure 4.39 Daily Variation in Feed and Reactor TSS: AASD#2

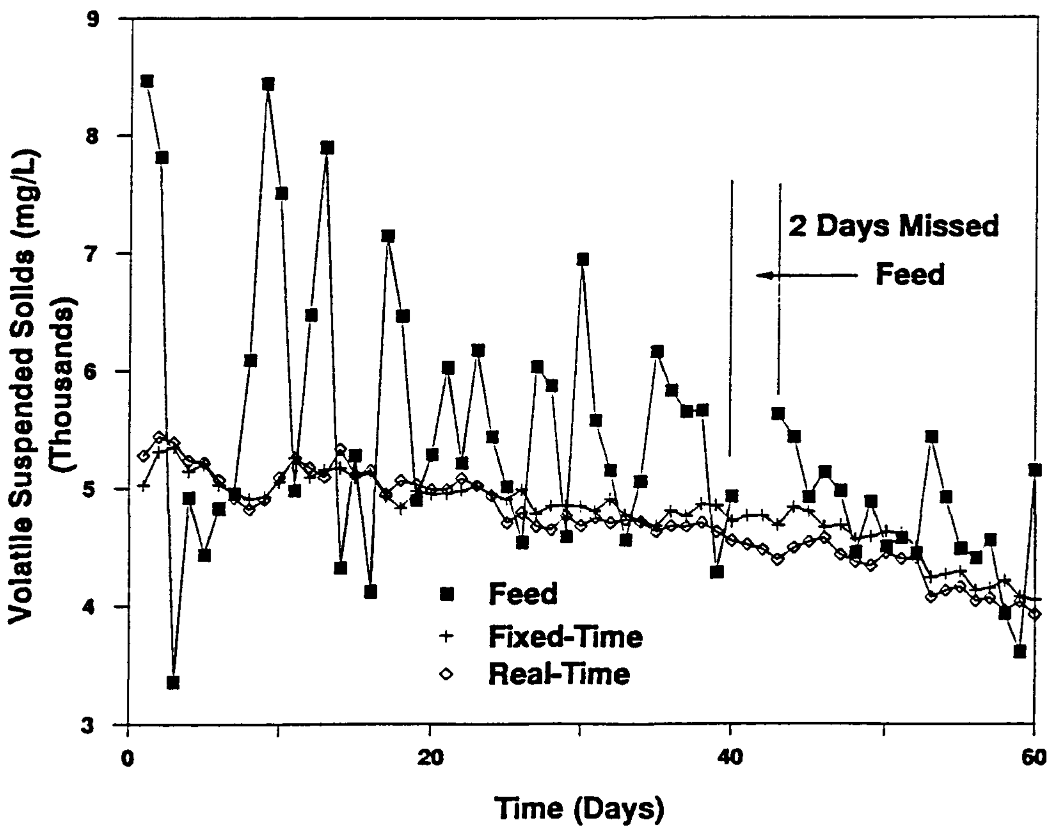


Figure 4.40 Daily Variation in Feed and Reactor VSS: AASD#2

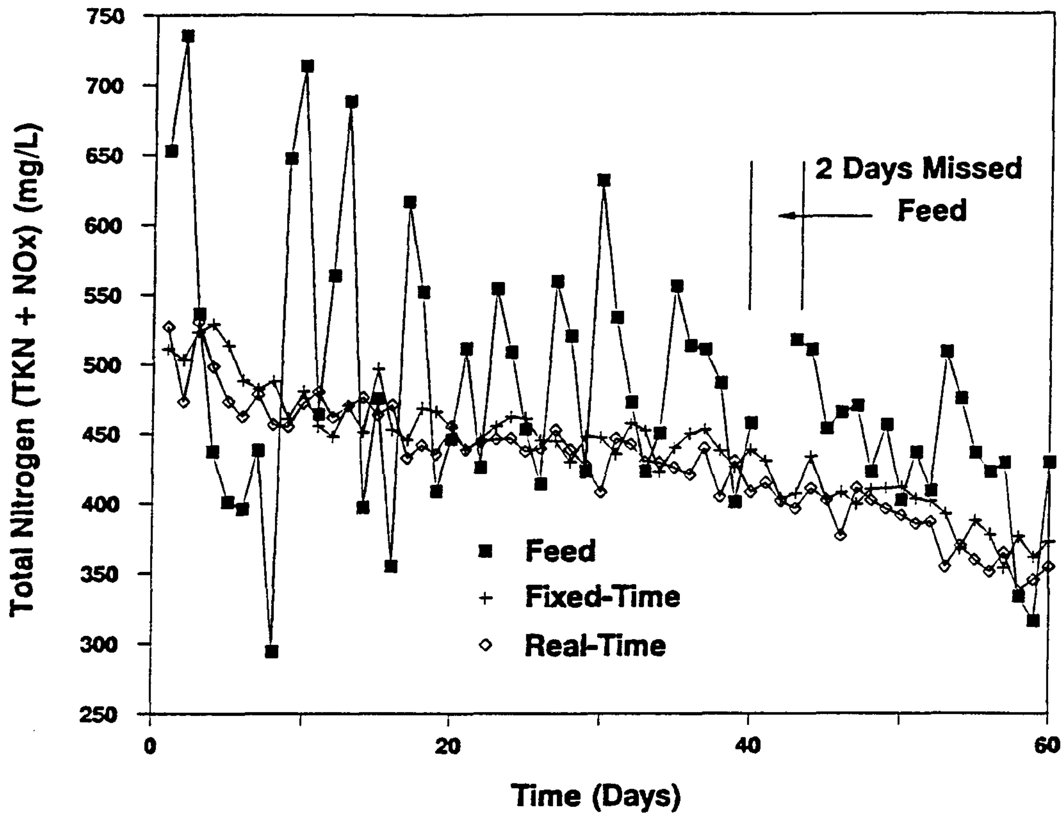


Figure 4.41 Fluctuations in Total Nitrogen Content: AASD#2

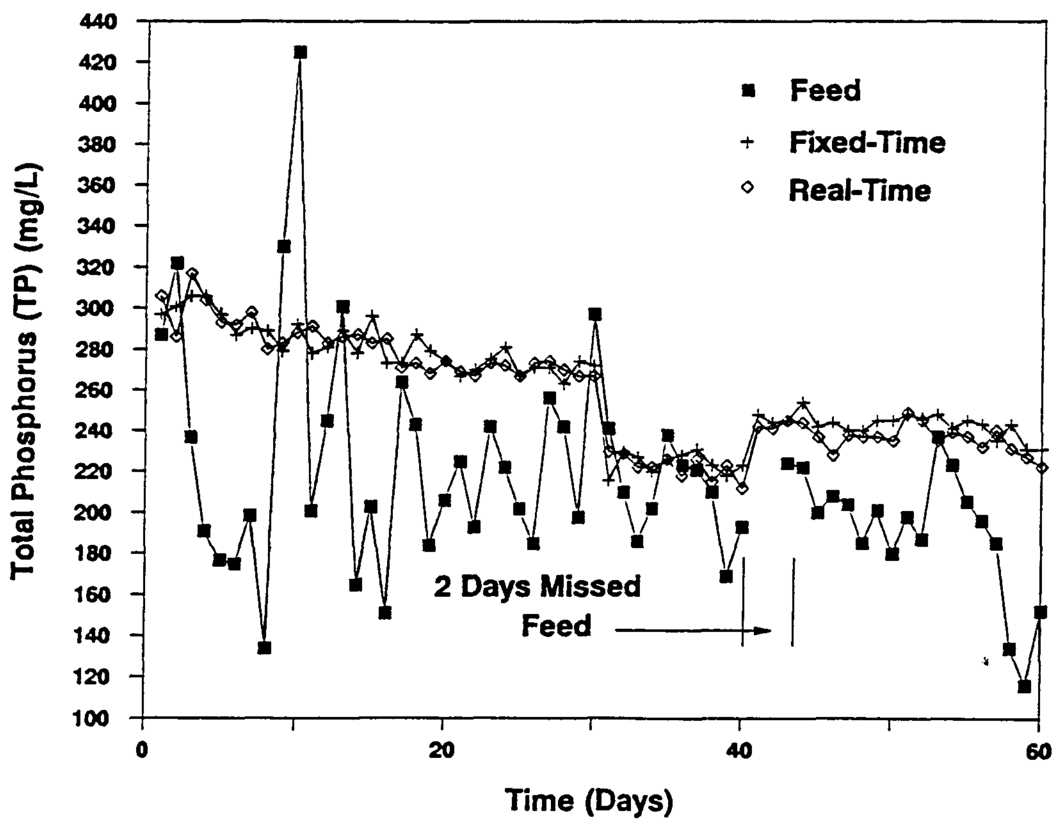


Figure 4.42 Fluctuations in Total Phosphorus Content: AASD#2

4.42 predicts that the mass balance calculation (Section 4.4.3) will yield a negative removal (i.e. an increase in phosphorus) similar in manner to the increase observed in AASD#1.

Figures 4.43 and 4.44 show profiles of the change in pH and alkalinity with time. The pH profile appears to show a slight increase with time; however, the vagaries inherent in the pH measuring apparatus can account for this and it is unlikely that any meaningful trend exists. It is visually discernable however that the feed alkalinity is (on the average) larger than the reactor value. This is also verified in Table 4.9. It is predicted therefore that a mass balance for alkalinity (Section 4.4.3) will show a net removal, despite hopes that the consumption of alkalinity during nitrification would be offset by the production of alkalinity during denitrification.

4.4.3 Mass Balance Perspective

As before, mass balances for solids (TSS and VSS), nitrogen (TKN + NOx), and phosphorus (TP) were performed around each reactor and these data have been compiled in Appendix F. Due to the KCN spike however, only 58 days of data (rather than the full 60) were used in the calculations. In addition, daily alkalinity measurements allowed a mass balance to be performed for this parameter as well.

Tables 4.10 and 4.11 represent a collation of the results, while for comparative purposes, the results from AASD#1 are also presented. As shown (Table 4.10), the Fixed-Time reactor removed essentially the same levels (TSS, VSS, nitrogen and phosphorus) for AASD#2 as for AASD#1. This was unexpected,

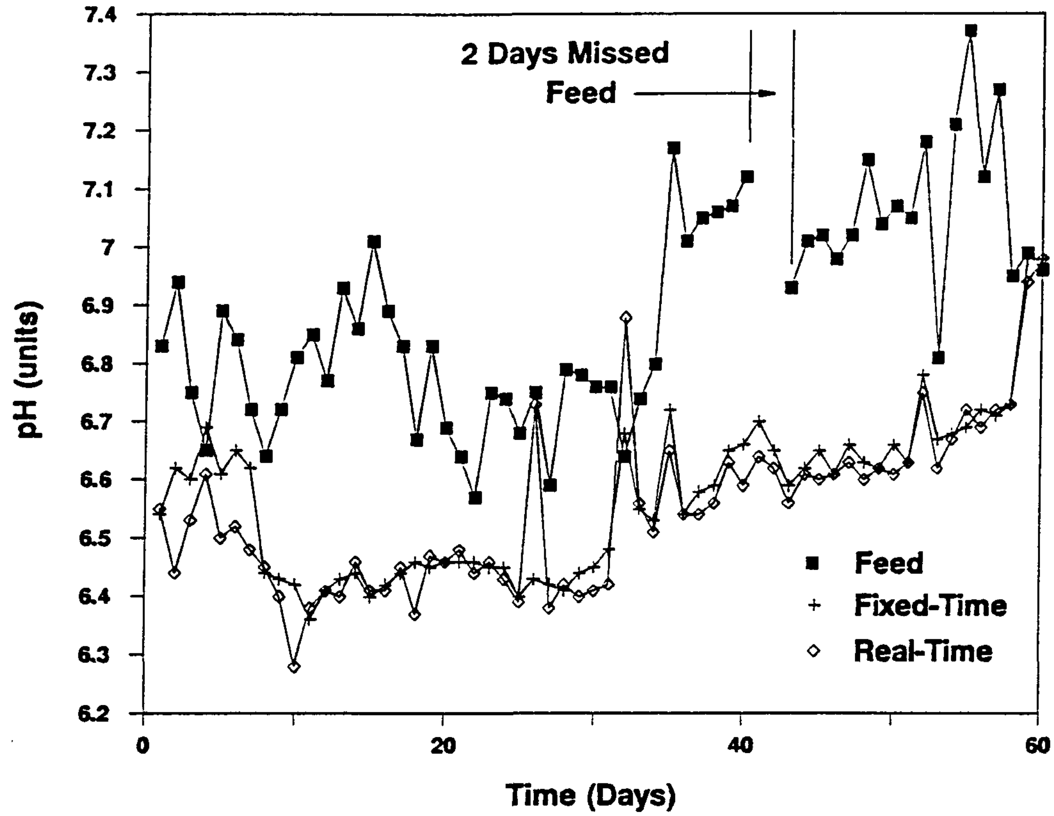


Figure 4.43 Daily Variation in Feed and Reactor pH: AASD#2

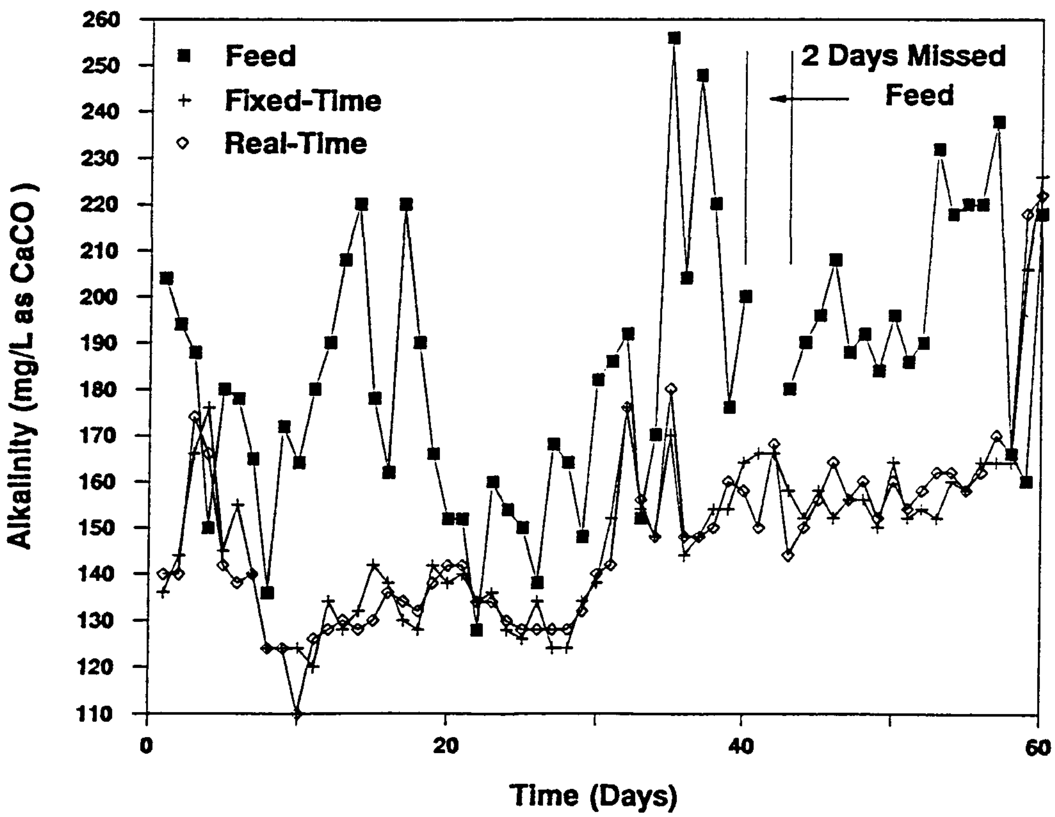


Figure 4.44 Daily Variation in Alkalinity: AASD#2

Table 4.10 Mass Balances for Fixed-Time Reactor: AASD#2

Mass Balance Parameter Percent Reduced	Moving Average Balance AASD#1 10 Day SRT	Moving Average Balance AASD#2 20 Day SRT	Overall Mass Balance AASD#1 10 Day SRT	Overall Mass Balance AASD#2 20 Day SRT
TSS	14.7 %	14.1 %	15.8 %	14.8 %
VSS	16.8 %	16.1 %	17.7 %	16.7 %
Total N	17.5 %	17.7 %	17.9 %	19.4 %
Total P	-6.5 %	-7.5 %	-6.2 %	-9.8 %
Alkalinity	------	13.8 %	------	15.5 %

Table 4.11 Mass Balances for Real-Time Reactor: AASD#2

Mass Balance Parameter Percent Reduced	Moving Average Balance AASD#1 10 Day SRT	Moving Average Balance AASD#2 20 Day SRT	Overall Mass Balance AASD#1 10 Day SRT	Overall Mass Balance AASD#2 20 Day SRT
TSS	15.2 %	18.5 %	15.7 %	19.9 %
VSS	18.0 %	20.2 %	18.3 %	21.5 %
Total N	19.5 %	20.6 %	21.1 %	25.9 %
Total P	-6.9 %	-5.0 %	-5.8 %	-5.3 %
Alkalinity	------	13.4 %	------	16.2 %

since AASD#2 operated at a 20 day SRT and the longer retention time was expected to produce significantly greater removals. No reason for this poor performance is readily apparent.

The Real-Time reactor (Table 4.11) did show a marginal increase (2 to 4 percentage points, depending upon the mass balance method used) in TSS, VSS, and nitrogen; however, again this removal level is surprisingly low for the long SRT used. Jenkins and Mavinic (1989a) reported overall mass balance removal levels of 21.9 % for TSS, 23.9 % for VSS, 22.7 % for nitrogen and 7.35 % for phosphorus, for an aerobic-anoxic run at a 20 day SRT (20 °C).

As predicted from Figure 4.44, the alkalinity mass balance showed a net removal of alkalinity, even though the pH remained in the neutral range. It is suspected, therefore, that if the run had been extended, periodic adjustments would have become necessary to buffer the pH. Alternatively, the aerated to non-aerated fraction of the cycle could be altered (incorporating longer non-aerated periods) to produce more alkalinity to offset any pH drop that occurred.

Due to the increase (relative to AASD#1) in the Real-Time reactor removals, small differences (up to 6 % depending upon the parameter and mass balance method used) exist in the performance of the two reactors. Again, it is not conclusive, but from a mass balance perspective, the Real-Time reactor may be removing (marginally) more than the Fixed-Time reactor (of the TSS, VSS and nitrogen). The lack of replication prevents a rigourous statement as to the statistical significance of these differences.

4.4.4 Evaluation: Unsteady Process Input Conditions

During this run, the reactors were subjected to one spike each of sodium nitrate, ammonium chloride and hydrogen peroxide. All spikes were at a level equivalent to the "high" spikes detailed in AASD#1. The pertinent statistics are recorded in Tables 4.12, 4.13 and 4.14, while Figures 4.45 through 4.50 show vignettes of the reactor responses to each spike. The different failure categories are again highlighted on each figure. Both "Incomplete Denitrification" and "Incomplete Nitrification" failures were observed, as well as the "Missed-Knee" failure described earlier.

Figures 4.45 and 4.46 reveal that the Real-Time reactor accommodated the sodium nitrate stress better than the Fixed-Time reactor, producing no failures directly attributable to the spike. Figures 4.47 and 4.48 indicate that both reactors had trouble assimilating the ammonium chloride spike, while Figures 4.49 and 4.50 indicate that the hydrogen peroxide spike created problems only for the Fixed-Time reactor. This latter failure is contrasted to run AASD#1 in which the hydrogen peroxide spikes produced no failures of any kind in either reactor.

Tables 4.15 and 4.16 tabulate the number of failures for each reactor according to both the type of stress and category of failure. From the data, it is evident that the Fixed-Time reactor failed 11 times, while the Real-Time reactor failed 32 times. These values, however, must be normalized (for

Table 4.12 Particulars of Sodium Nitrate Spike: AASD#2

Reactor Date Day Number	FT Oct/30/90 29	RT Oct/30/90 29
Sampled Nitrate Air On (Hr:Min) Concentration[1]	4:25 pm 2:00 1.64 mg/L	4:00 pm 1:05 0.81 mg/L
Time of Spike Amount[2]	4:25 pm 129.6 mg	4:00 pm 129.6 mg
Sampling Time Concentration[1]	4:30 pm 6.16 mg/L	4:05 pm 5.34 mg/L

[1]Concentration is measured as NO_3-N mg/L
[2]Amount is based on a weight of Sodium Nitrate

Table 4.13 Particulars of Ammonium Chloride Spike: AASD#2

Reactor Date Day Number	FT Nov/5/90 35	RT Nov/5/90 35
Sampled Ammonia Air Off(Hr:Min) Concentration[1]	3:00 pm 0:45 0.61 mg/L	2:40 pm 0:30 0.17 mg/L
Time of Spike Amount[2]	3:00 pm 129.6 mg	2:40 pm 129.6 mg
Sampling Time Concentration[1]	3:05 pm 6.79 mg/L	2:45 pm 6.43 mg/L

[1]Concentration is measured as NH_3-N mg/L
[2]Amount is based on a weight of Ammonium Chloride

Table 4.14 Particulars of Hydrogen Peroxide Spike: AASD#2

Reactor Date Day Number	FT Nov/20/90 50	RT Nov/20/90 50
Sampled D.O. Air On(Hr:Min) Concentration[1]	9:45 am 2:30 2.75 mg/L	12:15 pm 1:00 3.20 mg/L
Time of Spike Amount[2]	9:45 am 3 mL	12:15 pm 3 mL
Sampling Time Concentration[1]	9:47 am 10.9 mg/L	12:17 pm 11.2 mg/L

[1]Concentration is measured as Dissolved Oxygen (mg/L)
[2]Amount is on a volume basis of 3 % weight/volume H_2O_2

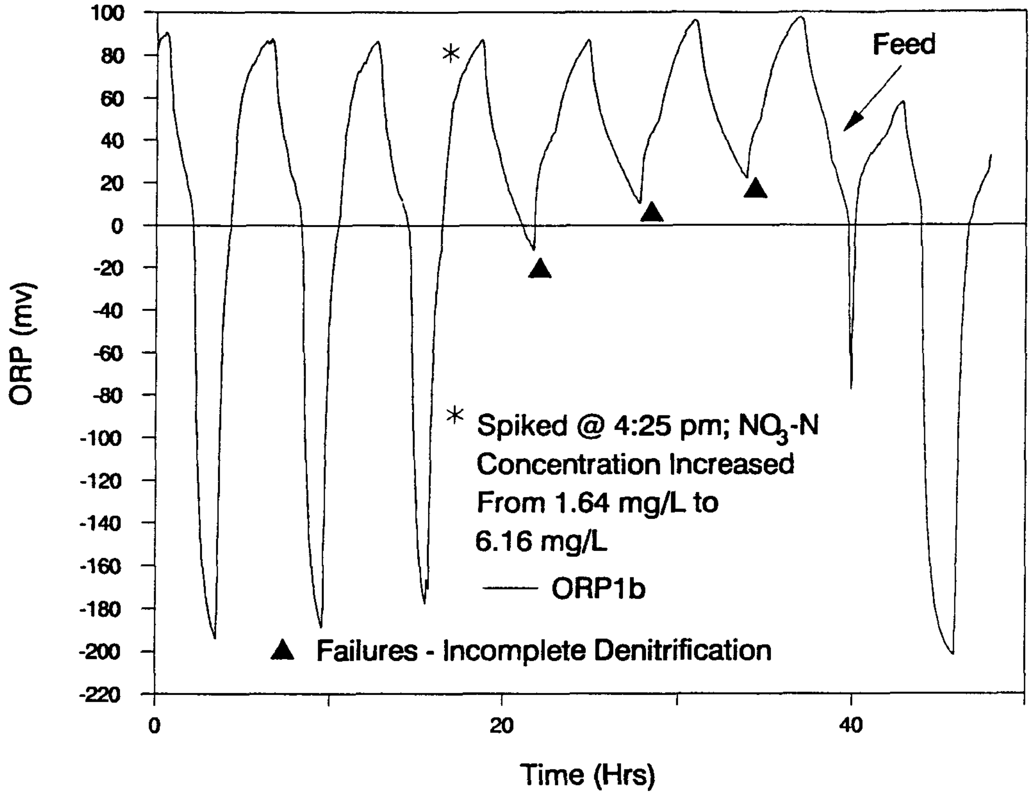


Figure 4.45 Spike of Sodium Nitrate to FT Reactor: AASD#2

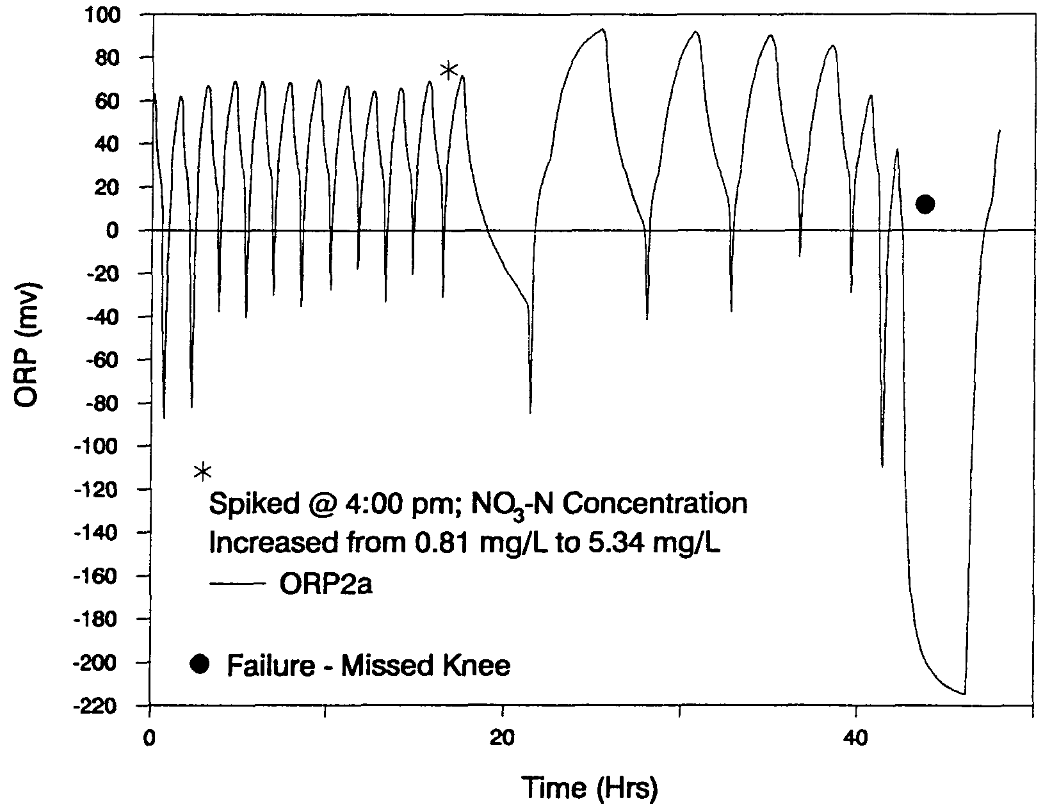


Figure 4.46 Spike of Sodium Nitrate to RT Reactor: AASD#2

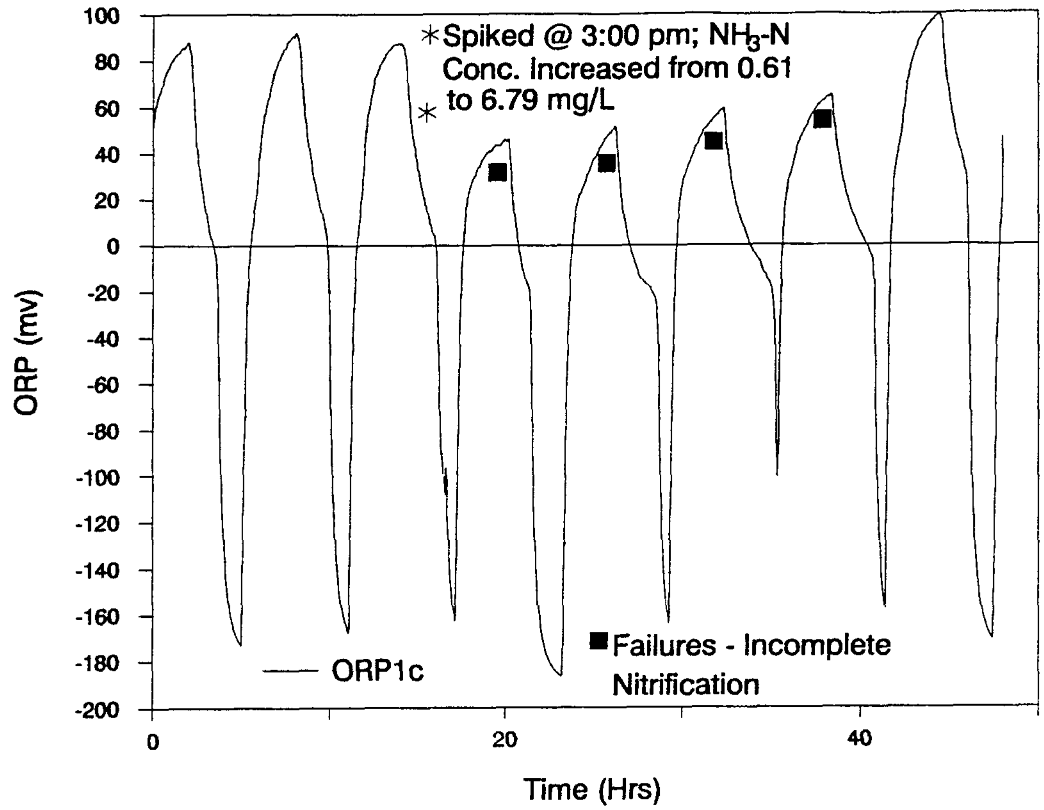


Figure 4.47 Spike of Ammonium Chloride to FT Reactor: AASD#2

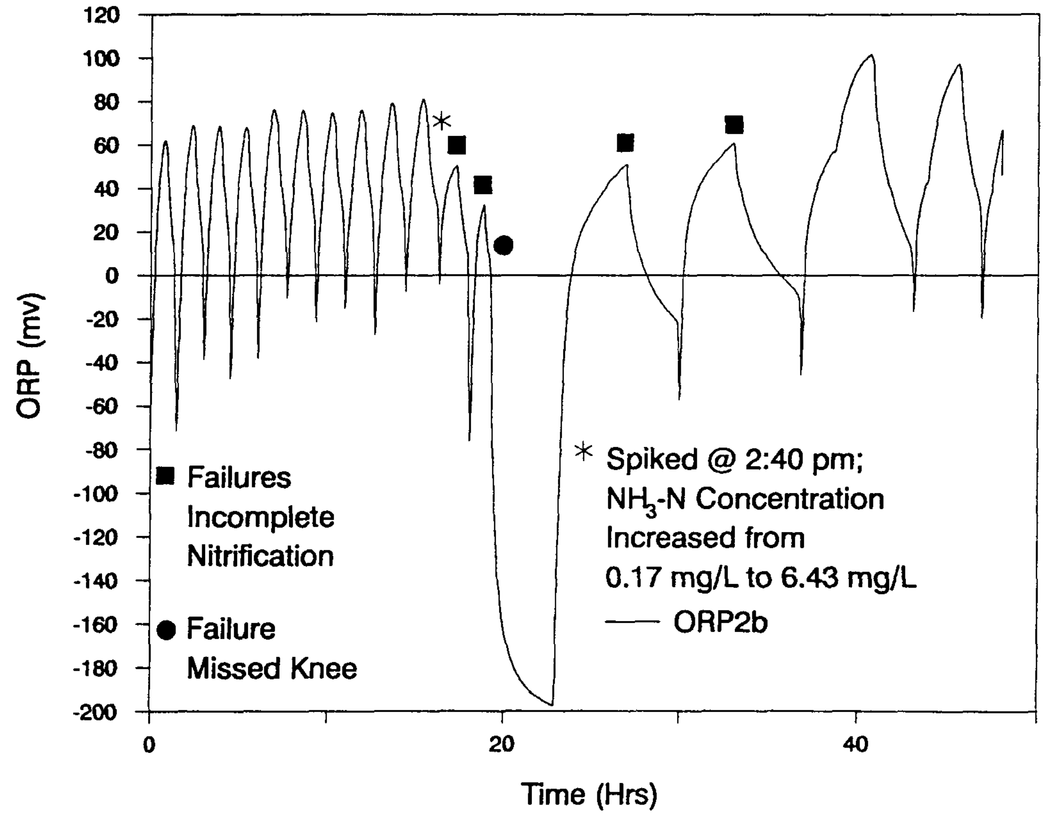


Figure 4.48 Spike of Ammonium Chloride to RT Reactor: AASD#2

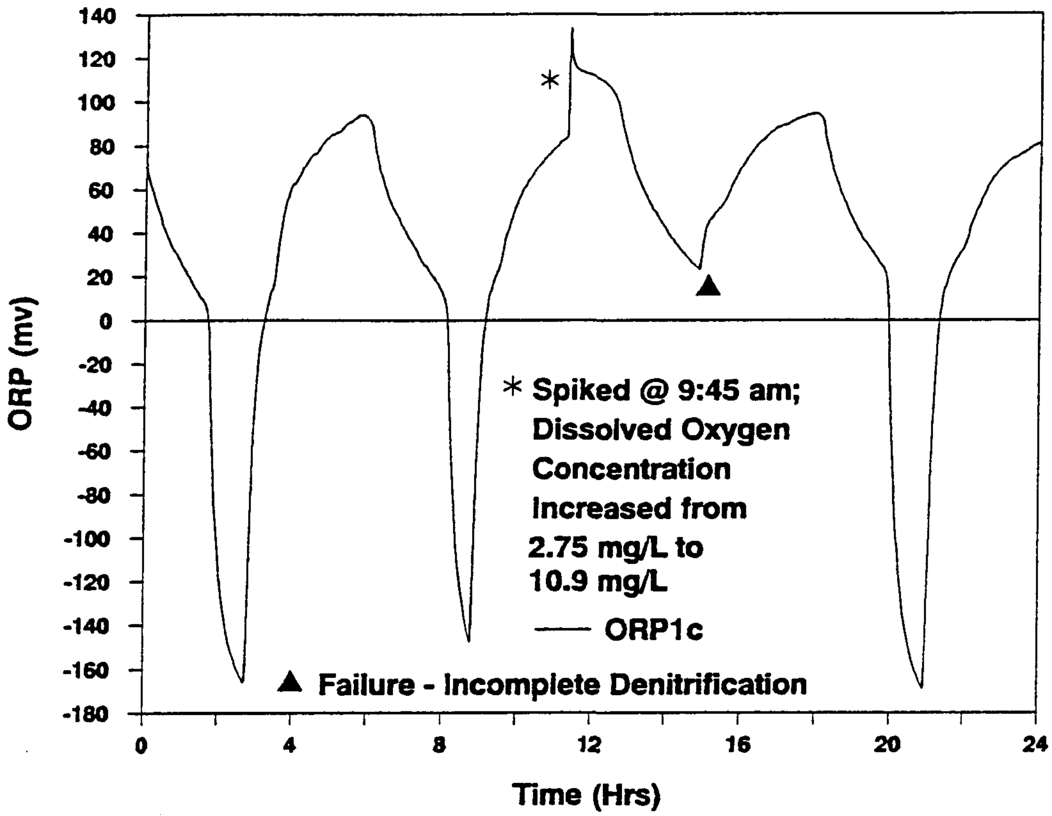


Figure 4.49 Spike of Hydrogen Peroxide to FT Reactor: AASD#2

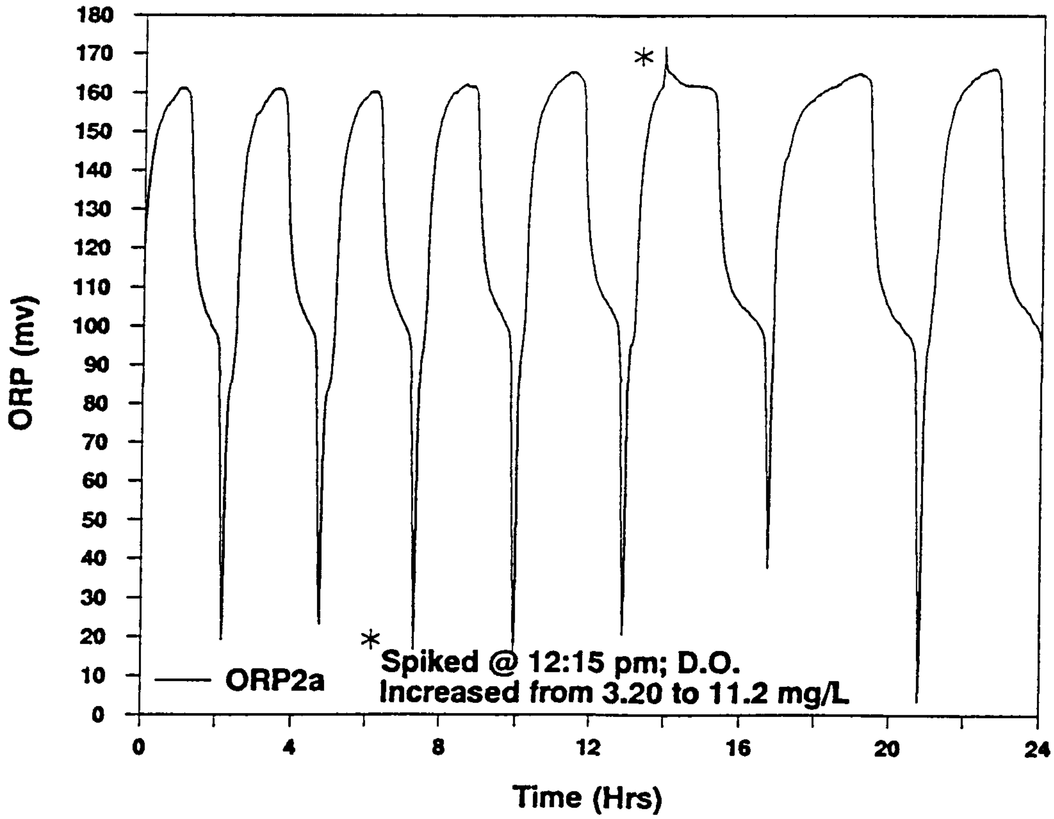


Figure 4.50 Spike of Hydrogen Peroxide to RT Reactor: AASD#2

Table 4.15 Failures Associated with FT Reactor Operation: AASD#2

Type of Stress	Incomplete Denitrification Failure	Incomplete Nitrification Failure	Missed Nitrate Breakpoint Failure	Total Number
Normal Operation	1	1	0	2
Sodium Nitrate Spike	3	0	0	3
Ammonia Chloride Spike	0	4	0	4
Hydrogen Peroxide Spike	1	0	0	1
Ommission of Daily Feed	1	0	0	1
Total Number of Failures	6	5	0	11

Table 4.16 Failures Associated with RT Reactor Operation: AASD#2

Type of Stress	Incomplete Denitrification Failure	Incomplete Nitrification Failure	Missed Nitrate Breakpoint Failure	Total Number
Normal Operation	0	1	25	26
Sodium Nitrate Spike	0	0	0	0
Ammonia Chloride Spike	0	4	0	4
Hydrogen Peroxide Spike	0	0	0	0
Ommission of Daily Feed	2	0	0	2
Total Number of Failures	2	5	25	32

each reactor) against the total number of cycles during the run. For example, the Real-Time reactor with its short cycle length had many more opportunities than the Fixed-Time reactor to fail. Accordingly, the Fixed-Time reactor sustained 217 cycles (a failure rate of 5.1 %), while the Real-Time reactor underwent 525 cycles (a failure rate of 6.1 %). Thus, from a "failures" perspective, both reactors performed essentially the same. Since the majority of the Real-Time failures were software-based, more sophisticated programming techniques may be able to reduce or even eliminate the "Missed-Knee" category of failure. If this occurs, there may be grounds for stating that the Real-Time AASD#2 operating strategy holds more promise of being better able to control the system; especially since it may have performed better than the Fixed-Time reactor in the mass balance category.

Finally, Figures 4.51 and 4.52 show the response of each reactor to the spike of 56 mg/L (0.5 millimoles/litre of potassium cyanide). This concentration is one half that suggested by the microbiological department at UBC, however it is clear that the KCN immediately affected the micro-organisms. Cyanide prevents the reaction of oxygen in the overall energy-producing process by binding with ferricytochrome oxidase, the last cytochrome in the oxidative phosphorylation pathway. In both reactors, the ORP gradually rose again as the concentration of dissolved oxygen increased in the reactor (to over 7 mg/L), due to the lack of bacterial demand for an electron acceptor.

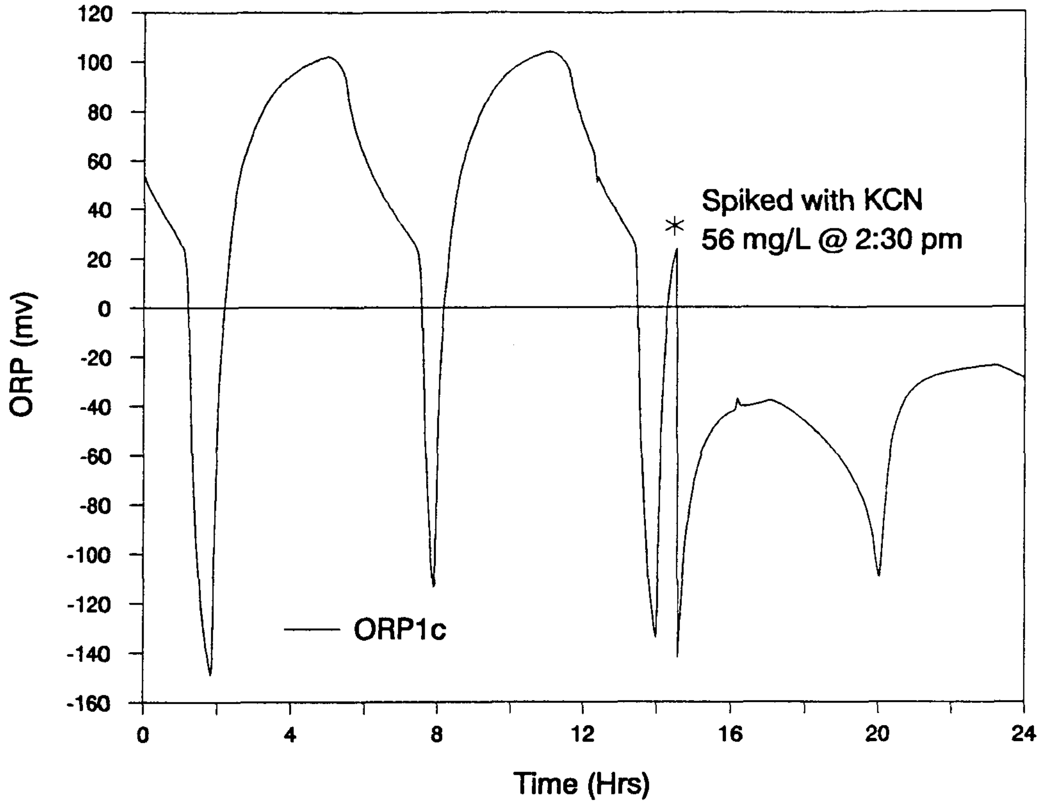


Figure 4.51 Spike of Potassium Cyanide to FT Reactor: AASD#2

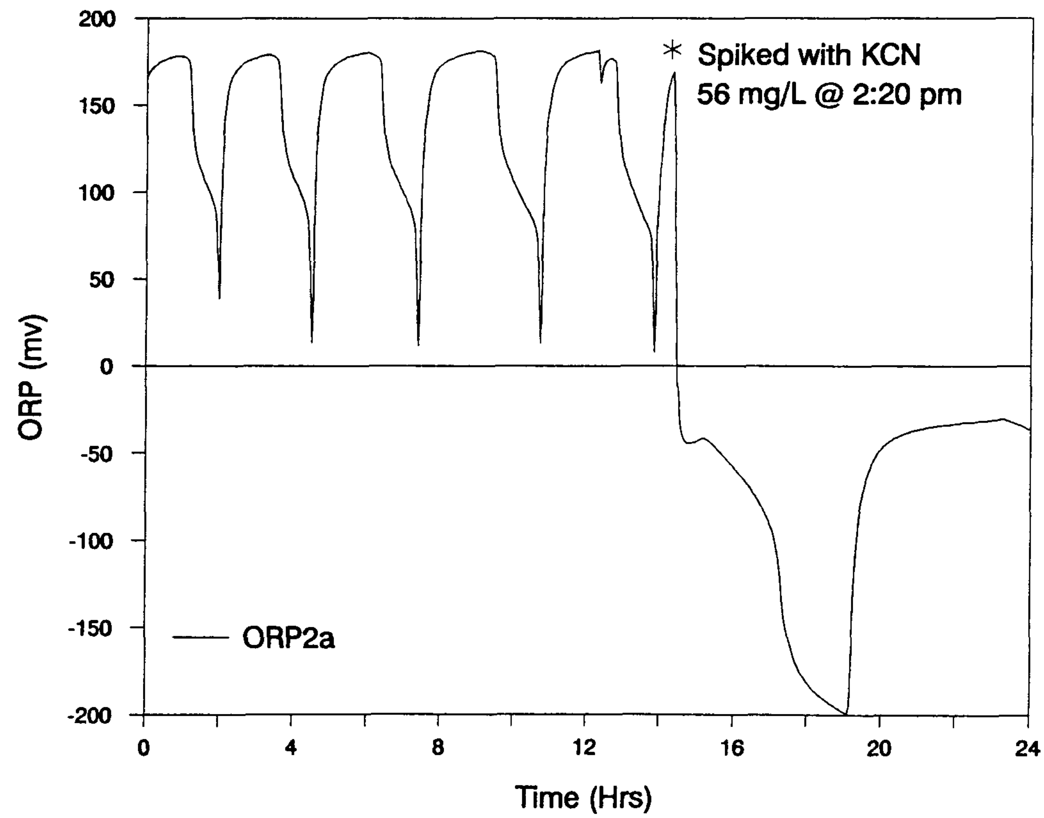


Figure 4.52 Spike of Potassium Cyanide to RT Reactor: AASD#2

CHAPTER 5

BIOLOGICAL PHOSPHORUS REMOVAL (BIO-P) EXPERIMENTS

5.1 Operating Characteristics and ORP Profiles

The biological phosphorus removal experiment was partitioned into two runs (Bio-P#1 and Bio-P#2), with each run being 2 SRTs (40 days) in length. The rationale for this segmentation was somewhat artificial, in that a solenoid malfunction drained one-half of the Real-Time reactor contents down the sink at the 40 day mark. It was felt however that the period was of sufficient length to extract useful data, and thus the second run was halted after a similar period of time.

During Bio-P#1, the raw feed was supplemented with inorganic phosphorus (Na_2HPO_4) to approximately a concentration of 7 mg/L ortho-P (calculated in Appendix G). However, the reactors failed to remove phosphorus during this run; therefore, this practice was discontinued when the reactors were restarted. Thus, during Bio-P#2, the feed to the reactors contained whatever ortho-P concentration naturally occurred in the pilot plant influent (usually around 2 mg/L). During both runs, the pilot plant strategy of adding alkalinity ($NaHCO_3$) to the raw sewage was continued in order to maintain the pH in the neutral range.

The reactors were operated at a 20 day SRT, since that reduced the need for acclimation time between the pilot plant and the reactor conditions. In theory, with a 20 day SRT, 240 mL of liquid should have been wasted on a daily basis. The solids level, however, declined dramatically over the run (Section 5.2) and therefore wasting was occasionally halted.

The Fixed-Time reactor operated with a scheduled time (1 hr 25 min into the anoxic period), for the addition of 30 mg acetate/litre of influent (calculated in Appendix G). In contrast, the Real-Time reactor's acetate addition was triggered by the detection of the nitrate breakpoint.

Before discussing the performance of the reactors, it is useful to consider the "ideal" ORP curve shape, generated under SBR Bio-P conditions. Unlike the AASD experiments (which had a distinct "indigenous" curve, particular to each reactor's operation), the curve shown in Figure 5.1 was not ubiquitous enough to be considered as "characteristic" of normal Bio-P operation. The reasons for this will be explained later.

Clearly evident in Figure 5.1 are the three distinct zones of the Bio-P process, with a sharp, pronounced nitrate knee initiating the Real-Time addition of acetate. Figure 5.1 does not, by itself, imply perfect biological conditions for the removal of phosphorus; for even when this curve shape was obtained, the reactors seldom achieved consistent excess removal of phosphorus. As will be discussed at the end of Section 5.2, there is a host of biological and chemical parameters that must be in harmony in order to ensure good P removal.

For comparison, Figure 5.2 illustrates a frequent shape of the ORP curve, generated when the reactor denitrified immediately after the FILL period had finished. The curve's extremely rapid decline meant that the Real-Time reactor's software could not trap the knee in any of the 3 cycles that day. The major reason for this seems to be that the Bio-P

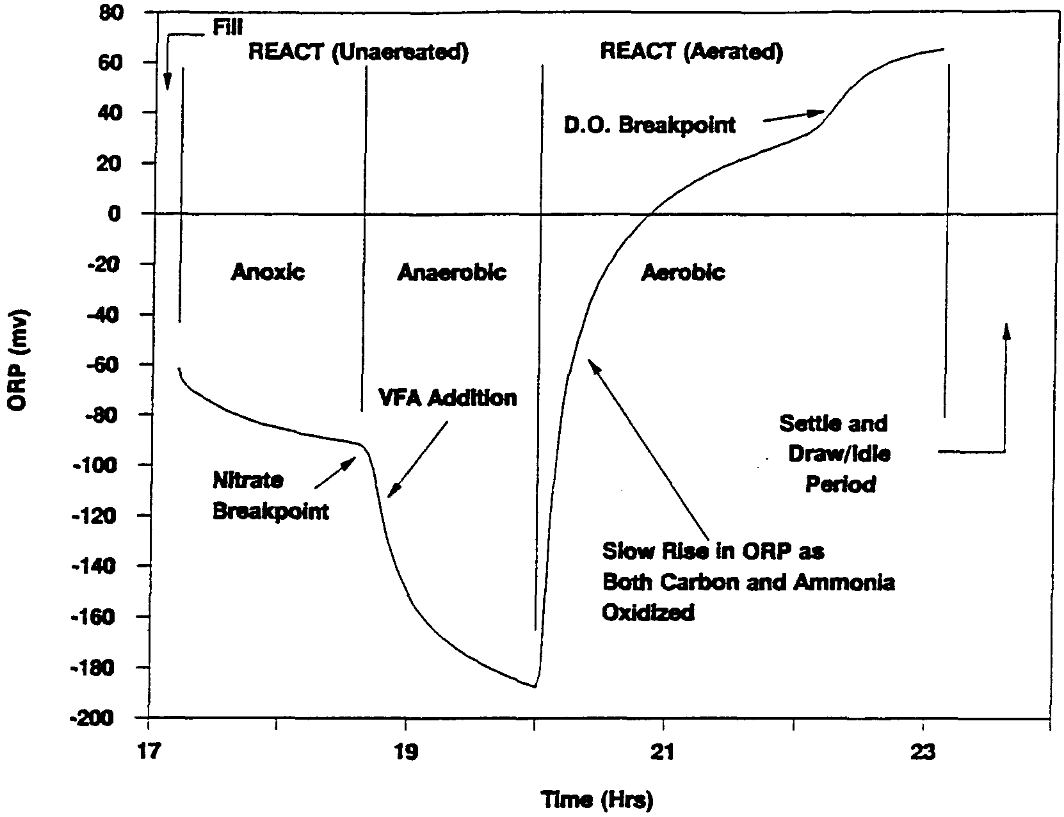


Figure 5.1 "Ideal" ORP Profile Under Bio-P Conditions

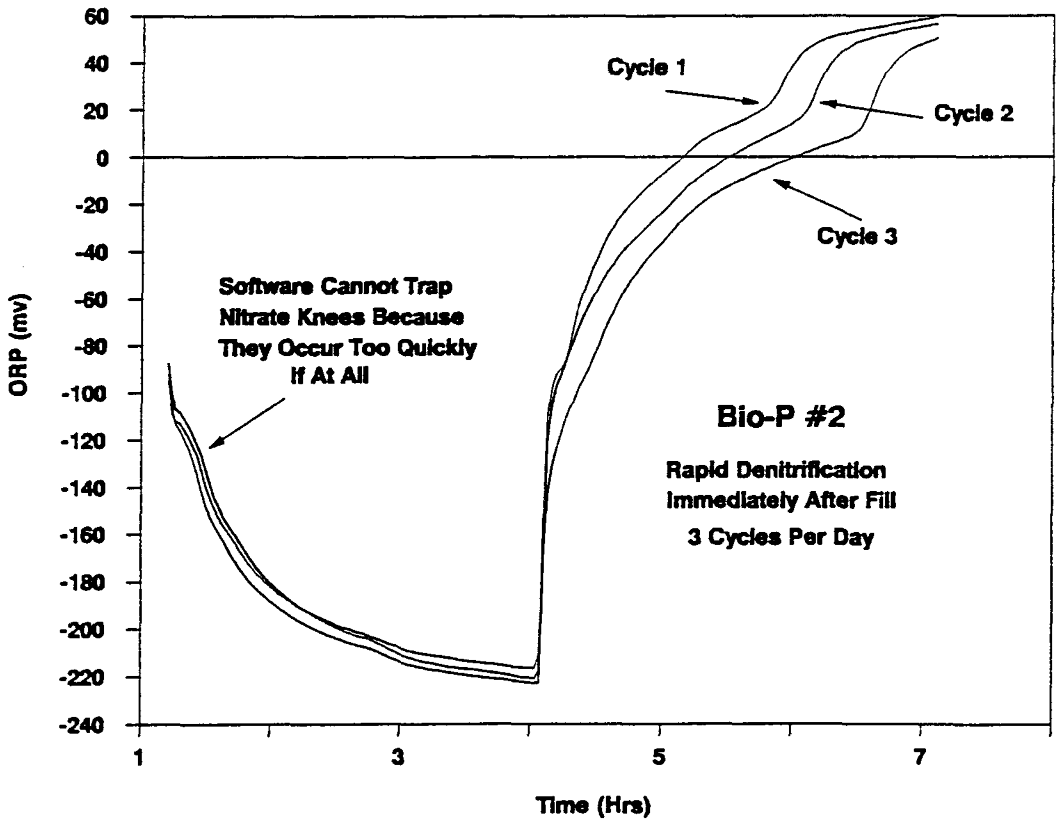


Figure 5.2 Software Failure Due to Rapid Denitrification

process is considered to be a highly-loaded carbon system, as compared to the AASD system which has very little soluble carbon available. Although not always the case in this experiment, in theory, a Bio-P system should have plenty of carbon available for denitrification, especially if relatively fresh feed has just been placed in the feed bucket. Since nitrate reduction is the first sequence in a Bio-P SBR, the denitrifying bacteria have few organisms competing with them for access to the substrate. Thus, they are easily (and apparently rapidly) able to eliminate the nitrates, causing the breakpoint to occur in the first several minutes.

A number of attempts were made during both runs to track the phosphorus and nitrate behaviour over the course of one complete cycle. Figures 5.3 and 5.4 show the <u>best</u> curves obtained during Bio-P#1. In the Fixed-Time reactor (Figure 5.3), the nitrate breakpoint occurs just prior to the addition of acetate, the impact of which, triggers the classical release/uptake phenomena necessary for Bio-P removal. As can be seen however, the reactor failed to take up excess phosphorus and thus the effluent was discharged from the reactor at essentially the same level at which it entered. Although acetate was measured during this track, it was utilised so quickly that none was detected on the gas chromatograph.

Figure 5.4 shows the behaviour of the Real-Time reactor. As has been illustrated earlier and as typified by this example, the nitrate disappeared almost immediately, causing true anaerobic conditions to develop. This was accompanied by a slow

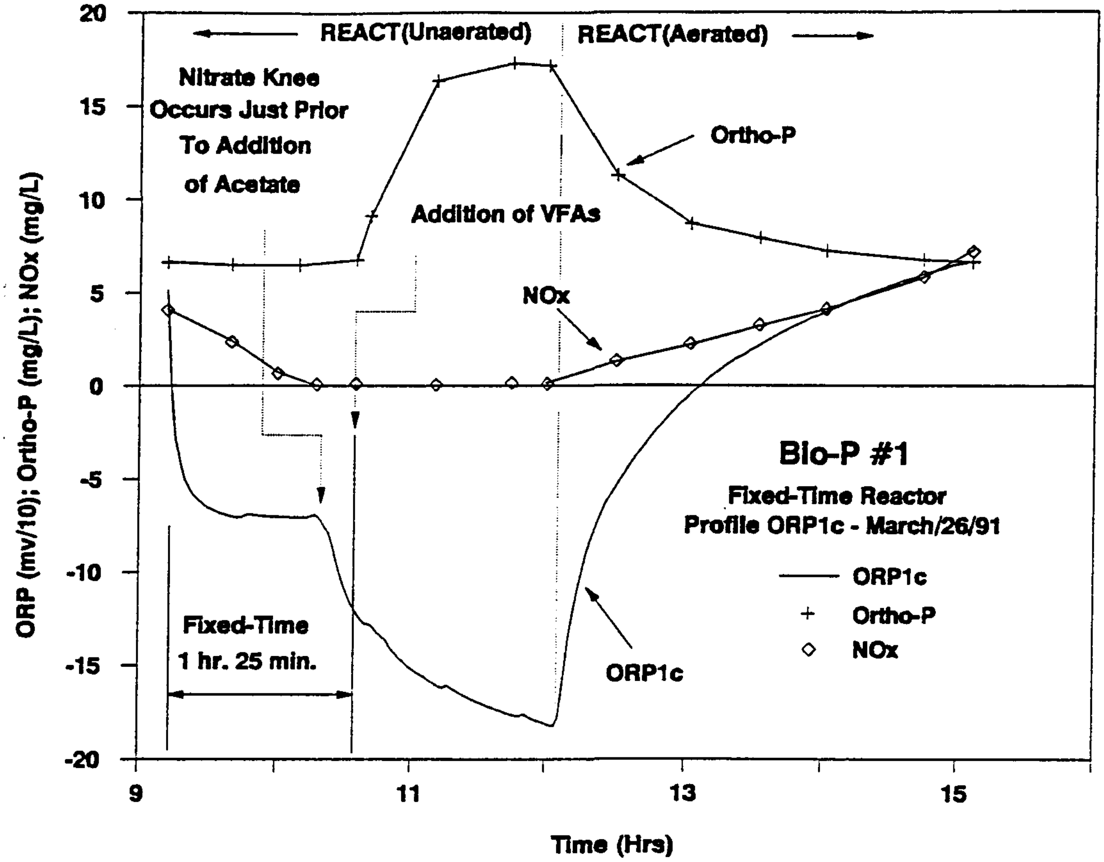


Figure 5.3 Fixed-Time Reactor Track Study: Bio-P#1

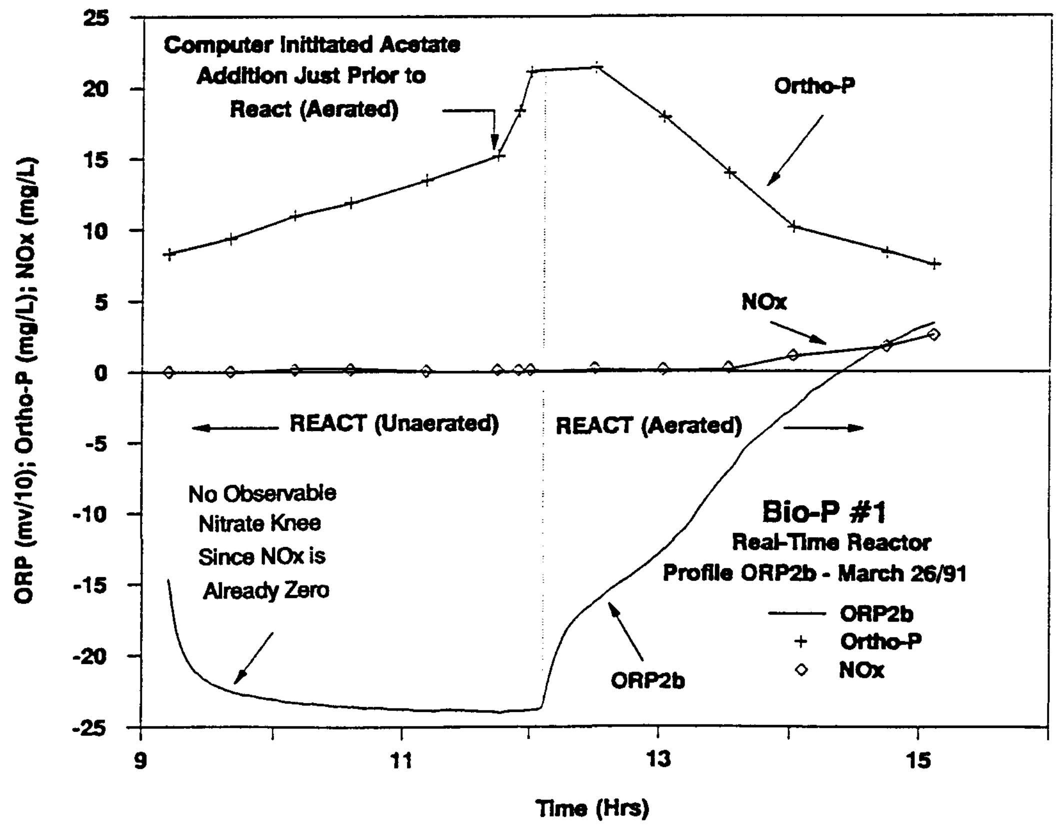


Figure 5.4 Real-Time Reactor Track Study: Bio-P#1

release of phosphorus, further accentuated by the addition of acetate, 2 hours and 40 minutes into the cycle (just prior to aeration). The computer added the acetate as a "fail-safe" measure, since at that time it "assumed" that the breakpoint had been missed. Again, whatever phosphorus was released was subsequently taken back up during aeration; however, no "excess" removal was observed.

Another frequent observation was the addition of acetate actually causing the knee itself, as shown in Figures 5.5 and 5.6. The Fixed-Time reactor (Figure 5.5) depicts the knee occurring at precisely the same time (i.e. 1 hour 25 minutes) into all 3 cycles. Although not directly confirmed by NOx analysis, this implies that acetate is being used as a source of easily oxidizable carbon for denitrification purposes, rather than for carbon storage by Bio-P organisms. Similarly, the Real-Time reactor (Figure 5.6) shows the computer initiating the acetate addition (since the knee had not been detected) after 2 hours and 40 minutes. This carbon is sufficient to complete the denitrification reaction which causes the nitrate breakpoint just prior to the onset of aeration.

The <u>best</u> track studies available for Bio-P#2 also reflect this trend. Figure 5.7 shows the addition of acetate to the Fixed-Time reactor causing a sharp drop in the nitrate concentration, with the breakpoint occurring shortly thereafter. In this particular example, the phosphorus was removed to a very low level; therefore, it appeared that the acetate was being partitioned between being used for nitrate reduction by

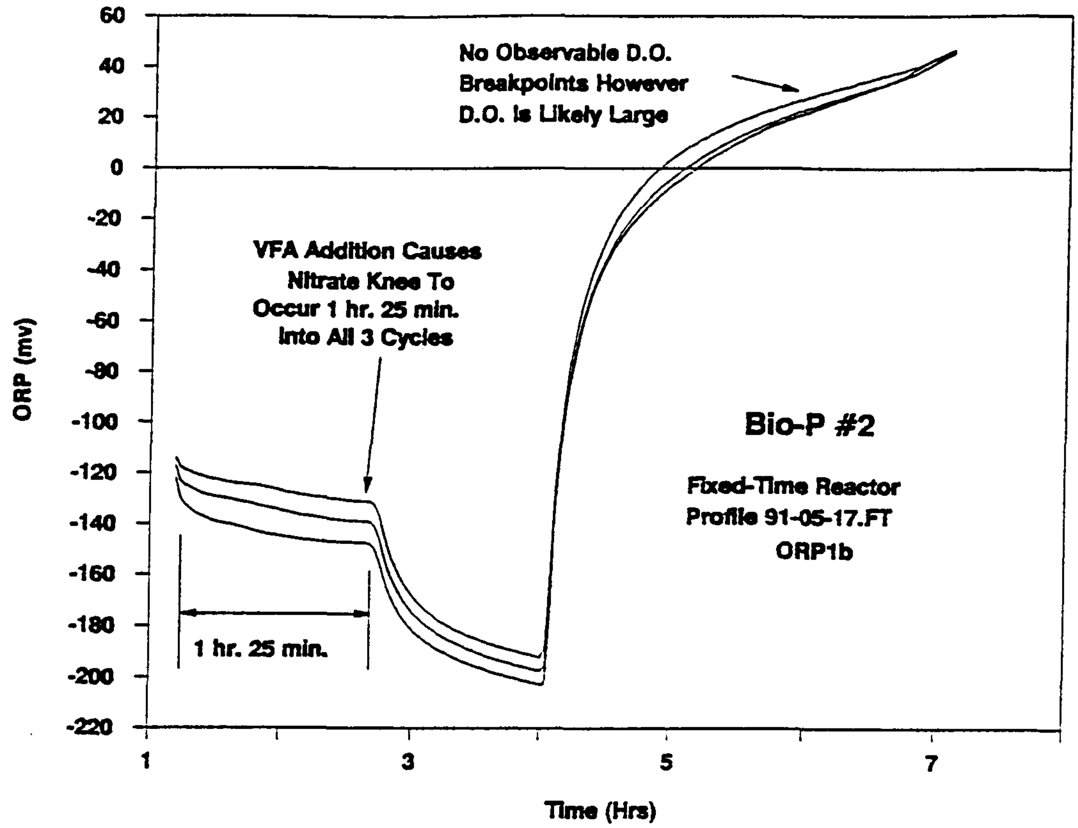


Figure 5.5 VFA-Caused Breakpoints in Fixed-Time Reactor

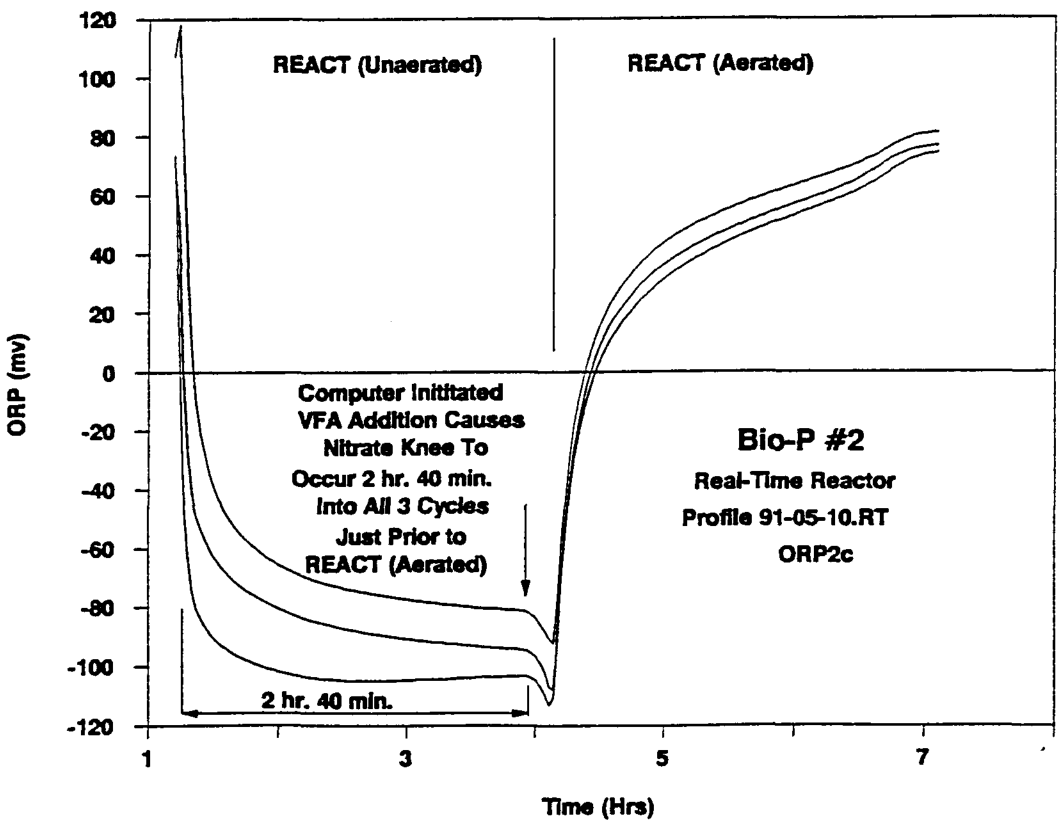


Figure 5.6 VFA-Caused Breakpoints in Real-Time Reactor

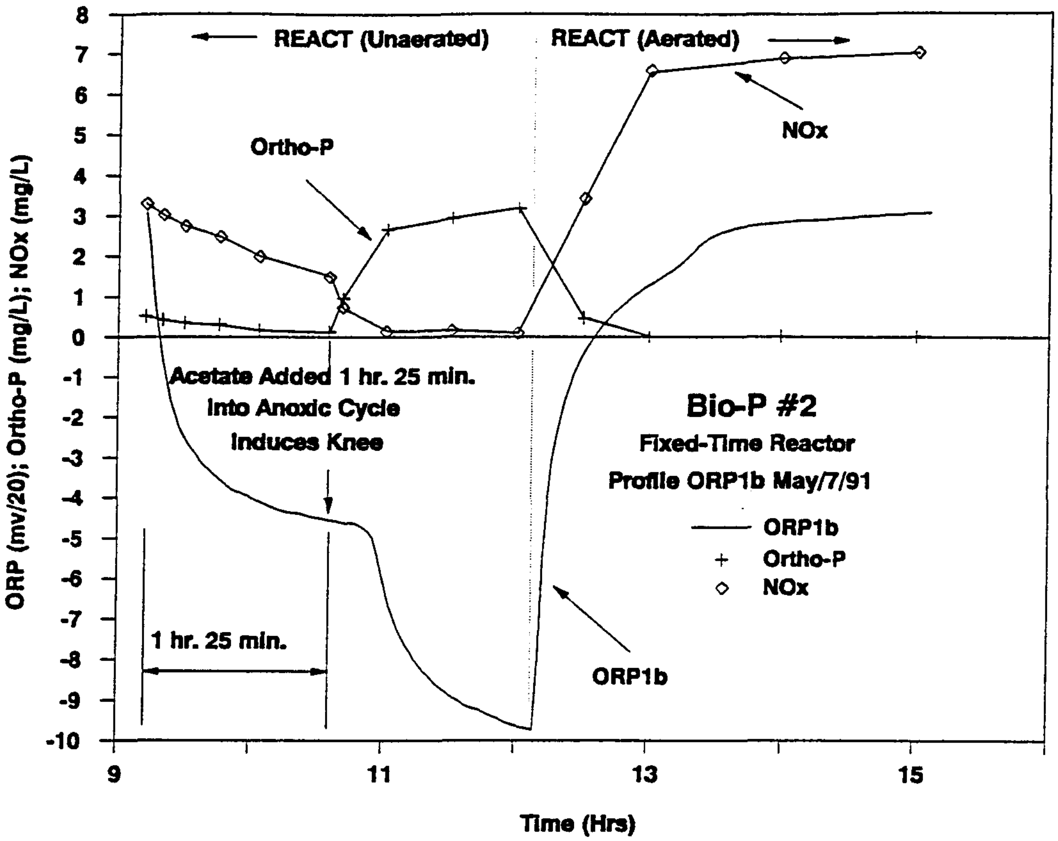


Figure 5.7 Fixed-Time Reactor Track Study: Bio-P#2

denitrifiers and being used for carbon storage by Bio-P organisms. The Real-Time reactor's breakpoint (Figure 5.8) was again induced by the addition of acetate, at the last possible minute before aeration. This was followed by a quick release prior to aerated uptake of phosphorus.

One recurring phenomena was the way in which the shape of the ORP curve was influenced by the operation of the experimental system. In particular, a delay in the time of occurrence for the nitrate breakpoint was often observed as the feed sludge weakened with time. As has been mentioned, raw sewage was collected in carboys and stored in the cold room for up to 12 days. Since the feed bucket could hold up to 3 days worth of sewage, every 4th day the bucket was replenished with "fresh/stored" sewage from the cold room. However, not only was there a decline in the carbon content in the raw sewage stored in the cold room (Figure 5.9), but there was also a significant decline in the carbon content during the 3 days in between "fresh/stored" feed (Figure 5.10) (the data used to plot these graphs have been included in Appendix H).

This latter decline occurred because the feed bucket sewage was continuously mixed (albeit at a very slow rate) in order to keep the solids in suspension. Despite being covered to minimize air entrainment, it is evident that sufficient air must have entered the mixture to allow bacteria to utilize short-chain organic compounds generated from the conversion of complex organics in the raw sewage.

The decrease in carbon content was therefore reflected in

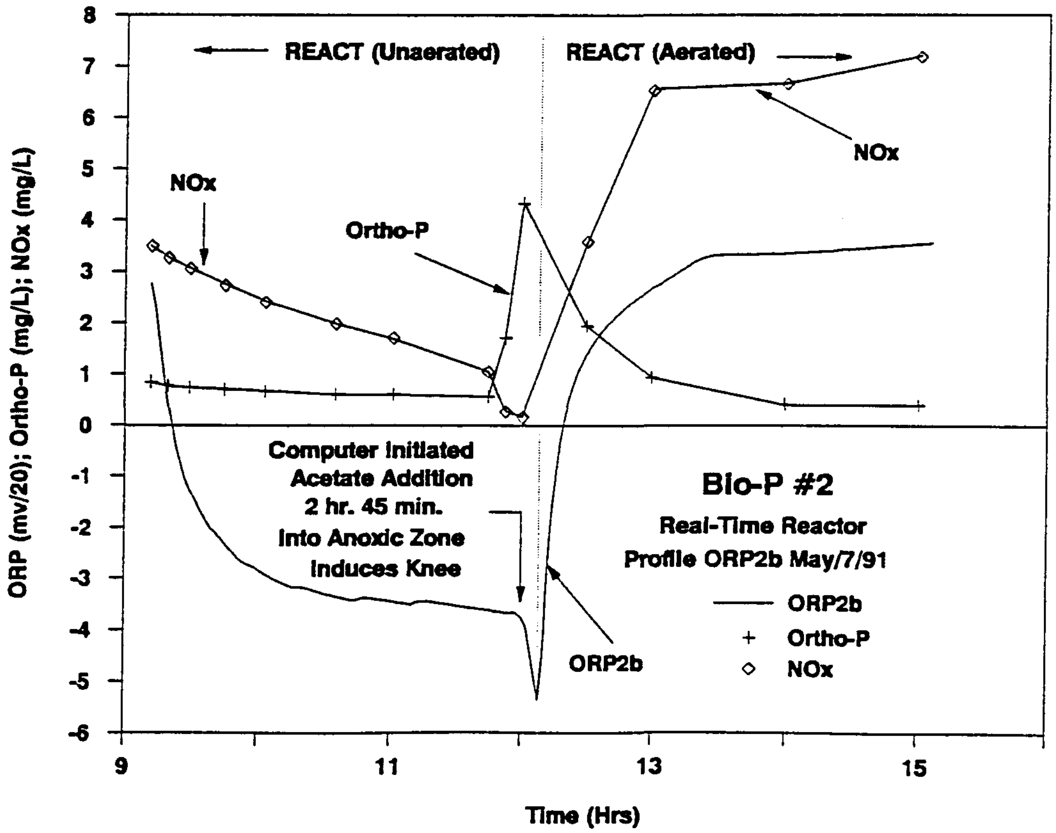


Figure 5.8 Real-Time Reactor Track Study: Bio-P#2

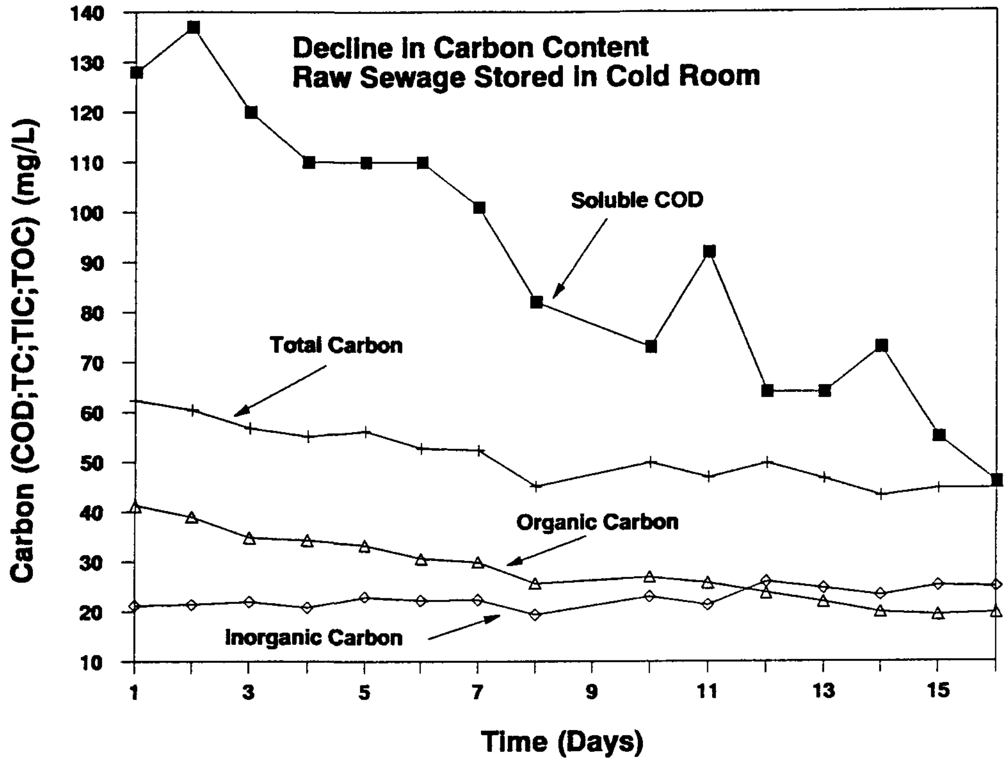


Figure 5.9 Decline in Carbon Content: Stored in Cold Room

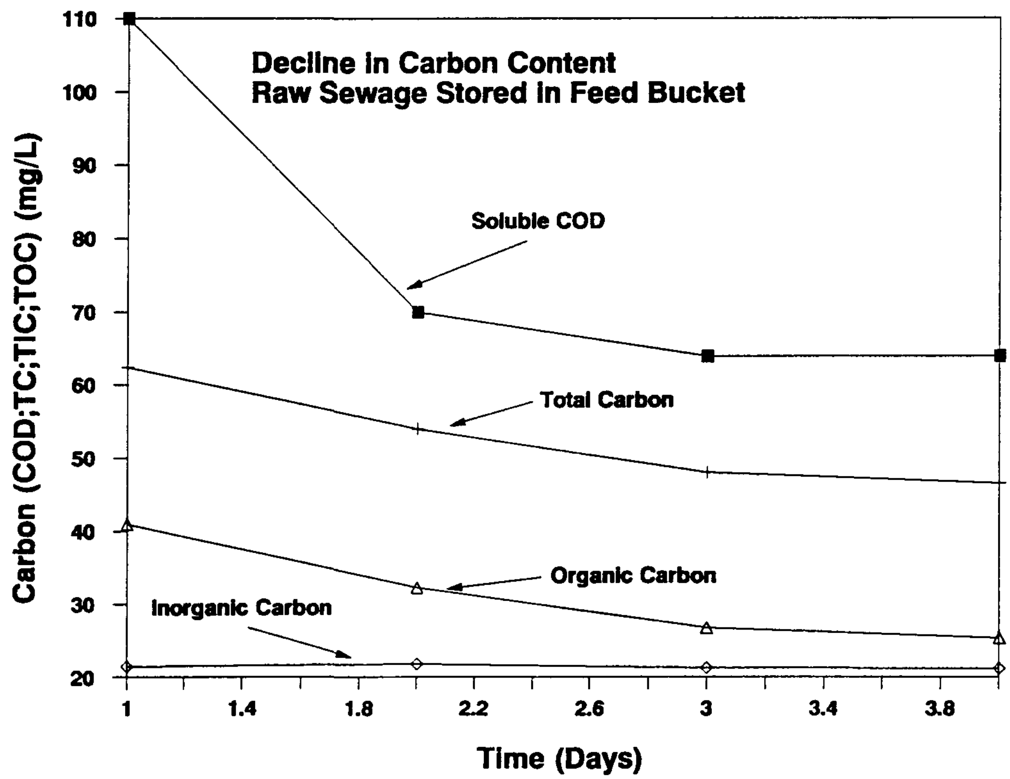


Figure 5.10 Decline in Carbon Content: Stored in Feed Bucket

a delay in the time that the knee occurred in any given cycle. This is illustrated in Figures 5.11 and 5.12. Figure 5.11 tracks the knee over the three cycles of the day and as pictured, there is no "average time" for denitrification, since it is constantly lengthening as a function of the strength of the incoming feed. Figure 5.12 continues Figure 5.11 into the next day, and illustrates how, during the last cycle before replenishment with fresh feed (from the cold room), the reactor "failed" to completely denitrify, in a manner reminiscent of the AASD set of experiments. The 6^{th} cycle occurred after replenishment and consequently the time taken to completely denitrify was considerably shortened once again. The fact that the knee associated with cycle 6 occurs slightly later than the knee associated with the first cycle, may be indicative of the gradual decline in the carbon content of the feed stored in the cold room itself.

5.2 Chemical Characteristics of Bio-P Experiments

Tables 5.1 and 5.2 detail some selected statistics of the solids, nitrogen and phosphorus levels measured during both Bio-P#1 and Bio-P#2. The detailed chemical data have been presented in Appendix H.

In both experiments, the feed TSS level was approximately 100 mg/L (Figures 5.13 and 5.14). Bio-P#2 however experienced a much larger standard deviation as indicated in Table 5.2. Figure 5.14 illustrates the major cause of this, as occurring between the 3rd and 4th data points on the graph. The first 3 points are from sewage stored in the cold room, but initially collected

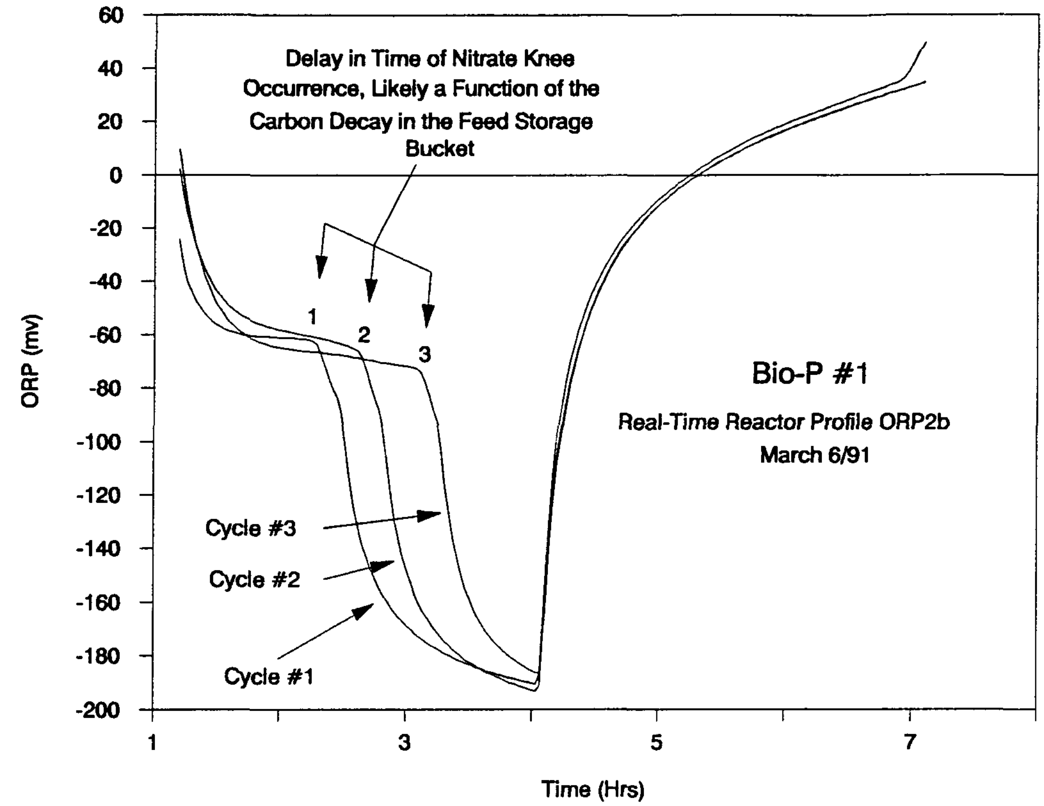


Figure 5.11 Delay in Time of Nitrate Breakpoint Occurrence

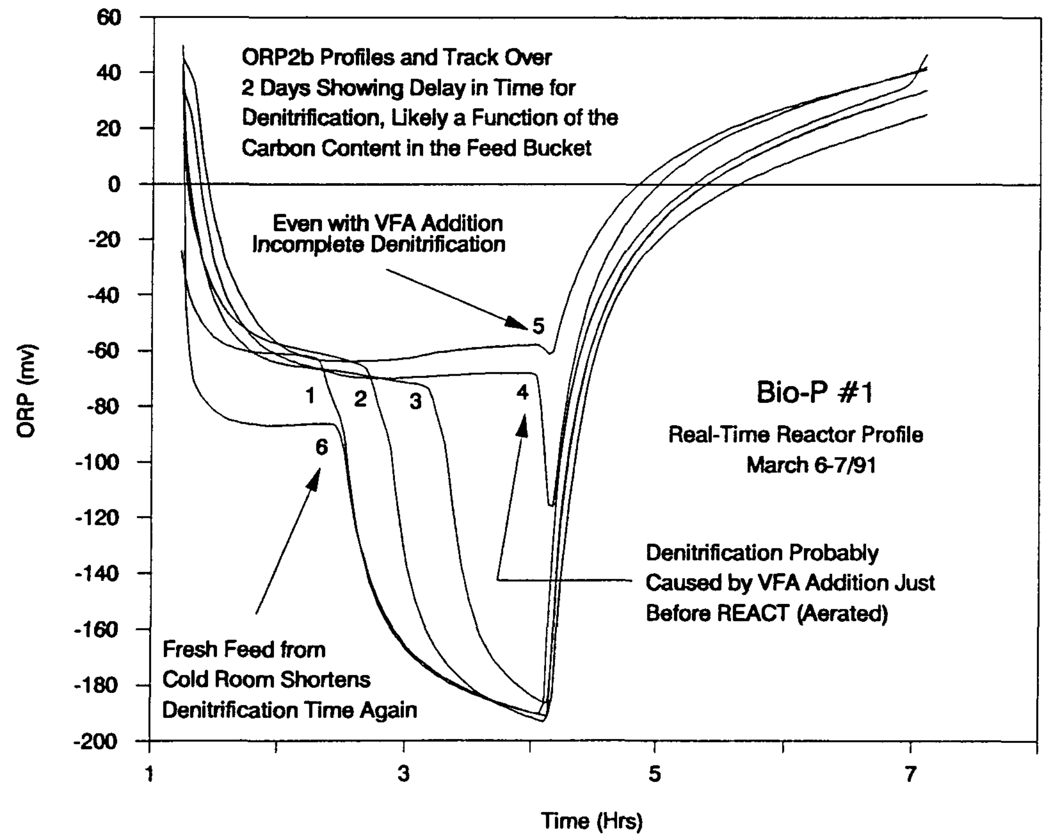


Figure 5.12 Two Day Track of Delayed Nitrate Breakpoint

Table 5.1 Solids, Nitrogen and Phosphorus Chemical Data: Bio-P#1

Chemical Parameter	Statistic	FEED	Fixed-Time RCTR	Fixed-Time Effl	Real-Time RCTR	Real-Time Effl
TSS (mg/L)	Maximum	121	2376	11	2612	5
	Mean	100	2124	4	2281	3
	Minimum	77	1620	1	1890	1
	Std.Dev.	15	226	3	205	1
VSS (mg/L)	Maximum	107	1834	11	2012	5
	Mean	88	1616	4	1727	3
	Minimum	68	1280	1	1392	1
	Std.Dev.	13	196	3	195	1
TKN - Feed (mg/L)	Maximum	30.3	----		----	
	Mean	28.4	----		----	
	Minimum	26.8	----		----	
	Std.Dev.	1.4	----		----	
% N - RCTR (%)	Maximum	----	5.72		5.19	
	Mean	----	5.32		4.90	
	Minimum	----	4.81		4.53	
	Std.Dev.	----	0.25		0.10	
NOx-N (mg/L)	Maximum	0.35		9.43		12.89
	Mean	0.14		7.97		7.70
	Minimum	0.00		6.31		2.69
	Std.Dev.	0.09		0.94		2.40
NH_3-N (mg/L)	Maximum	17.0		0.1		2.5
	Mean	13.0		N/D		0.4
	Minimum	9.8		N/D		N/D
	Std.Dev.	2.4		N/D		0.8
TP - Feed (mg/L) %P - RCTR (%P)	Maximum	9.7	3.56		4.07	
	Mean	9.5	3.25		3.20	
	Minimum	9.1	2.92		2.53	
	Std.Dev.	0.4	0.25		0.40	
Ortho-P (mg/L)	Maximum	7.64		10.70		8.80
	Mean	6.44		6.38		5.60
	Minimum	4.91		3.26		2.51
	Std.Dev.	0.87		2.17		1.70

Table 5.2 Solids, Nitrogen and Phosphorus Chemical Data: Bio-P#2

Chemical Parameter	Statistic	FEED	Fixed-Time RCTR Effl	Real-Time RCTR Effl
TSS (mg/L)	Maximum	181	3018 10	3026 10
	Mean	107	2194 6	2159 6
	Minimum	65	1598 2	1630 2
	Std.Dev.	41	417 2	439 3
VSS (mg/L)	Maximum	162	2648 10	2650 10
	Mean	97	1825 6	1791 6
	Minimum	59	1266 2	1276 2
	Std.Dev.	36	410 2	431 3
TKN - Feed (mg/L)	Maximum	41.2	----	----
	Mean	31.0	----	----
	Minimum	24.0	----	----
	Std.Dev.	7.4	----	----
% N - RCTR (%)	Maximum	----	6.82	6.26
	Mean	----	6.32	5.83
	Minimum	----	5.45	5.53
	Std.Dev.	----	0.36	0.24
NOx-N (mg/L)	Maximum	0.30	9.71	10.68
	Mean	0.16	8.49	9.00
	Minimum	0.04	7.19	7.40
	Std.Dev.	0.06	0.65	0.88
NH_3-N (mg/L)	Maximum	13.8	N/D	N/D
	Mean	12.4	N/D	N/D
	Minimum	11.6	N/D	N/D
	Std.Dev.	0.6	N/D	N/D
TP - Feed (mg/L) %P - RCTR (%P)	Maximum	6.3	3.36	3.52
	Mean	4.7	2.50	2.54
	Minimum	3.7	1.12	1.22
	Std.Dev.	1.1	0.71	0.71
Ortho-P (mg/L)	Maximum	3.18	2.07	1.92
	Mean	2.19	0.52	0.52
	Minimum	1.60	0.00	0.01
	Std.Dev.	0.36	0.78	0.59

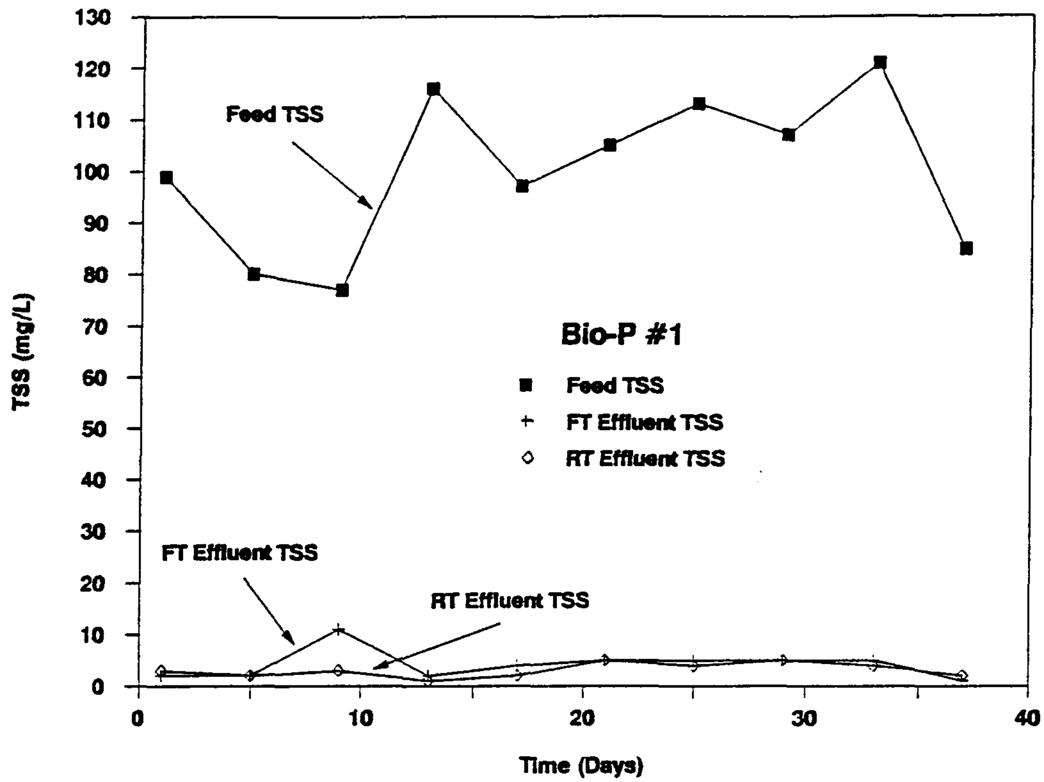


Figure 5.13 Variation in Feed and Effluent TSS: Bio-P#1

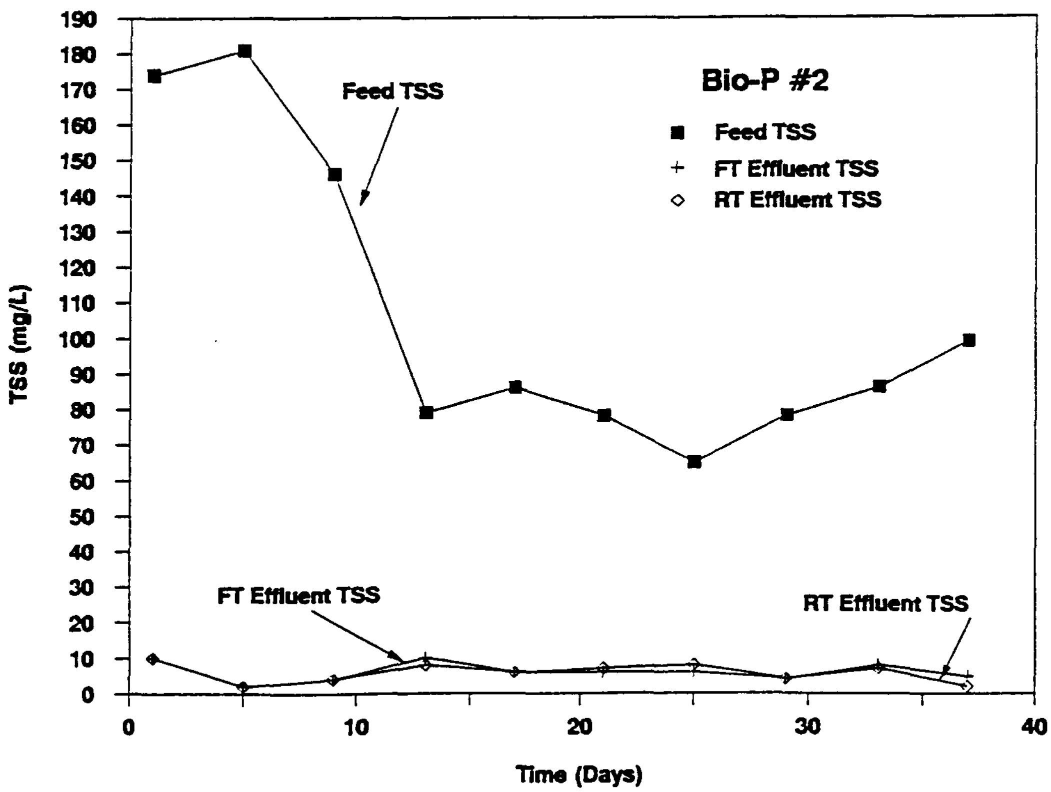


Figure 5.14 Variation in Feed and Effluent TSS: Bio-P#2

during a relatively dry weather spell. In contrast, subsequent data points are from feed collections made when the sewage had been diluted by the influx of water from several days of rain. This caused a significant drop in the feed TSS as depicted in Figure 5.14.

In both figures the reactor effluents for each run were generally less than 10 mg/L. Visual inspection of the sludge settling characteristics revealed a highly clarified effluent, produced by a sludge blanket interface settling well below the decanting solenoid port.

The solids variation inside the reactors is shown in Figures 5.15 and 5.16. In the latter experiment especially, the TSS level declined dramatically, with bacterial growth not being sufficient to counterbalance the loss in solids due to wastage. Wasting was halted several times (as reflected in occasional horizontal plateaus in the latter portion of the Bio-P#2 curve); however, it is evident that this was not practiced frequently enough to stem the decline in solids. This will be expanded upon in more detail later, when discussing the F:M ratio. Ultimately though this means that the actual SRT is substantially less than 20 days; a factor having major ramifications for the P removal performance.

The VSS/TSS ratio was greater in the Feed (Bio-P#1 - 0.88, Bio-P#2 - 0.90) than the Fixed-Time (Bio-P#1 - 0.76, Bio-P#2 - 0.83) and Real-Time (Bio-P#1 - 0.76, Bio-P#2 - 0.82) reactors, respectively. In both runs, the few effluent solids that were released as decanted supernatant (generally less than 10 mg/L

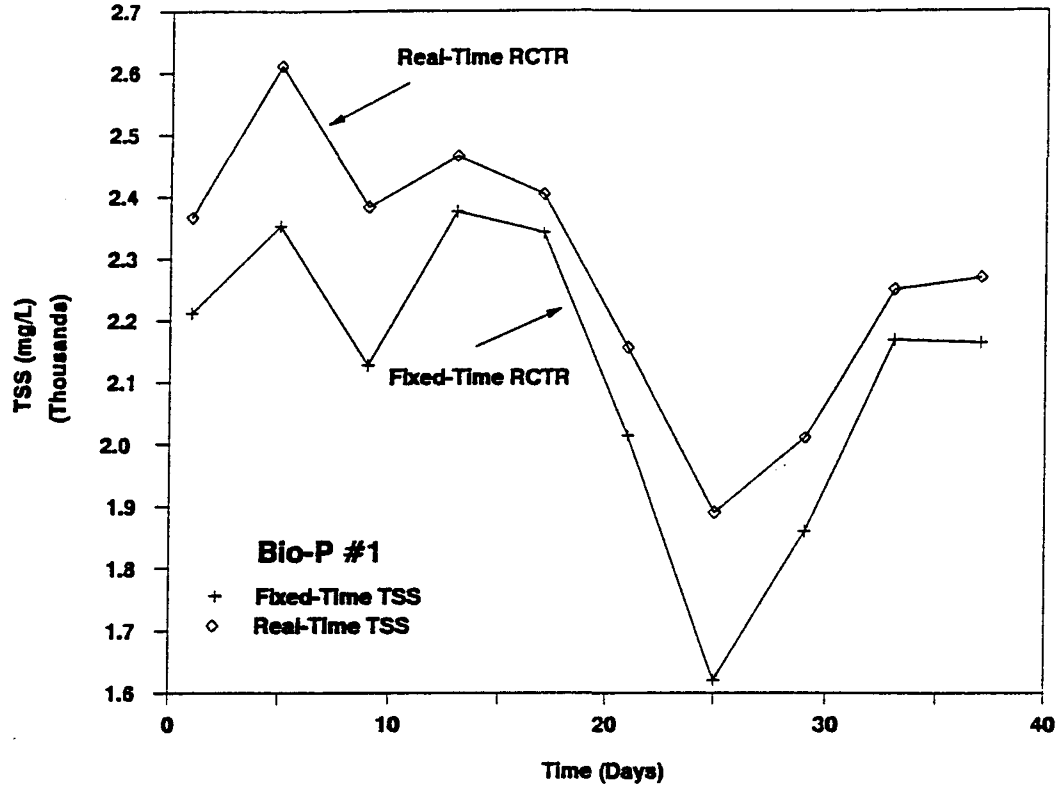


Figure 5.15 Variation in Reactor TSS: Bio-P#1

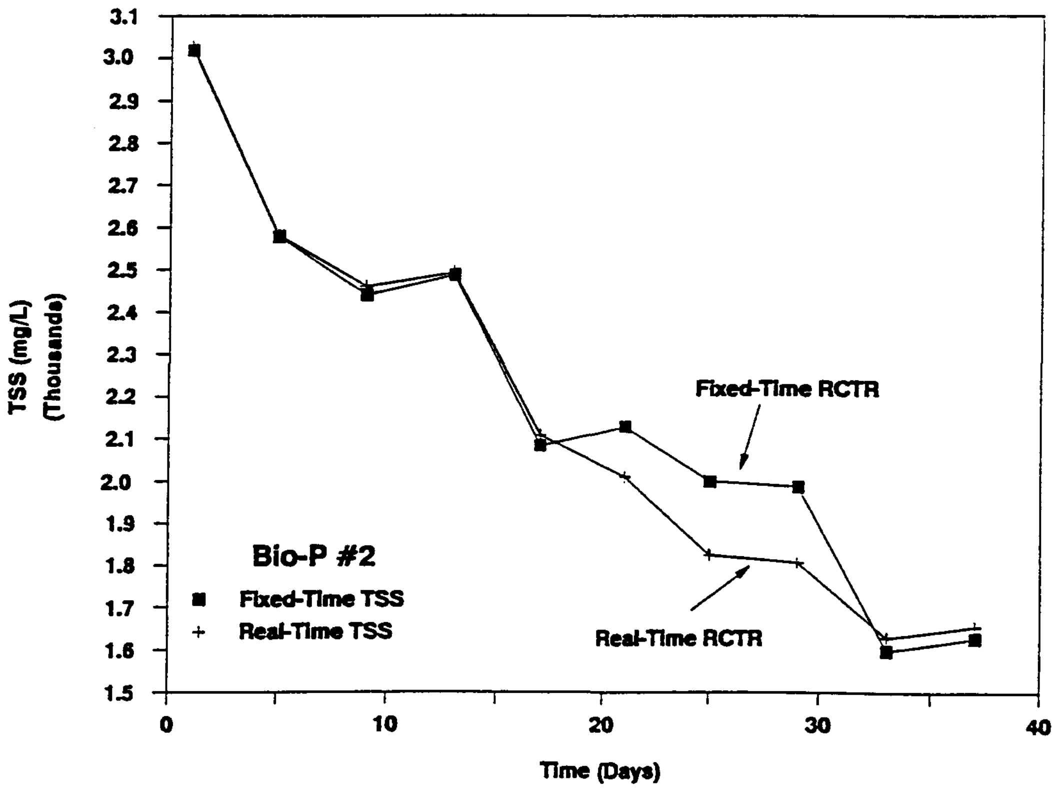


Figure 5.16 Variation in Reactor TSS: Bio-P#2

(Appendix H)) were essentially all volatile solids.

The feed sewage TKN was approximately 30 mg/L, with about 40 percent being in the form of ammonia. In almost all cases the ammonia was completely nitrified, with effluent NH_3 values below the detectable limit of 0.05 mg/L. Nitrate levels in the effluent were between 7 and 9 mg/L; these could not be denitrified, since a single SBR operating under this strategy cannot be optimized to obtain concurrent nitrogen and phosphorus removal. Manning and Irvine (1985), operating a similar system, also reported a highly nitrified effluent (> 27 mg/L NOx).

Due to inorganic P additions to the feed during Bio-P$^{\#}$1, well over 68 % of the TP (average value of 9.5 mg/L) was in the form of soluble ortho-P. Bio-P$^{\#}$2 however had 47 % of the TP (average value 4.7 mg/L) in soluble form.

Figures 5.17 and 5.18 track the progress of the % N and % P values for both reactors (both runs) and indicate that the second run had a slightly larger average % N value than the first run. This is verified in Tables 5.1 and 5.2. In both runs (especially Bio-P$^{\#}$2), there was a tendency for the % P to increase with time. In theory, this should occur as phosphorus is removed from the bulk liquid; however, the fact that little ortho-P removal was observed makes this observed trend more fortuitous than certain.

In fact, the ortho-P behaviour was less than ideal as illustrated in Figures 5.19 and 5.20. In Figure 5.19, the reactor's effluent phosphorus level oscillates around the influent feed phosphorus level; thus, on the average, whatever

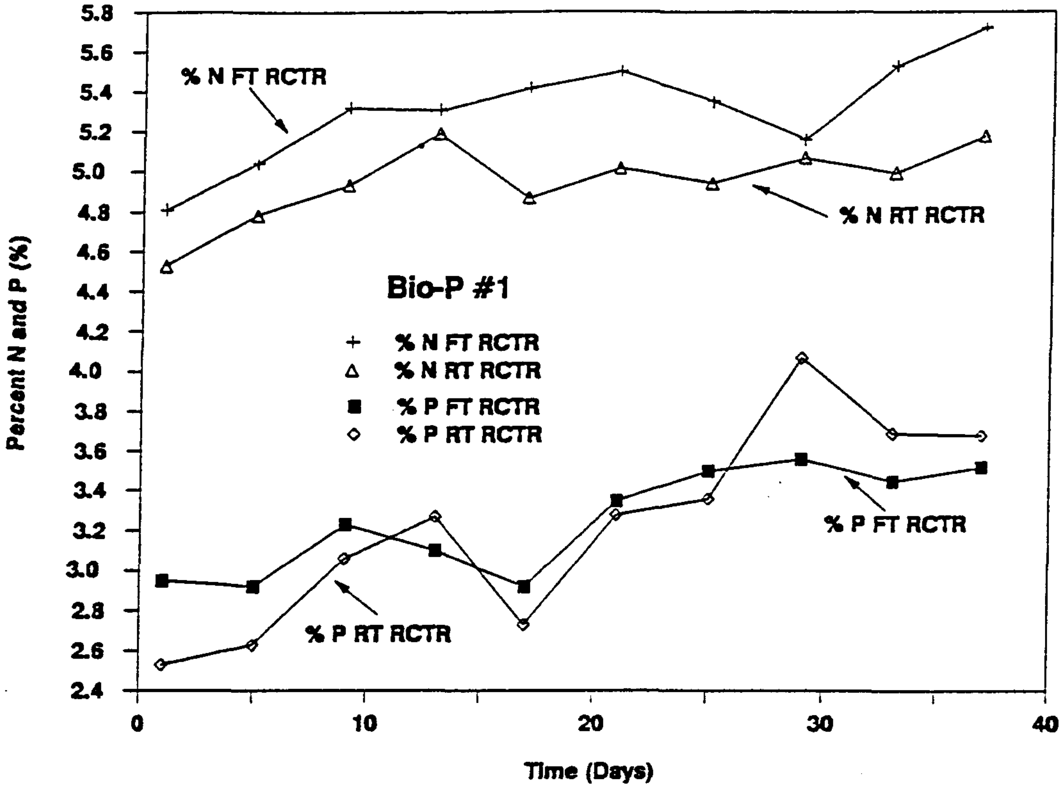


Figure 5.17 Reactor Plot of Percent N and P: Bio-P#1

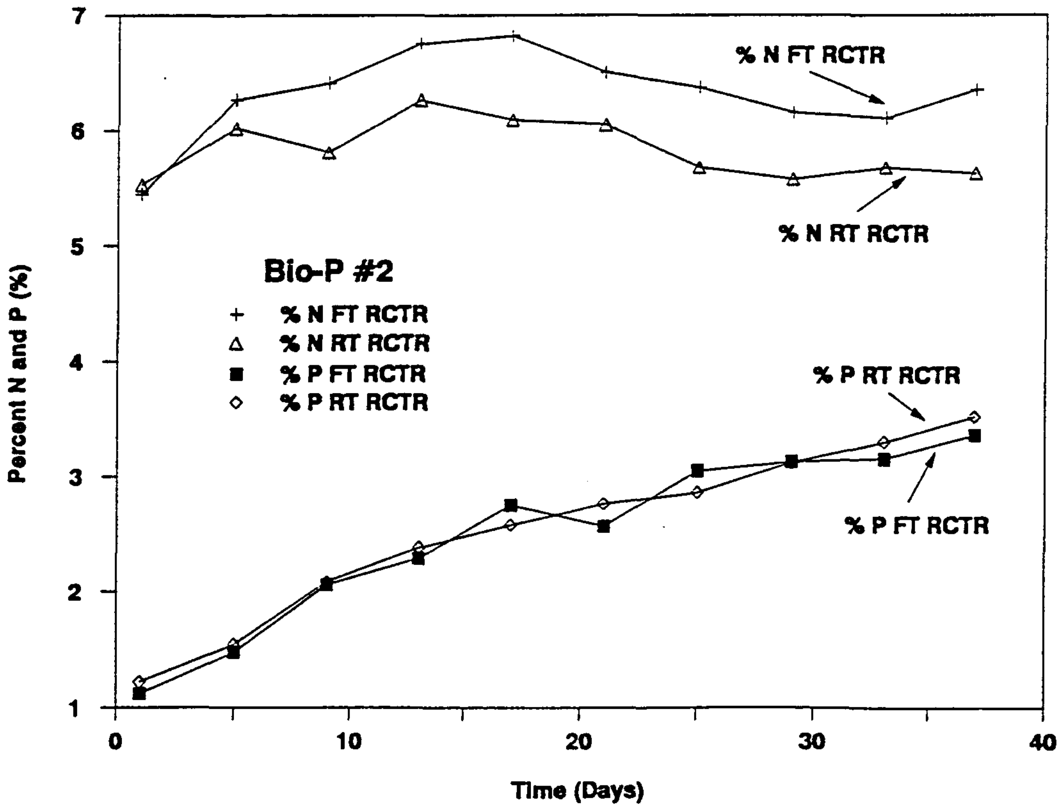


Figure 5.18 Reactor Plot of Percent N and P: Bio-P#2

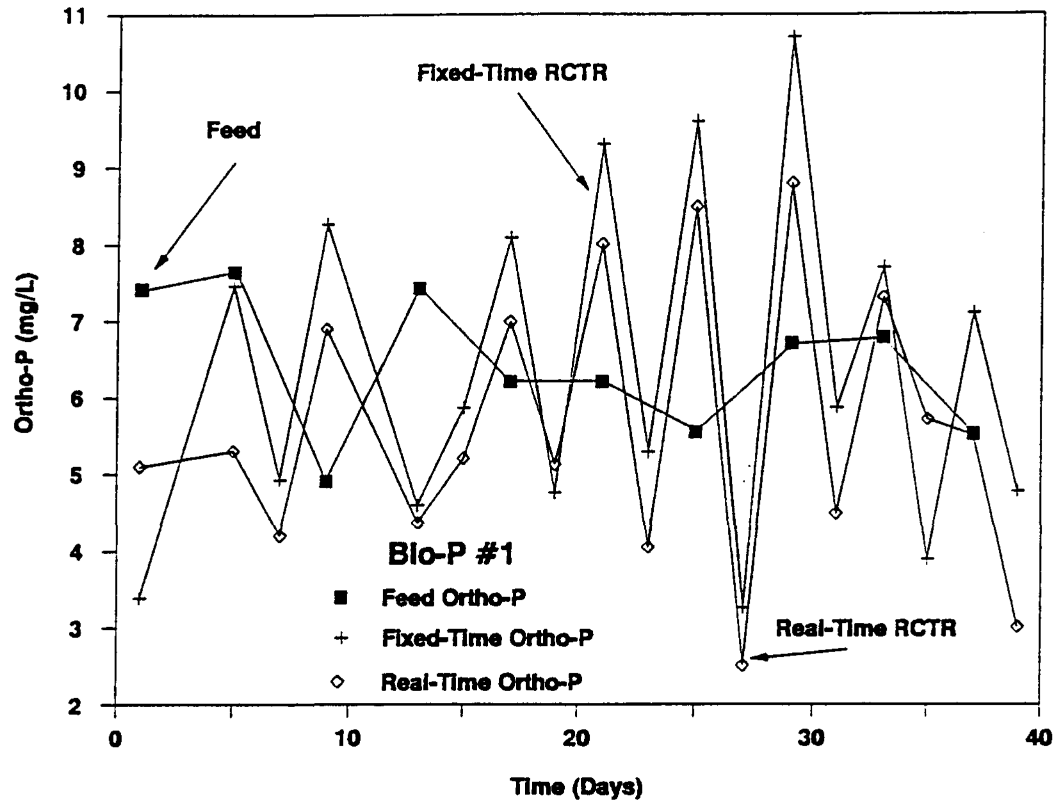


Figure 5.19 Track of Ortho-P Concentrations: Bio-P#1

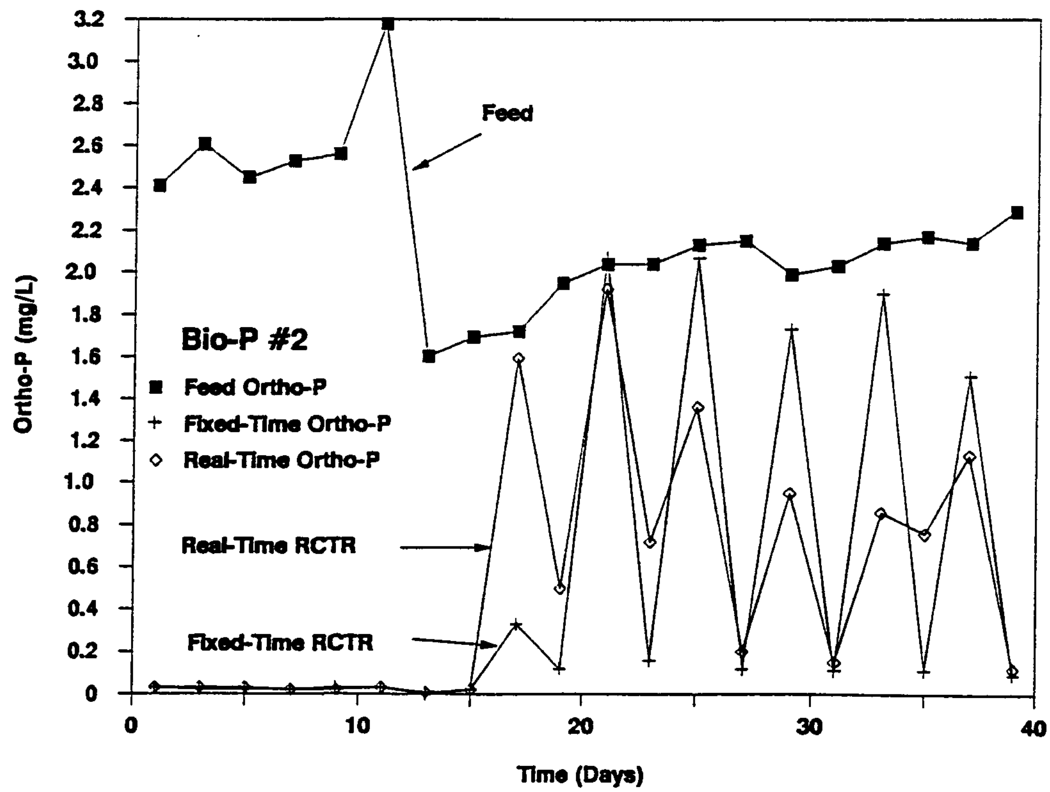


Figure 5.20 Track of Ortho-P Concentrations: Bio-P#2

entered the reactor was also released from the reactor. The parallel behaviour of both reactors (in terms of synchronous high/low oscillations) can be correlated with the decline in the carbon content in the feed bucket as elaborated below.

Ortho-P was measured every second day; thus, one sample would be taken relatively close to the day in which fresh sewage had been added to replenish the feed bucket. On such days the feed would be relatively rich in carbon, and therefore denitrification would proceed rapidly (Figure 5.2) and be followed by a good release of phosphorus when the acetate was added to the reactor. Subsequently, during the aerated sequence, the microorganisms would take up phosphorus and the effluent level would be below average, with some "excess" removal observed.

The next samples, however, would be taken just prior to replenishing the feed bucket; thus, they would be furthest from the previous "fresh/stored" feed day. Denitrification would therefore be delayed (perhaps even incomplete) and some (or all) of the acetate added would be used for denitrification purposes, rather than for carbon storage by Bio-P organisms. On such days, relatively large values of effluent P were observed, because aerated P uptake had been preceded by poor P release. This established the alternating high/low effluent ortho-P pattern shown in Figure 5.19.

The decline in the carbon content in the feed bucket and the lack of steady-state conditions are advocated as the major causes of the poor P removal observed during this research. This will be emphasized repeatedly in later sections of the analysis.

During Bio-P#2 (Figure 5.20), the raw sewage influent P values were much lower than Bio-P#1, due to the absence of inorganic P supplements. Good P removal was observed only up to where the feed sewage had been subjected to several days of rain. The dilution of the carbon in the sewage (coupled with its subsequent decay), although producing an attendant drop in the influent P value, was evidently enough to push the P values into exhibiting the parallel high/low behaviour, as explained above.

Table 5.3 and 5.4 detail the carbon, oxygen, alkalinity and pH statistics for both runs. Figures 5.21 and 5.22 depict the soluble COD behaviour of the feed and reactors during each run. The effluent from both reactors was generally below 30 mg/L for Bio-P#1 and 20 mg/L for Bio-P#2. Using the mean values, this made for soluble COD removals of 81 % and 83 % for the FT and RT reactors (Bio-P#1) and 75 % and 79 % for the FT and RT reactors (Bio-P#2). As indicated however, significant removal was occurring inside the feed bucket, during the days in between replenishment. Figure 5.22 (Bio-P#2) reveals the sharp drop in feed COD from the dry spell to the wet period, commencing after the 3rd data point. Pilot plant data showed a drop in the influent total COD from over 400 mg/L to 230 mg/L, for these collection dates.

Figures 5.23 and 5.24 show carbon plots for the feed from both runs. During Bio-P#1 (Figure 5.23), both the inorganic and organic carbon comprise roughly equal amounts of the total carbon. This is substantiated in Table 5.3. During run Bio-P#2

Table 5.3 Carbon, Oxygen, Alkalinity and pH Data: Bio-P#1

Chemical Parameter	Statistic	FEED TC	FEED IC	FEED TOC	Fixed-Time TC	Fixed-Time IC	Fixed-Time TOC	Real-Time TC	Real-Time IC	Real-Time TOC
Carbon (mg/L)	Maximum	114	66	60	63	52	11	63	53	10
	Mean	95	48	47	45	37	8	45	38	7
	Minimum	79	31	38	31	25	6	31	25	6
	Std.Dev.	11	10	6	11	10	1	10	9	1
COD (mg/L)	Maximum	155			29			28		
	Mean	143			27			25		
	Minimum	118			20			15		
	Std.Dev.	13			3			4		
Dissolved Oxygen (mg.L)	Maximum	----			7.00			6.90		
	Mean	----			4.60			2.90		
	Minimum	----			0.70			0.70		
	Std.Dev.	----			2.07			2.37		
Alkalinity	Maximum	320			310			312		
	Mean	237			254			253		
	Minimum	164			192			178		
	Std.Dev.	47			37			36		
pH	Maximum	7.56			7.37			7.38		
	Mean	7.28			7.12			7.15		
	Minimum	6.81			6.64			6.97		
	Std.Dev.	0.21			0.18			0.14		

Table 5.4 Carbon, Oxygen, Alkalinity and pH Data: Bio-P#2

Chemical Parameter	Statistic	FEED TC	FEED IC	FEED TOC	Fixed-Time TC	Fixed-Time IC	Fixed-Time TOC	Real-Time TC	Real-Time IC	Real-Time TOC
Carbon (mg/L)	Maximum	129	79	50	78	64	14	78	66	13
	Mean	93	56	37	55	47	8	56	47	8
	Minimum	74	42	28	38	31	6	35	28	6
	Std.Dev.	15	11	8	13	12	2	14	13	2
COD (mg/L)	Maximum	72			20			18		
	Mean	53			13			11		
	Minimum	42			10			4		
	Std.Dev.	11			3			3		
Dissolved Oxygen (mg.L)	Maximum	----			8.00			8.00		
	Mean	----			6.65			7.26		
	Minimum	----			1.20			4.20		
	Std.Dev.	----			1.36			0.84		
Alkalinity	Maximum	360			392			390		
	Mean	265			277			282		
	Minimum	210			172			170		
	Std.Dev.	46			66			69		
pH	Maximum	7.59			7.86			7.97		
	Mean	7.38			7.54			7.66		
	Minimum	7.09			7.11			7.34		
	Std.Dev.	0.16			0.19			0.19		

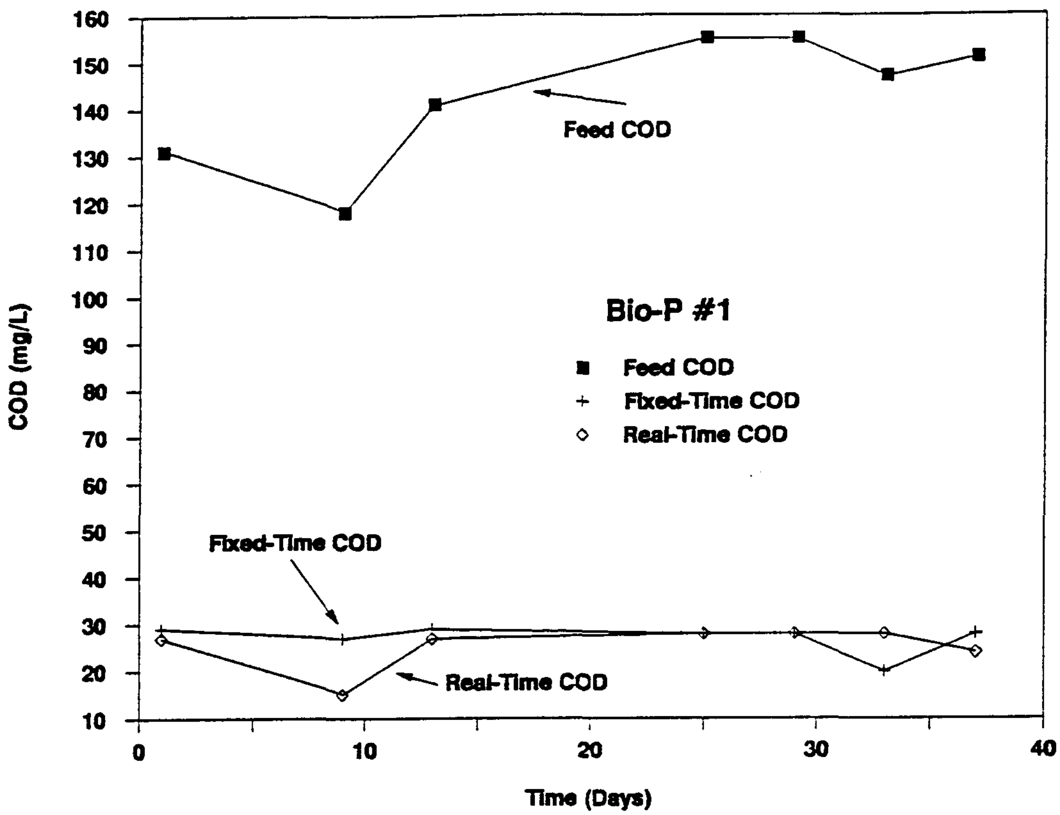


Figure 5.21 Variation in Feed and Reactor COD: Bio-P#1

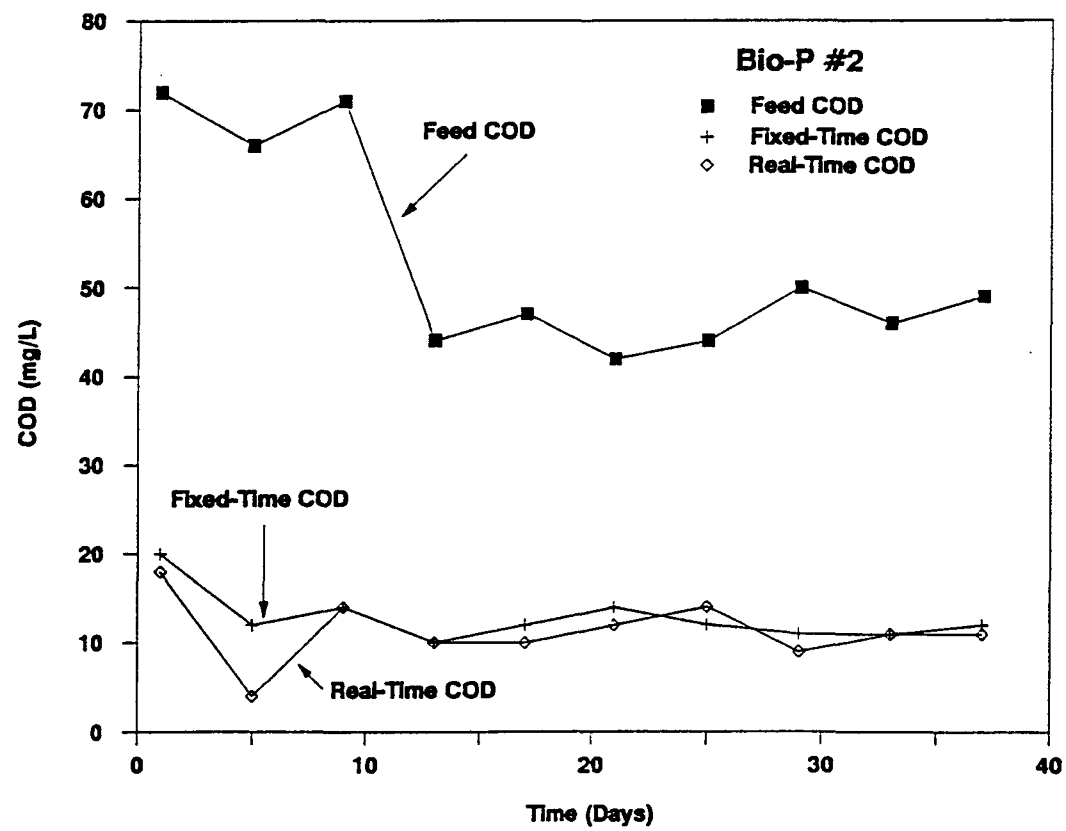


Figure 5.22 Variation in Feed and Reactor COD: Bio-P#2

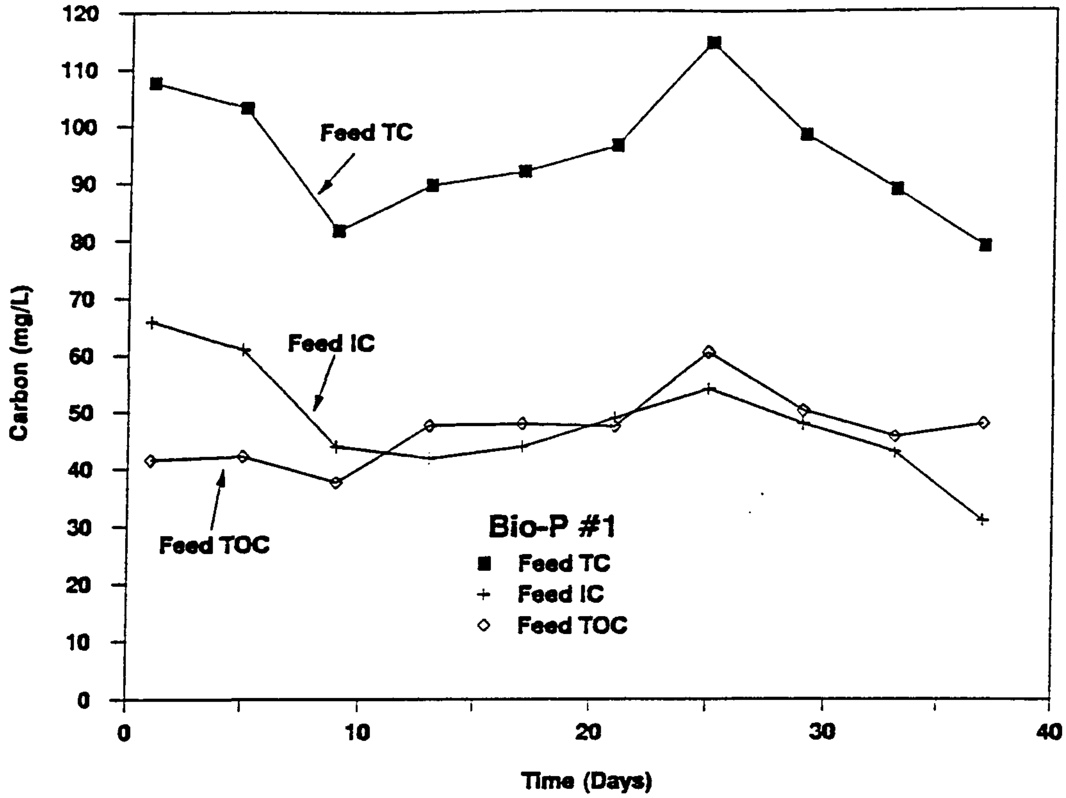


Figure 5.23 Carbon (TC, IC, TOC) Plots for Feed: Bio-P#1

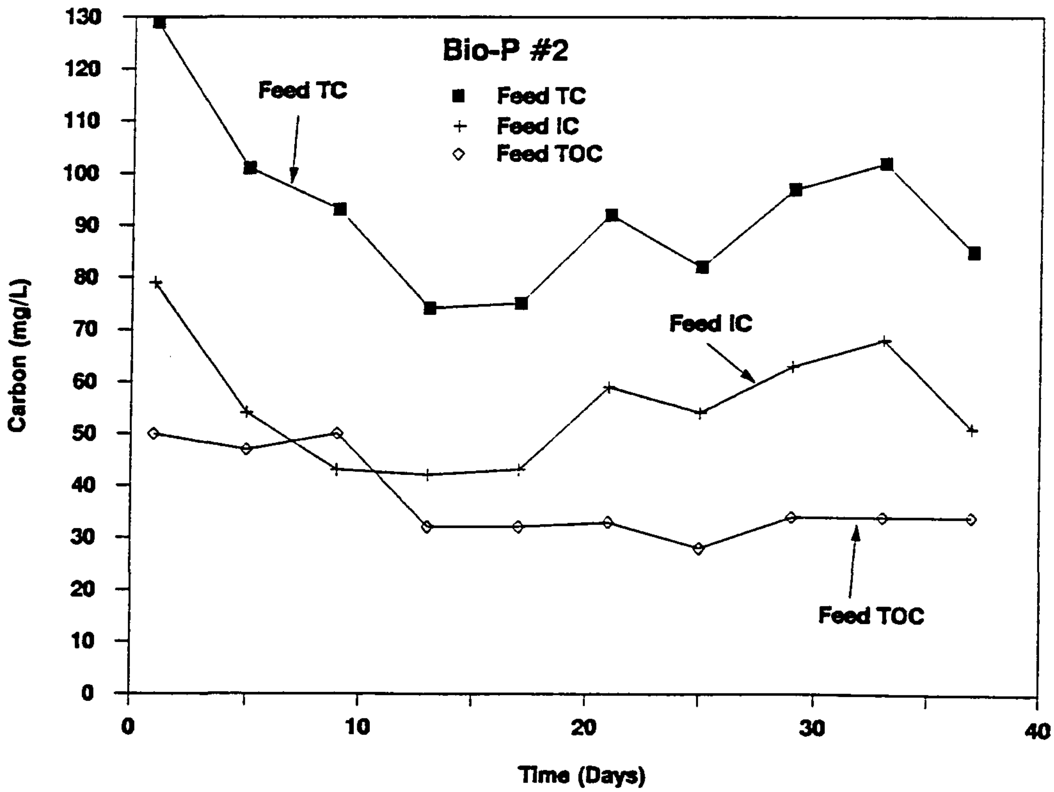


Figure 5.24 Carbon (TC, IC, TOC) Plots for Feed: Bio-P#2

however, the percentage of inorganic carbon is larger than the organic carbon, another indication of the generally "weaker" sewage used during this run. The decline in feed TOC from the 3rd to 4th data points (Bio-P#2) is not as marked as it was in the COD profile; however, it is still sufficiently pronounced, to be suggested as a partial reason for the sudden change in the P behaviour from generally stable low values to the fluctuating behaviour described earlier.

Figures 5.25 and 5.26 illustrate (for both runs) the behaviour of the carbon in the Fixed-Time reactor. As can be seen, the TOC was very low ($\leq$ 10 mg/L) and fairly constant as indicated by the horizontal nature of the TOC plot and the relatively even distance separating the IC from the TC profile. The Real-Time reactor, if plotted, would show a similar trend.

The large standard deviations (Tables 5.3 and 5.4) for the reactor dissolved oxygen concentrations, are indicative of the lack of control achievable at the lab scale. Small adjustments to the needle flow control valves produced wide swings in the D.O measurement in the bulk liquid. A plot of these values would be essentially stochastic and of little value, especially since, in the Real-Time reactor (Bio-P#1), the standard deviation was almost as large as the mean. In run Bio-P#2 no attempt was made to control the oxygen supply and thus the D.O. level was often at a maximum, usually around 7 mg/L.

The alkalinity values were also random in nature, reflecting the casual manner in which two scoops of sodium bicarbonate were tossed into the feed bucket, every time it was

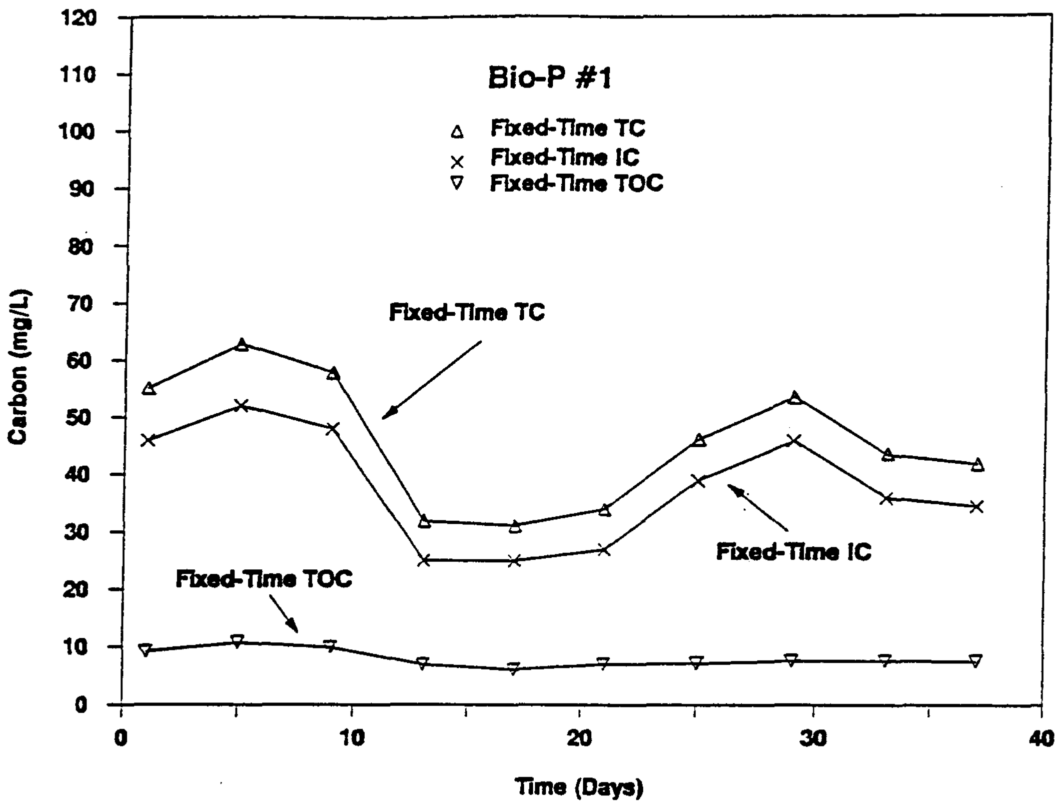


Figure 5.25 Carbon (TC, IC, TOC) Plots for FT RCTR: Bio-P#1

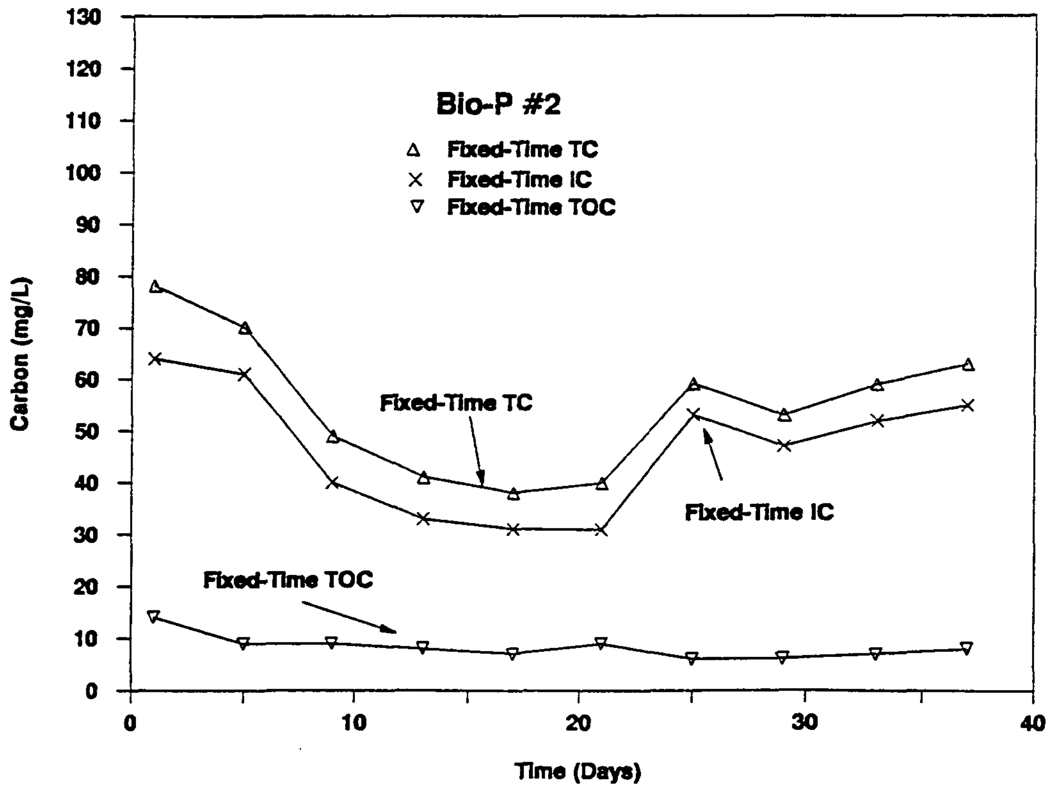


Figure 5.26 Carbon (TC, IC, TOC) Plots for FT RCTR: Bio-P#2

filled. Plots of the variation in pH with time are shown in Figures 5.27 and 5.28; since all pH measurements fall within the neutral range, it is clear that the alkalinity additions were more than sufficient to supply the consumptive needs of nitrification. Some unduly large pH values were recorded, and it is suspected that some CO_2 was being stripped from solution due to excessive aeration.

When all of the preceding observations are considered, it is evident that several key biological and chemical parameters must be in balance in order to consistently achieve good P removal. One such relationship is the TKN/COD ratio, which in effect quantifies the denitrification capacity of the influent sewage. Researchers have long recognized the importance of this ratio. For example, Ekama et al., (1984) critiqued the Modified Bardenpho (Phoredox) process and predicted it would experience complete nitrification/denitrification, only when the influent sewage possessed a TKN/COD ratio less than 0.07. (i.e. a COD/TKN ratio of greater than 14:1). TKN/COD ratios larger than 0.07 seemed to have difficulty in providing enough carbon for denitrification.

The need to accommodate lower strength sewages was one reason (among others) behind the development of the UCT process, reported to be able to cope with TKN/COD ratios of up to 0.14 (i.e. COD/TKN ratios as low as 7:1). Working within these ratios, Ekama et al., (1984) were able to guarantee enough carbon available (in most instances) to ensure that nitrates did not bleed through to the anaerobic reactor.

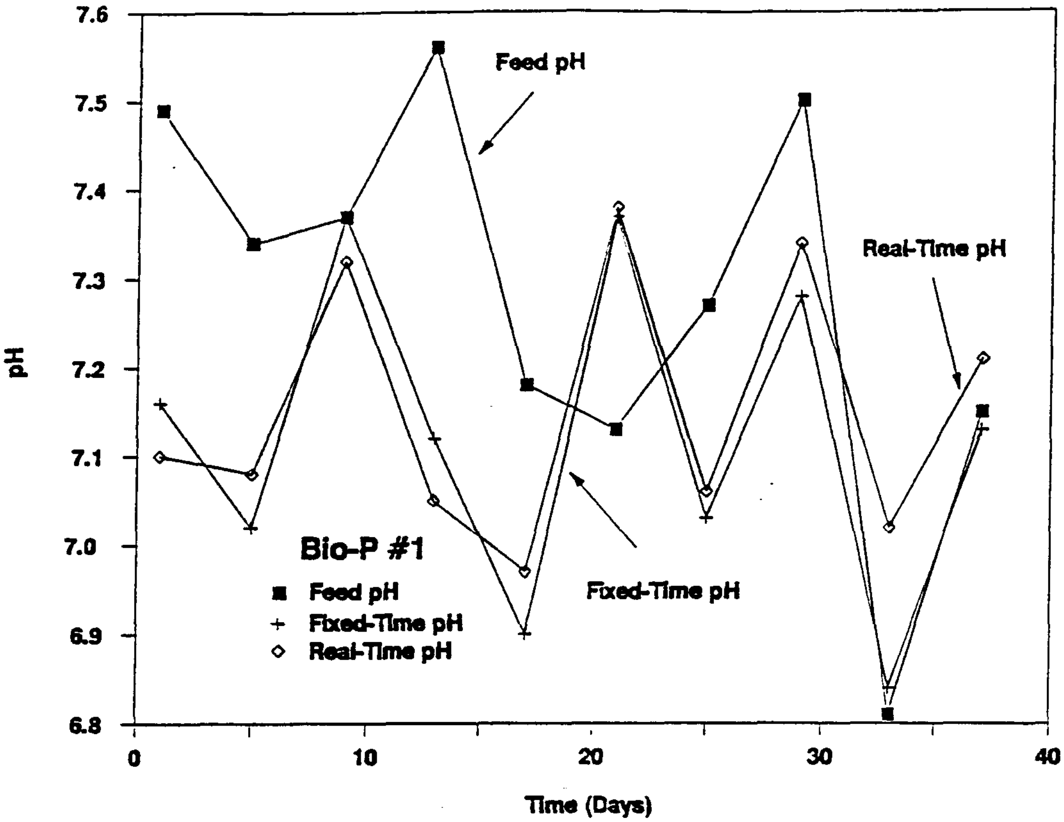


Figure 5.27 Variation in pH Feed, FT and RT RCTRS: Bio-P#1

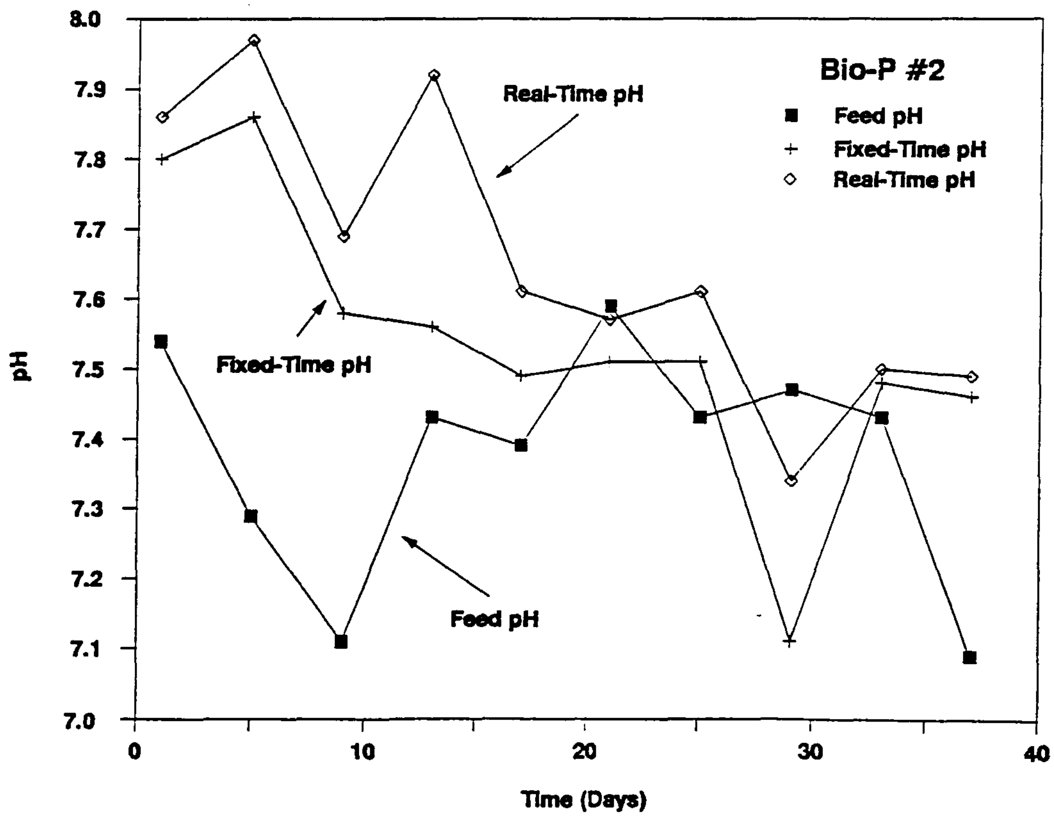


Figure 5.28 Variation in pH Feed, FT and RT RCTRS: Bio-P#2

Barnard et al. (1985), however, showed that the Kelowna B.C., Bio-P process was able to achieve good P removal with ratios between 7:1 and 10:1, despite predictions that it would need a COD/TKN ratio of at least 14:1 in order to function effectively,

The pilot plant's TKN/COD ratio is usually between 0.06 and 0.08 (Comeau (1989)). Unfortunately, in this research, total COD values are only available for the feed collection days. Accordingly, the average total CODs for Bio-P#1 and Bio-P#2 were 261 mg/L and 292 mg/L, respectively.

Using the mean values for TKN (Tables 5.1 and 5.2), a TKN/COD ratio of 0.11 was calculated for both Bio-P#1 and Bio-P#2. As large as this ratio is, it is still lower than the actual ratio present on most days, since the COD values do not consider the decline in COD during the days in between replenishment of the feed bucket. Moreover, in this experiment, the ratio was unusually affected by the vagaries in local weather patterns, since one collection would influence the following 12 days.

The fact that the TKN/COD ratio on most days is quite large is somewhat overshadowed by the peculiarity of the SBR treatment method, in that it transposes the traditional (ex. UCT or UBC) order of zones, from anaerobic, anoxic, aerobic, to anoxic, anaerobic, aerobic. This has the effect of accentuating the concern about whether sufficient carbon is available for Bio-P organisms to predominate.

To illustrate, in the traditional sequence, the emphasis has not only been to ensure enough carbon enters the first (anaerobic) zone, but also that it enters in the right form (i.e. as rapidly biodegradable (RBD) carbon (Nicholls and Osborn (1979)). The RBD fraction of the carbon is understood to be that portion of the carbon that can easily pass through the cytoplasmic membrane of the cell by diffusion or osmotic pressure. RBD carbon is usually comprised of short-chain fatty acids (SCFA), such as acetate, propionate, butyrate etc., and much work has been done at UBC on processes designed to enhance the production of these substrates in the incoming sewage (Rabinowitz et al. (1986), (1987), Elefsiniotis (1992)). Seibritz, Ekama and Marais (1983) have established that there must be at least 25 mg/L of RBD COD available in the anaerobic zone to ensure good P release/carbon storage.

Further to this, there must be enough remaining carbon to reduce the nitrates in the second (anoxic) zone, as implied by the earlier comments about the TKN/COD ratio. If insufficient carbon is available, nitrates will bleed through (via the recycle line) into the anaerobic zone, inhibiting P release.

Current theories suggest that nitrates inhibit P release (as measured by bulk liquid orthophosphate concentrations) by providing an electron acceptor for facultative denitrifiers. Consequently, Bio-P organisms do not have exclusive access to all of the RBD substrate. There is, however, considerable evidence (Hascoet and Florentz (1985), Vlekke (1988) and Comeau (1989)), that at least a fraction of Bio-P bacteria are capable of assimilating polyphosphates in the presence of nitrates. Thus, the reason for poor P release (when nitrates are present in the anaerobic zone), becomes one of competition between Bio-P organisms (rather than inhibition by other organisms) and is a function of the relative mix of organisms in the wastewater (those releasing P and those accumulating P).

Although it is likely that a combination of the above reasons is responsible for P release not being as vigourous in the presence of nitrates, this research will explain its results from the first premise (i.e. nitrates provide electron acceptors for bacteria, which in the process of denitrifying, utilize some of the carbon which should have been stored by Bio-P bacteria).

The SBR trait however, of inverting the first two sequences, means that <u>all</u> of the carbon in the influent sewage is primarily available for denitrification. This includes all of the RBD COD, although it is appreciated that other than the first (and perhaps a portion of the second) day after fresh sewage has replenished the feed bucket, most of the RBD fraction of the sewage would have disappeared. Upon entering the reactor, unless there is a large amount of carbon (specifically RBD COD) available in the influent, practically all of it will be utilized by denitrifying bacteria and none will be available for storage by Bio-P organisms.

Several researchers have suggested different values of COD utilized / mg of nitrate reduced. Ekama et al. (1984) has estimated the amount of RBD in a sewage by assuming that every mg of nitrate reduced by RBD carbon, utilizes 8.6 mg of the carbon for synthesis and energy production (U.S. EPA (1987)). Rabinowitz (1985), in a series of acetate fed batch experiments derived a rate of 3.60 mg COD / mg NO_3-N, a value less than one half of the value quoted above. In fact, this value is very close to the theoretical (stoichiometric) value for acetate (3.53 mg COD/mg NO_3-N) as calculated by McCarty et al. (1969). Whichever method is used, it is apparent that a considerable fraction of the influent carbon would be utilized for denitrification just because of the order of sequences in the SBR.

At the full-scale level there is much less of a problem, since fresh feed is available on a daily basis. At the laboratory scale however, the SBR characteristic of inverting the two unaerated sequences (as it relates to the quantity and partitioning of carbon), can be accommodated in one of several ways.

Manning and Irvine (1985) have circumvented the difficulty by using synthetic feed (not seeded with microorganisms and therefore not subject to substantial COD decay), prepared daily at the desired COD/TKN ratio. In their case, using SBRs on a 8 hour cycle, they used a relatively low COD/TKN ratio of 7.5:1, but were still able to reduce the ortho-P from 13 mg/L to 0.5 mg/L.

The other method of ensuring enough RBD carbon, is the approach utilized in this research. As demonstrated, it involves artificially adding substrate when the denitrification reaction is suspected (Fixed-Time) or known (Real-Time) to be complete. This procedure operates from the premise that none of the influent carbon will be available for Bio-P carbon storage.

However, as already seen in this analysis, the fluctuation in the carbon content when using real sewage still influences the operation of the SBRs significantly. On days when there is fresh feed available, denitrification happens quickly, often foiling the attempt by the Real-Time reactor to trap the nitrate breakpoint. During subsequent cycles, when the influent carbon content is low, denitrification likely occurs using carbon generated through endogenous reactions, much like the AASD set of experiments. On these days, the delay in the nitrate breakpoint clashes with the reactor's addition of acetate (especially the Fixed-Time reactor). In such cases, the acetate is used partially for denitrification and partially for Bio-P carbon storage. Thus, poor P uptake in the aerobic zone is observed and, as mentioned, this often degenerates into an oscillating high/low behaviour exhibited by the effluent P.

A second critical parameter that must be in balance is the Food:Microorganism (F:M) ratio in the reactor. Many researchers consider the F:M ratio as having a major influence on the biological nutrient removal process (in terms of its operation and performance (Krichten et al. (1985), Tracy and Flammino (1987)). Of the SBR studies reviewed for this research, Manning and Irvine (1985) used an F:M ratio of 0.26 g COD/g VSS/d while Irvine et al. (1985) reported successful full-scale P removal at the Culver Indiana SBR, with F:M ratios of 0.16 and 0.42 kg BOD_5/kg MLVSS/d.

Maier et al. (1984), in a series of pilot plant experiments, observed that the rate of phosphorus uptake/unit of

MLVSS decreased by a factor of 2.6, as the F:M ratio declined from 0.2 to 0.1 kg TBOD/kg MLVSS/day. Tracy and Flammino (1985) reported bench-scale results in which the TBOD:TP ratio was held constant at 16:1, while the F:M ratio was decreased from 0.44 to 0.24 TBOD/kg MLVSS/d. They observed that the rate of phosphorus uptake in the aerobic zone decreased by a factor of three. McCartney and Oleszkiewicz (1988) used synthetic feed in lab scale SBRs, but were unable to achieve excess P removal. They hypothesized that, among other reasons, their F:M ratio (not stated in the paper) was too low to get good P removal.

The lack of uniformity in both the way of reporting the F:M ratio and in the operation and type of Bio-P systems for which results are available, make comparisons with this research difficult. As evidenced by the preceding discussion however, there is little doubt that the F:M ratio is an important parameter and can considerably influence the propensity for P removal in a system.

Most wastewater treatment systems are designed to be operated at steady-state. In this research however, the mass of solids in the reactor declined dramatically over the course of the run. The lack of aeration control may have contributed to an over-oxidized biomass (loss in solids); however, since little solids were lost in the effluent, it is clear that the major cause of this was a lack of bacterial growth inside the reactor. Thus, insofar as the solids were concerned, steady-state conditions were not achieved.

Comeau (1989) operated SBRs in a similar manner using an

8 hour cycle and a 20 day SRT. His objective was to characterize the addition of various levels of acetate on PHA storage. The results for the 30 mg/l acetate addition were very similar to the results from this research, in that both release and uptake occurred to about the same levels observed in this study. No excess removal of phosphorus was observed for any of the acetate additions (0, 15, 30, 45 mg/L) and thus the effluent P levels were virtually the same as the influent values. He does comment however, both on the lack of aeration control and the lack of steady-state conditions; however, no time-series solids data is presented.

As is evident in this research, the F:M ratio was constantly changing with time due to fluctuations in both the carbon content in the feed bucket and the decline in the solids in the reactor; thus, no calculations are presented for this analysis. Using the averages for the total COD and the MLVSS is invalid, and it does not reflect the reality of the trends experienced in the reactor. It is suspected however, that the lack of steady-state conditions influencing the F:M ratio, also contributed to the lack of excess phosphorus removal observed during the course of this research.

5.3 Evaluation of Reactors: Breakpoint Categories

As is evident from the above analysis, during both runs the reactors failed to remove, for any reasonable length of time, a level of phosphorus that could be considered as "excess". Thus, the reactors cannot be compared on the basis of successful P removal. Moreover, the characteristic curve shape (i.e. the ideal ORP-time profile depicted in Figure 5.1) was never achieved, for either reactor, for any significant period of time. Therefore, a tabulation of deviations from an "indigenous" profile (due to spikes or otherwise) is not possible (as was done for the AASD set of experiments). In fact, no spikes of any kind were performed, due to the general lack of stability (both phosphorus related and ORP related) in the reactor.

It is possible, however, to outline a protocol for evaluating the reactors, which could be followed in the event that excess biological phosphorus removal is regularly achieved. This is done by categorizing the nitrate breakpoints into distinct groupings and tabulating the number of occurrences of each kind.

For example, since a key criterion for successful Bio-P removal involves the elimination of nitrates from the anaerobic sequence, a reactor operating under Fixed-Time conditions may prematurely implement the addition of VFAs, before all nitrates have been reduced by denitrifying bacteria. Thus, a proportion (or all) of the acetate may be used to reduce nitrates, rather than being sequestered into carbon reserves by Bio-P organisms. This has already been observed in Figures 5.5 and 5.6. Partitioning of the acetate between denitrifiers and Bio-P microbes represents a "failure" category, since, in essence, the objective of VFA addition has been partially thwarted. Such a category can be recognized by a detailed examination of the time-of-occurrence of the breakpoints. If the nitrate breakpoint occurs either simultaneously with or after the acetate addition (i.e greater than or equal to), it defeats the purpose of VFA addition since all or a portion of the acetate is being used to reduce nitrates, rendering it unavailable for the exclusive use of micro-organisms capable of excess P removal.

Categorizing the nitrate breakpoints into different groupings is illustrated in Figures 5.29 and 5.30. Figure 5.29 shows a detailed snapshot over two days, itemizing the breakpoints into those that occurred before the addition of acetate (and thus the acetate was used solely for carbon storage), those that were directly attributable to (i.e induced by) the addition of acetate, and those that occurred after VFA addition and thus had a portion of (or all of) the acetate utilized for denitrification. As implied in the previous paragraph, the latter two categories can be considered as one category.

A longer snapshot in time is presented in Figure 5.30. This plots (over 8 days) the length of time taken to denitrify in the Fixed-Time reactor, as measured by the length of time from the end of the FILL period to the nitrate breakpoint. Similar to the AASD experiments, a cyclical pattern (on a larger scale) develops, this time a function of the carbon content in the feed bucket. The dotted line represents the point of Fixed-Time addition of acetate (i.e. 1 hour and 25 minutes into the anoxic zone). Thus, those cycles which possess denitrification times below the line are operating in true Bio-P fashion, that is, having acetate additions which comply with the stated objective (i.e. used solely for carbon storage). Those cycles greater than

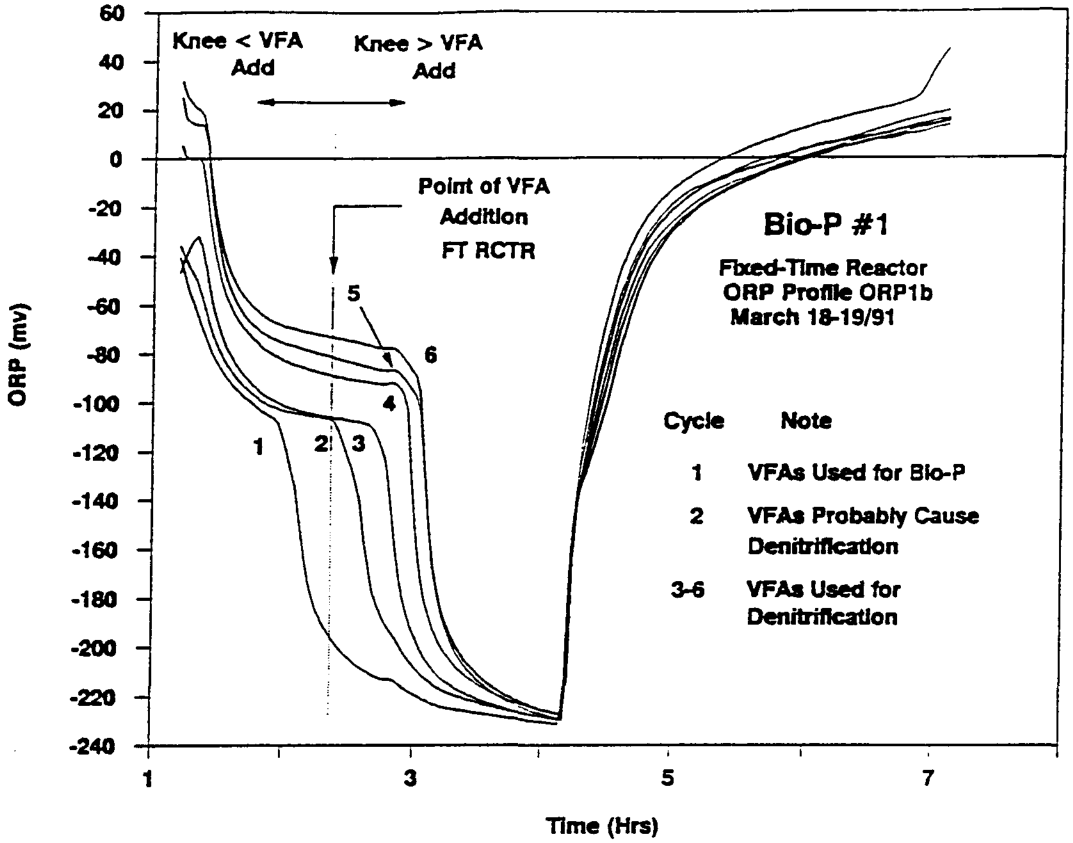


Figure 5.29 Breakpoints Classified According to Acetate Use

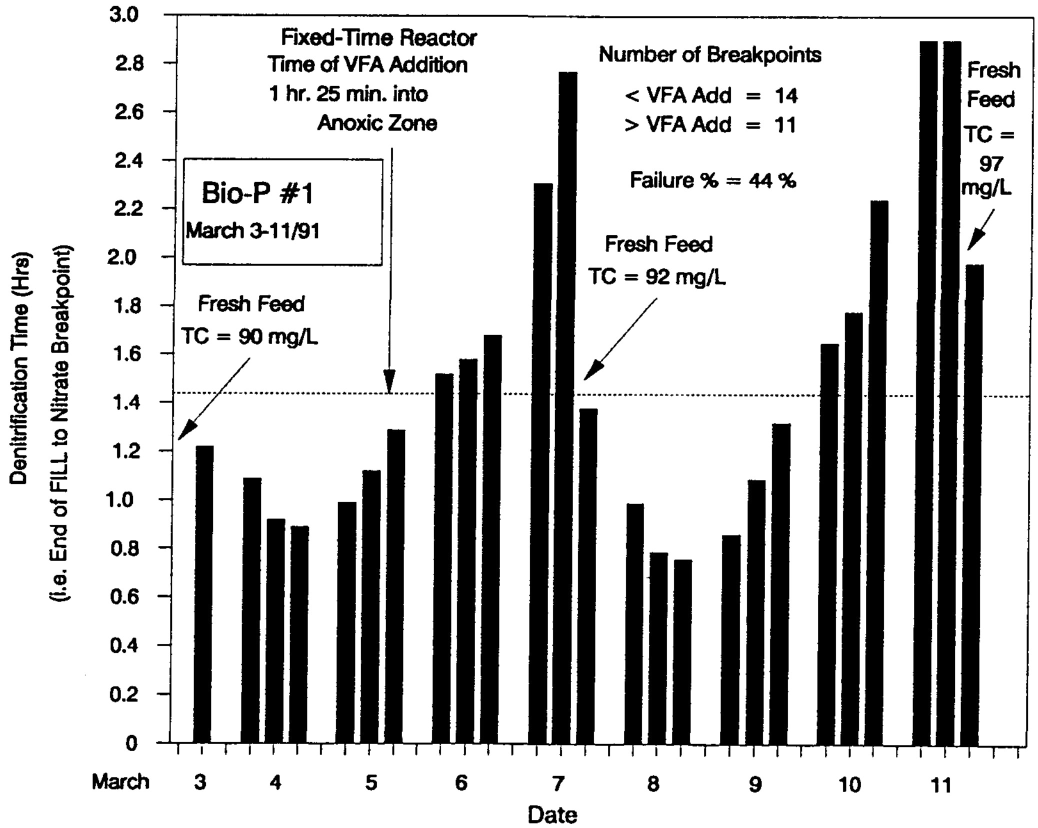


Figure 5.30 Nine Day Track of Denitrification Time

or equal to the line are "failing" insofar as the purpose of acetate addition is concerned, since the acetate is not being exclusively stored in carbon reserves. As can be seen, in this particular period, for a full 44 % of the time, the acetate was not used solely for carbon storage.

Other breakpoint categories involve the Incomplete Denitrification failure previously shown in Figure 5.12. There did not seem to be a corresponding Incomplete Nitrification failure, as measured by the NH_3 level in the effluent. This is due to the large D.O. values observed during reactor aeration.

One further "failure" category is the "Rapid Denitrification" pattern previously documented in Figure 5.2 and which occurs when denitrification happens immediately after the FILL period has ended. This category is a "failure" insofar as the Real-Time reactor is concerned, since it is unable to detect the breakpoint, upon which proper acetate addition is contingent. It is not a "failure" from the Fixed-Time reactor perspective, however, since the acetate is added regardless of when the knee occurs.

Another "failure" particular to Real-Time control is "Curve Distortion" which makes the true knee impossible to ascertain. Since Real-Time control hinges upon clean reproducible curves, any time there is distortion, the software has difficulty in detecting the breakpoint. For example, Figure 5.31 depicts the curve generated when the decanting solenoid failed, by remaining open after the DRAW/IDLE period had terminated. Thus, during the next FILL period, the incoming sewage mixed with the settled

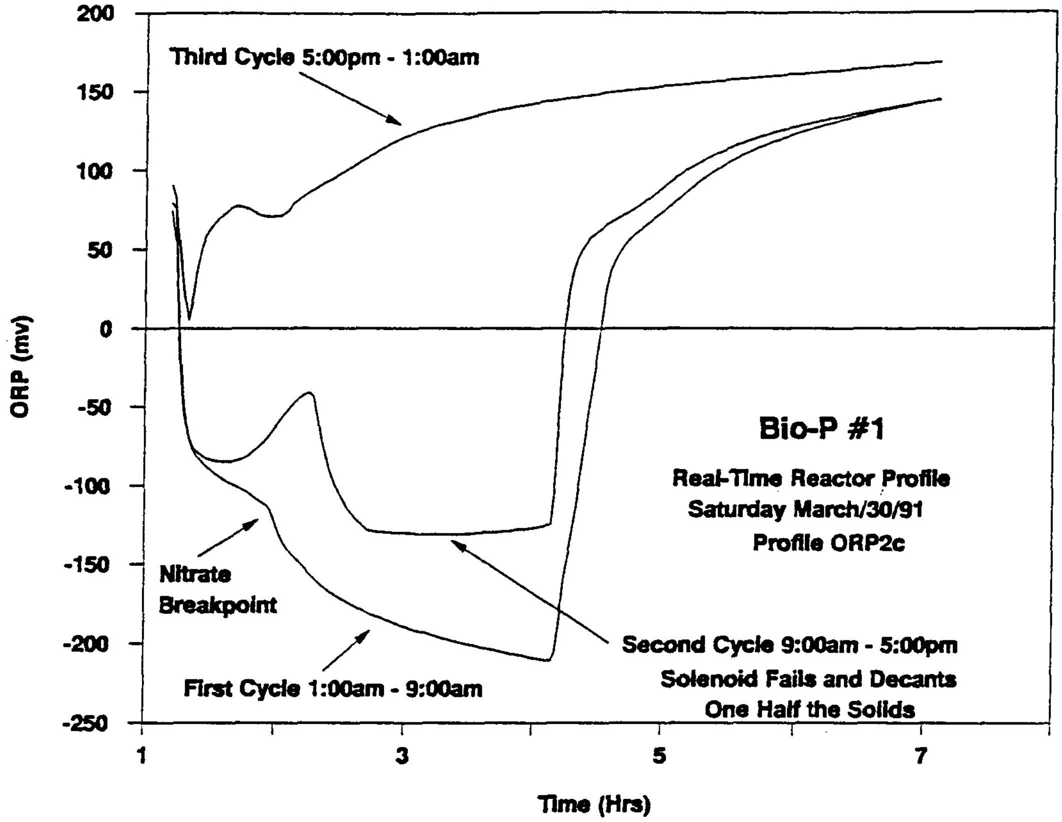


Figure 5.31 Disruption of Reactor Due to Solenoid Failure

reactor contents and then immediately exited the reactor, carrying half the solids with it. Thus, the ORP probes measured the contents of a reactor that was much diluted. In Figure 5.32, the profile is shown which results from a mixer dislodging (allowing the reactor contents to settle). In this particular figure, the ORP probe measured the value obtained in the clarified supernatant, rather than from a reactor that was uniformly mixed.

The final breakpoint categories can be considered as "success" categories, in the sense that the purpose of acetate addition (to an SBR operating in Bio-P fashion) is being realized. For the Fixed-Time reactor, this translates into the breakpoint occurring well before the addition of acetate (1 hour and 25 minutes). For the Real-Time reactor, it represents a sharp, detectable breakpoint which can be used to trigger the release of acetate to the bulk liquid.

Tables 5.5 and 5.6 tabulate the number of occurrences (for both runs) of each type of breakpoint category and tallies those considered to be failures for each reactor. The total number of cycles in each run should theoretically be 120 (i.e. 40 days x 3 cycles/day); however, a few days were disregarded in each run due to power failures (longer than the UPS back-up capability) and days in which the reactor operation was momentarily halted in order to download the data.

As can be seen, the tables indicate a rather high percentage (40-70 %) of failures for both reactors. No conclusions about the relative performance of the reactors can

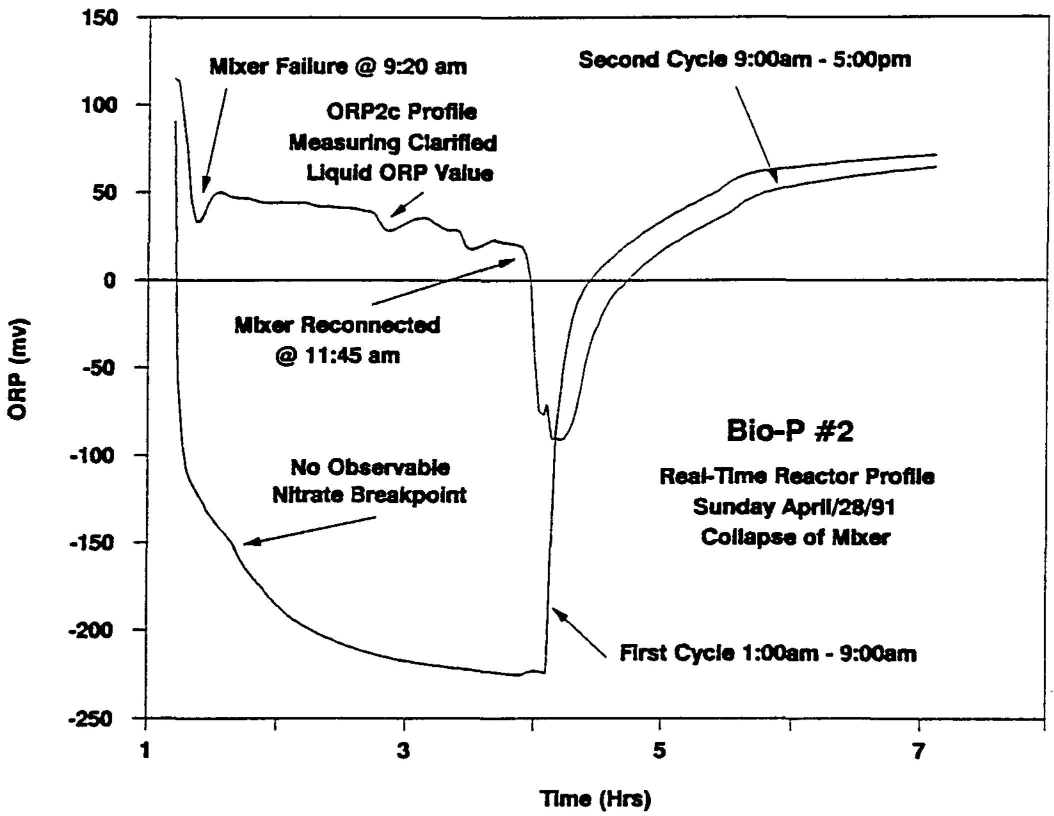


Figure 5.32 Disruption of Reactor Due to Mixer Failure

Table 5.5 Breakpoint Classification Categories: Bio-P#1

Breakpoint Classification Category Bio-P#1	# of Cycles	% of Cycles
Fixed-Time Reactor		
Breakpoint < VFA Addition	51	43 %
Failure - Breakpoint ≥ VFA Addition	56	48 %
Failure - Incomplete Denitrification	7	6 %
Rapid Denitrification - No Breakpoint	4	3 %
Fixed-Time Failure Percentage = 54 %	118	100 %
Real-Time Reactor		
Sharp Detectable Breakpoint	69	59 %
Failure - Breakpoint = VFA Addition	7	6 %
Failure - Incomplete Denitrification	11	9 %
Failure - Rapid Denitrification	25	21 %
Failure - Curve Distortion	6	5 %
Real-Time Failure Percentage = 41 %	118	100 %

Table 5.6 Breakpoint Classification Categories: Bio-P#2

Breakpoint Classification Category Bio-P#2	# of Cycles	% of Cycles
Fixed-Time Reactor		
Breakpoint < VFA Addition	7	6 %
Failure - Breakpoint ≥ VFA Addition	67	58 %
Failure - Incomplete Denitrification	3	3 %
Rapid Denitrification - No Breakpoint	38	33 %
Fixed-Time Failure Percentage = 61 %	115	100 %
Real-Time Reactor		
Sharp Detectable Breakpoint	33	29 %
Failure - Breakpoint = VFA Addition	35	30 %
Failure - Incomplete Denitrification	4	4 %
Failure - Rapid Denitrification	37	32 %
Failure - Curve Distortion	6	5 %
Real-Time Failure Percentage = 71 %	115	100 %

be drawn from these results, since the purpose of this exercise was merely to illustrate one aspect of the protocol that would be followed in evaluating the performance of the reactors. Perhaps the only comment that can be made is a relativistic one, in terms of the difference between Bio-P#1 and Bio-P#2. The generally weaker sewage of Bio-P#2 is likely the major reason behind the greater number of failures (30%) in the "Breakpoint = VFA" category, as compared to Bio-P#1 (6 %). In this case it seems reasonable to suggest that weaker sewage directly caused a greater proportion of times that acetate was used to directly induce the breakpoint.

To summarize, the above method involves categorizing the breakpoints into distinct groupings based upon whether they assist or hinder the purpose of VFA addition in SBR Bio-P removal. This would be incorporated into a larger protocol for evaluating a system successfully removing phosphorus. That is, the above analysis could be considered in conjunction with measurements of effluent ortho-P (presented as a time-series analysis), from a successfully operating Bio-P system. Graphically depicting the differences in effluent quality between a functional process (one in which ortho-P levels were consistently low and constant) and a non-functional process (one with either high or erratic P levels) would assist in deciding which system was the preferred one in terms of control stability. It is hoped, of course, that an ORP-driven system would be recognizable as the better alternative; however, more research is needed to substantiate this.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Many of the traditional methods of controlling activated sludge plants (ex. F:M and SRT), use variables which are historical in nature, in the sense that they convey what has historically happened to the biomass. A system at steady-state can be effectively controlled by the proper application of such parameters. There exists a need however, to continue to investigate parameters which can rapidly assess the current status of the biomass, since, during transient conditions, the parameters mentioned above can not be evaluated rapidly enough.

This research, therefore, has addressed the need for a process control strategy for biological wastewater treatment systems to be founded on a bacterial vision of the process scheme. In particular, the bacterial correlation with the relative change with time in oxidation-reduction potential has been explored. Specific conclusions particular to the operating strategies considered in this research, include the following:

1) There is a clear, distinct breakpoint in the ORP-time curve which can be definitively correlated with the disappearance of nitrates and can therefore be assumed to represent the point of complete denitrification.

2) The nitrate breakpoint has been observed to be reproducible from cycle to cycle, such that it can be reliably used for control purposes. In the majority of instances, it is sufficiently pronounced to be readily detected by a computer

program, subject to proper instalment of the necessary interfacing equipment between the computer and the ORP probe.

3) For the AASD#1 operating strategy (FT - 3 hours air-on/3 hours air-off, RT - 3 hours air-on/nitrate-breakpoint-determined air-off) the reactors performed essentially the same in terms of solids degradation (15 % - 18 %), depending upon the mass balance method used and the solids (TSS or VSS) considered. The Real-Time reactor seemed to perform slightly better (up to 3 %) in relation to nitrogen removal; however, this difference was deemed to be insubstantial with regards to forming conclusions. The phosphorus recorded an apparent increase of 6 %, which was not considered excessive, as other researchers using the same TP digestion technique have encountered errors of the same magnitude.

4) For the AASD#1 operating strategy, the reactors were subjected to spikes of hydrogen peroxide, sodium nitrate and ammonium chloride. For each reactor, the number of deviations from the "indigenous" curve shape were tabulated and considered as "failures", since they predominantly represented a failure to complete a biological reaction (i.e. either nitrification or denitrification). The Fixed-Time reactor "failed" 9.5 % of the time while the Real-Time reactor failed 5.3 % of the time. Thus, the Real-Time reactor under this strategy was considered to more readily accommodate disturbances to the system.

5) The AASD#2 operating strategy (FT - 3 hours each for air-on/air-off, RT - air-on the same time as the air-off (determined by the nitrate breakpoint), seemed to perform marginally better

both in terms of solids removal (up to 4 %) and nitrogen removal (up to 6 %). Again, these results are subject to some interpretation since replicate experiments were not performed due to the prohibitive workload involved.

6) The AASD#2 operating strategy was subjected to the same spikes as AASD#1; however, in this case, the reactors accommodated the stresses in a similar manner, when normalization (in terms of the number of cycles that had potential for failure) was taken into account.

7) Under the Bio-P experimental conditions investigated in this research, excess biological phosphorus removal was not observed for any significant period of time. This was attributed primarily to the lack of steady-state conditions and the declining strength of the influent carbon.

8) A screening protocol was developed which could aid in evaluating a Bio-P SBR should excess P removal be observed. It consists of categorizing the time-of-occurrences of the nitrate breakpoints according to whether they hinder or assist the purpose of acetate addition to reactors operating in a Bio-P SBR fashion. An example of the application of this protocol was demonstrated.

9) In summary, the Fixed-Time and Real-Time strategies represent two antithetical management approaches. Fixed-Time control strategies are based on rapidly antiquated knowledge of the process dynamics. From the bacterial vantage point, this represents wasted treatment potential and/or inefficient reactor operation. Real-Time control strategies, however, evaluate the

process dynamics vicariously, through the bacterial "eyes" of ORP. A process functioning at the micro-organism environmental level, in most cases, should be more versatile in its response to transient influent conditions, since it is operating more fully cognizant of the bacterial needs.

6.2 Recommendations

The results from this research indicate a number of areas worthy of consideration for further research. They include the following possibilities.

1) A critical analysis of the current algorithm (Lawrence 1991), reveals that the breakpoint algorithmn can be represented by the following general equation...

$$\text{DELTA} = \{X_{i+9} - X_{i+5} - X_{i+4} - X_i\} \;/\; 5 \qquad (6.1)$$

where... X_i - any ORP value (i = 1 to 180).

In some applications, this may not be enough points to detect the knee, and in such instances attention would have to be directed to a more robust design.

2) Many post-denitrification strategies use external carbon sources (such as methanol) for denitrification. These are added on a continual basis with no feedback as to whether the carbon is actually needed for that particular cycle. The ORP nitrate breakpoint could be used to trigger the addition of the carbon source on an "as-needed" basis, reflecting the fact that some cycles would have sufficient carbon available generated through endogenous reactions. Considerable savings in terms of the cost of methanol may result from a strategy which always ensured complete elimination of NOx, either through carbon generated

internally or carbon added externally.

3) None of the AASD strategies considered in this research examined vector reduction. Most digesters are subject to regulations which specify certain log kills (Class A, B, etc.) for pathogenic organism control. It would be worthwhile to compare aerobic digestion log kills with ORP controlled AASD log kills to see if there is a comparable reduction in pathogens.

4) As previously noted, the AASD ORP-time curve contains other distinctive features which show potential for control. In particular, the "dissolved oxygen breakpoint" seems to represent the point where the ammonia is reduced to a very low (if not zero) level. Thus, proceeding past this point may in effect be supplying air that is not needed (i.e. overaeration). A strategy could be formulated in which the air is cycled on and off according to detection of both breakpoints, one on other side of the cycle. A pulsating air strategy such as this may result in considerable savings of air while simultaneously ensuring nitrification / denitrification.

5) The AASD strategy could be used with different sludges, in particular high rate (short SRT) sludges, mixes of primary and secondary sludges, and industrial sludges to see if ORP control has a broader applicability.

6) Using the Bio-P screening protocol, acetate additions could be added on a sequential basis. If the nitrate breakpoint did not occur in a "reasonable" length of time, the acetate could be added in a two-stage process. The first (smaller) pulse could be used to eliminate any remaining nitrates and the second

(larger) addition could be used solely for carbon storage by Bio-P bacteria. This would always ensure maximum carbon storage/P release in the anaerobic sequence of the SBR, even when using weaker strength sewages.

7)The Bio-P process should be investigated again, perhaps at a larger scale (pilot scale) and most certainly at steady-state. It is felt that the pilot scale level would reduce the effect of some of the variability that surfaced during the operation of these lab-scale reactors. Most notably, the lack of aeration control might matter less at a larger scale and/or be eliminated with a more sophisticated control apparatus. Secondly, the declining strength of the influent carbon could be circumvented by direct additions of influent from the sewer line.

It is appreciated that there would be some unique difficulties associated with this latter approach. Most noticeably a stronger sewage would increase the rapid denitrification "failures". In this research, the overwhelming majority of such failures occurred at the beginning of the Bio-P#2 run, when the sewage was the strongest. Unfortunately, the Real-time control software could not detect the breakpoint because it occurred too rapidly after the FILL period. As mentioned, this coincided with the best period of P removal. When the sewage was diluted with rain however, better breakpoints occurred but excess P removal was lost. Thus, a concession must be made between quality of effluent and quality of curves - a compromise that might be difficult to rationalize.

REFERENCES

Abufayed, A.A. and E.D. Schroeder, 1986a. "Performance of SBR/ Denitrification with a Primary Sludge Carbon Source". Journal Water Pollution Control Federation, 58(5):387.

Abufayed, A.A. and E.D. Schroeder, 1986b. "Kinetics and Stoichiometry of SBR/Denitrification with a Primary Sludge Carbon Source". Journal Water Pollution Control Federation, 58(5):398.

Alleman, J.E. and R.L. Irvine, 1980a. "Nitrification in the Sequencing Batch Biological Reactor". Journal Water Pollution Control Federation, 52(11):2747.

Alleman, J.E. and R.L. Irvine, 1980b. "Storage-Induced Denitrification using Sequencing Batch Reactor Operation". Water Research, 14:1483.

American Public Health Association (A.P.H.A.), 1980. Standard Methods for the Examination of Water and Wastewater. 15th Ed., Washington, D.C., 1134p.

American Society for Testing and Materials (A.S.T.M.), 1983. Section 11: Water and Environmental Technology. Volume 11:01, Section D1498 Standard Practice for Oxidation-Reduction Potential of Water, p.233.

Anderson, B.C., 1989. "Improvements in the Aerobic Digestion of Waste Activated Sludge through Chemical Control of Mixed Liquor pH: Pilot - Scale Investigations". Ph.D. Thesis, University of British Columbia, Vancouver, B.C. 418p.

Armiger, W.B., Lee, G., Bordacs, K. and K.D. Tracy, 1990. "Automated On-Line Control Strategy for the Optimization of Nutrient Removal Processes". Instrumentation, Control and Automation of Water and Wastewater Treatment and Transport Systems, In Proceedings of the 5th IAWPRC Workshop, 26 July-3 August, Yokohama and Kyoto, Japan, p. 187.

Arora, M.L., Barth, E.F. and M.B. Umphries, 1985. "Technology Evaluation of Sequencing Batch Reactors". Journal Water Pollution Control Federation, 57(8):867.

Barnard, J.L.., 1976. "A Review of Biological Phosphorus Removal in the Activated Sludge Process". Water S.A., 2(3):136.

Barnard, J.L., Stevens, G.M. and P.J. Leslie, 1985. "Design Strategies for Nutrient Removal Plants". IAWPRC, Paris. Water Science Technology, 17:233.

Benefield, L.D., Judkins, J.F. and B.L. Weand, 1982. Process Chemistry for Water and Wastewater Treatment. Prentice - Hall Inc., Englewood Cliffs, N.J., 510p.

Blanc, F.C. and A.H. Molof, 1973. "Electrode Potential Monitoring and Electrolytic Control in Anaerobic Digestion". Journal Water Pollution Control Federation, 45(4):655.

Bockris, J. O'M. (ed.), 1972. Electrochemistry of Cleaner Environments. Plenum Press, New York, N.Y., 296p.

Boyd, R.F., 1984. General Microbiology. Times Mirror/Mosby College Publishing, 807p.

Burbank, N.C. Jr., 1981. "ORP - A Tool for Process Control?". In Application of On-Line Analytical Instrumentation to Process Control R.M. Arthur (ed.), p. 65.

Charpentier, J., Florentz, M. and G. David, 1987. "Oxidation - Reduction Potential (ORP) Regulation: A Way to Optimize Pollution Removal and Energy Savings in the Low Load Activated Sludge Process". IAWPRC, Rio, Water Science Technology, 19:645.

Charpentier, J., Godart, H., Martin, G. and Y. Mogno, 1989. "Oxidation-Reduction Potential (ORP) Regulation as a Way to Optimize Aeration and C, N, and P Removal: Experimental Basis and Various Full-Scale Examples". IAWPRC, Brighton, Water Science Technology, 21:1209.

Comeau, Y., Rabinowitz, B., Hall, K.J. and W.K. Oldham, 1987a. Phosphate Release and Uptake in Enhanced Biological Phosphorus Removal from Wastewater". Journal Water Pollution Control Federation, 59(7):707.

Comeau, Y., Oldham, W.K. and K.J. Hall, 1987b. "Dynamics of Carbon Reserves in Biological Dephosphatation of Wastewaters". In Advances in Water Pollution Control IAWPRC International Conference, Rome, Italy, Sept. 28-30, p. 39.

Comeau, Y., 1989. "The Role of Carbon Storage in Biological Phosphate Removal from Wastewater". Ph.D Thesis, University of British Columbia, Vancouver, B.C., 194p.

Dahod, S.K., 1982. "Redox Potential as a Better Substitute for Dissolved Oxygen in Fermentation Process Control". In Biotechnology and Bioengineering, 9, Gaden, E.L. Jr.(ed.), John Wiley and Sons Inc., p. 2123.

DataTranslation Inc., 1988. Users Manual for DT2814 Document UM-05198-B, 70p.

De la Menardiere, M., Charpentier, J., Vachon, A. and G. Martin, 1991. "ORP as a Control Parameter in a Single Sludge Biological Nitrogen and Phosphorus Removal Activated Sludge System". Water S.A., 17(2):123.

Dickinson, D., 1969. "Redox Measurement of Treatability by the Activated Sludge Process". Water Research, 3:955.

Dold, P.L., Ekama, G.A. and G.v.R. Marais, 1980. "A General Model for the Activated Sludge Process". Progress In Water Technology, 12:47.

Dyson, R.D., 1974. Cell Biology: A Molecular Approach, Allyn and Bacon Inc., Boston, 701p.

Eckenfelder, W.W. Jr. and J.W. Hood, 1951. "The Application of Oxidation-Reduction Potential to Biological Waste Treatment Process Control". In Proceedings of the 6th Purdue Industrial Waste Conference, Feb. 21-23 1951, Purdue University, West Lafayette, Indiana, p. 221.

Eckenfelder, W.W. Jr., 1958. "A Discussion - Redox Potentials in the Laboratory". Sewage and Industrial Wastes, 30(4):501.

Eilbeck, W.J., 1984. "Redox Control in Breakpoint Chlorination of Ammonia and Metal Ammine Complexes". Water Research, 18(1):21.

Eilbeck, W.J., and G. Mattock, 1987. Chemical Processes in Wastewater Treatment, John Wiley and Sons, Ellis Horwood Ltd., Chichester, England, 331p.

Ekama, G.A., Marais, G.v.R. and I.P. Siebritz, 1984. "Chapter 7: Biological Excess Phosphorus Removal". In Theory, Design and Operation of Nutrient Removal Activated Sludge Processes, Water Research Commission, P.O. Box 824, Pretoria, 0001

Elefsiniotis, P., 1992. "The Acid-Phase Fermentation in the Biological Phosphorus Removal Process". Ph.D. Thesis, University of British Columbia, Vancouver, B.C.

Evans, B. and D. Filman, 1988. "Solids Handling Costs at Large Sewage Treatment Plants". In Proceedings of Joint ASCE/ CSCE Environmental Engineering Conference, July 12-19, Vancouver, B.C., p.590.

Grune, W.N. and Chun-Fei Chueh, 1958. "Redox Potentials in Waste Treatment - Laboratory Experiences and Applications". Sewage and Industrial Wastes, 30(4):479.

Harrison, D.E.F., 1972. "Physiological Effects of Dissolved Oxygen Tension and Redox Potential on Growing Populations of Microorganisms". Journal of Applied Chemistry and Biotechnology, 22:417.

Hascoet, M.C. and M. Florentz, 1985. "Influence of Nitrates on Biological Phosphorus Removal". Water S.A. 11(1):1.

Hashimoto, S., Fujita, M. and K. Terai, 1982. "Stabilization of Waste Activated Sludge through the Anoxic-Aerobic Digestion Process". Biotechnology and Bioengineering, 24:1789.

Heduit, A. and D.R. Thevenot, 1989. "Relation Between Redox Potential and Oxygen Levels in Activated-Sludge Reactors". IAWPRC, Brighton, Water Science Technology, 21:947.

Hood, J.W., 1948. "Measurement and Control of Sewage Treatment Process Efficiency by Oxidation-Reduction Potential". Sewage Works Journal, 20(4):640.

Hoover, S.R., Jasewicz L. and N. Porges, 1952. "Biochemical Oxidation of Dairy Wastes. IV. Endogenous Respiration and Stability of Aerated Dairy Sludge". Sewage and Industrial Wastes, 24(9):1144.

Ip, S.Y., Bridger, J.S. and N.F. Mills, 1987. "Effect of Alternating Aerobic and Anaerobic Conditions on the Economics of the Activated Sludge System". IAWPRC. Rio de Janerio. Water Science Technology, 19:911.

Irvine, R.L. and A.W. Busch, 1979. "Sequencing Batch Biological Reactors - An Overview". Journal Water Pollution Control Federation, 51(2):235.

Irvine, R.L., Ketchum, L.H. Jr., Breyfogle, R. and E.F. Barth, 1983."Municipal Application of Sequencing Batch Treatment". Journal Water Pollution Control Federation, 55(5):484.

Irvine, R.L., Ketchum, L.H. Jr., Arora, M.L. and E.F. Barth, 1985. "An Organic Loading Study of Full-Scale Sequencing Batch Reactors". Journal Water Pollution Control Federation, 57(8):847.

Irvine, R.L., Murthy, D.V.S., Arora, M.L., Copeman, J.L. and J.A. Heidman, 1987. "Analysis of Full-Scale SBR Operation at Grundy Centre, Iowa". Journal Water Pollution Control Federation, 59(3):132.

Jenkins, C.J., 1988. "Anoxic-Aerobic Digestion of Waste Activated Sludge: A Lab Scale Comparison to Aerobic Digestion With and Without Lime Addition". M.A.Sc. Thesis, University of British Columbia, Vancouver, B.C., 223p.

Jenkins, C.J. and D.S. Mavinic, 1989a. "Anoxic-Aerobic Digestion of Waste Activated Sludge: Part I - Solids Reduction and Digested Sludge Characteristics". Environmental Technology Letters, 10:355.

Jenkins, C.J. and D.S. Mavinic, 1989b. "Anoxic-Aerobic Digestion of Waste Activated Sludge: Part II - Supernatant Characteristics, ORP Monitoring Results and Overall Rating System". Environmental Technology Letters, 10:371.

Ketchum, L.H. Jr., and Ping-Chau Liao, 1979. "Tertiary Chemical Treatment for Phosphorus Reduction Using Sequencing Batch Reactors". Journal Water Pollution Control Federation, 51(2):298.

Ketchum, L.H. Jr., Irvine, R.L., Breyfogle, R.E. and J.F. Manning Jr., 1987. "A Comparison of Biological and Chemical Phosphorus Removals in Continuous and Sequencing Batch Reactors". Journal Water Pollution Control Federation, 59(1):13.

Kim, M.H. and O.J. Hao, 1990. "Comparison of Activated Sludge Stabilization under Aerobic or Anoxic Conditions". Research Journal of the Water Pollution Control Federation,62(2):160.

Kjaergaard, L., 1976. "Influence of Redox Potential on the Glucose Catabolism of Chemostat Grown Bacillus licheniformis". European Journal of Applied Microbiology, 2:215.

Kjaergaard, L., 1977. "The Redox Potential: Its Use and Control in Biotechnology". In Advances in Biochemical Engineering, 7 Ghose, T.K., Fiechter, A. and N. Blakebrough (eds.), Springer - Verlag, Berlin, p. 131.

Kjaergaard, L. and B.B. Joergensen, 1979. "Redox Potential as a State Variable in Fermentation Systems". In Computer Applications in Fermentation Technology, Arminger, W.B. (ed.), Biotechnology and Bioengineering Symposium No. 9 p. 85.

Kjaergaard, L. and B.B. Joergensen, 1981. "The Redox Potential, A Hitherto Seldom Used Parameter in Fermentation Systems". In Advances in Biotechnology Vol I - Scientific and Engineering Principles. M. Moo-Young (ed.), Pergamon Press, p. 371.

Koch, F.A. and W.K. Oldham, 1985. "Oxidation - Reduction Potential- A Tool for Monitoring, Control and Optimization of Biological Nutrient Removal Systems". IAWPRC, Paris. Water Science Technology, 17:259.

Koch, F.A., Oldham, W.K. and H.Z. Wang, 1988. "ORP as a Tool for Monitoring and Control in Bio-Nutrient Removal Systems". In Proceedings of Joint ASCE/CSCE Environmental Engineering Conference, July 12-19, Vancouver, B.C., p.162.

Koers, D.A., 1979. "Studies of the Control and Operation of the Aerobic Digestion Process Applied to Waste Activated Sludges at Low Temperatures". Ph.D. Thesis, University of British Columbia, Vancouver, B.C., 288p.

Krichten, D.J., Hong, S.N. and K.D. Tracy, 1985. "Applied Biological Phosphorus Removal Technologies for Municipal Wastewater Treatment by the A/O Process". In Management Strategies for Phosphorus in the Environment, R.Perry and M. Schmidtke (eds.). Selper Ltd. London, pg. 399

Lawrence, P.D., 1991. Personal Communications

Lohmann, J., 1985. "State of Automation of Wastewater Treatment Plants in the F.G.R.". Instrumentation and Control of Water and Wastewater Treatment and Transport Systems, In Proceedings 4th IAWPRC Workshop, 27 April - 4 May, Houston and Denver, USA, p.9.

Maier, W. et al., 1984. "Pilot Scale Studies on Enhanced Phosphorus Removal In a Single Sludge Activated Sludge Plant". In Enhanced Biological Phosphorus Removal from Wastewater, Vol (II), IAWPRC Post Conference Seminar, Paris, France, pg.51.

Manning, J.F. and R.L. Irvine, 1985. "The Biological Removal of Phosphorus in a Sequencing Batch Reactor". Journal Water Pollution Control Federation, 57(1):87.

Matsuda, A., Ide, T., and S. Fujii, 1988. "Behaviour of Nitrogen and Phosphorus During Batch Aerobic Digestion of Waste Activated Sludge - Continuous Aeration and Intermittent Aeration by Control of D.O.". Water Research, 22(12):1495.

McCartney, D.M. and J.A. Oleszkiewicz, 1988. "Removal of C, N and P in a SBR at Low Temperatures". In Proceedings of Joint ASCE/CSCE Environmental Engineering Conference, July 12-19, Vancouver, B.C., p.320.

McCartney, D.M. and J.A. Oleszkiewicz, 1990. "Carbon and Nutrient Removal in a Sequencing Batch Reactor at Low Temperatures". Environmental Technology Letters, 11:99.

McCarty,P.L., Beck, L. and P.St.Amat, 1969. "Biological Denitrification of Wastewaters by Addition of Organic Materials". Proceedings of 24th Industrial Waste Conference, Purdue University, West Lafayette, Indiana.

Melcer, H., Bedford, W.K., Topnik, B.H. and N.W. Schmidtke. 1987. "Conversion of Small Municipal Wastewater Treatment Plants To Sequencing Batch Reactors". Journal Water Pollution Control Federation, 59(2):79.

Metcalf and Eddy Inc., 1979. Wastewater Engineering : Treatment Disposal, Reuse. Second Ed., McGraw-Hill Co., N.Y., 920p.

MetraByte Corporation, 1989. Data Acquisition and Control Catalogue, 21, p78.

Microsoft Corporation, 1987a. Microsoft QUICKBASIC 4.0: Learning and Using Microsoft Quickbasic, 386p.

Microsoft Corporation, 1987b. Microsoft QUICKBASIC 4.0: Programming in Basic - Selected Topics, 322p.

Microsoft Corporation, 1987c. Microsoft QUICKBASIC 4.0: BASIC Language Reference, 530p.

Midgley D. and K. Torrence, 1978. Potentiometric Water Analysis. John Wiley and Sons Inc., 409p.

Milligan, P.A.T., 1989. Personal Communications.

Minister of Supply and Services Canada, 1981. National Inventory of Municipal Waterworks and Wastewater Systems in Canada. Ottawa, Ontario, Canada.

Morris, J.C. and W. Stumm, 1967. "Redox Equilibria and Measurements of Potentials in the Aquatic Environment". Advances Chemistry Series, No. 67, Article 13, p. 270.

Nicholls H.A. and D.W. Osborn, 1979. "Bacterial Stress: A Prerequisite for Biological Removal of Phosphorus". Journal Water Pollution Control Federation, 51(3):557.

Nussberger, F.E., 1953. "Applications of Oxidation-Reduction Potentials to the Control of Sewage Treatment Processes". Sewage and Industrial Wastes, 25(9):1003.

Oleszkiewicz, J.A. and S.A. Berquist, 1988. "Low Temperature Nitrogen Removal in Sequencing Batch Reactors". Water Research, 22(9):1163.

O'Rourke, J.T., Tomlinson, H.D. and N.C. Burbank, Jr., 1963. "Variation of ORP in An Activated Sludge Plant with Industrial Waste Load". Industrial Water and Wastes, 8(6):15.

Palis, J.C. and R.L. Irvine, 1985. "Nitrogen Removal in a Low Loaded Single Tank Sequencing Batch Reactor". Journal Water Pollution Control Federation, 57(1):82.

Peddie. C.C. and D.S. Mavinic, 1988. "Preliminary Results of a Pilot Scale Evaluation of Aerobic/Anoxic Sludge Digestion".In Proceedings Canadian Society of Civil Engineering Annual Conference, 25-27 May 1988, Calgary, Alberta, p. 461.

Peddie, C.C., Koch, F.A., Jenkins, C.J. and D.S. Mavinic, 1988. "ORP as a Tool for Monitoring and Control of SBR Systems for Aerobic Sludge Digestion". In Proceedings of Joint ASCE/CSCE Environmental Engineering Conference, July 12-19, Vancouver, B.C., p.171.

Petersen, G.K., 1966. "Redox Measurements: Their Theory and Technique". Radiometer A/S Emdrupvej72 DK 2400 Manual8, Copenhagen, Denmark, 30p.

Poduska, R.A. and B.D. Anderson, 1981. "Successful Storage Lagoon Odour Control". Journal Water Pollution Control Federation, 53(3):299.

Rabinowitz, B., 1985. "The Role of Specific Substrates in Excess Biological Phosphorus Removal". Ph.D. Thesis, University of British Columbia, Vancouver, B.C.

Rabinowitz, B. and W.K. Oldham, 1986. "Excess Biological Phosphorus Removal in the Activated Sludge Process Using Primary Sludge Fermentation". Canadian Journal of Civil Engineering, 13:345.

Rabinowitz, B., Koch, F.A., Vassos, T.D. and W.K. Oldham, 1987. "A Novel Operational Model for a Primary Sludge Fermenter for Use with the Enhanced Biological Phosphorus Removal Process". In Proceedings of the IAWPRC Specialized Conference on Biological Phosphorus Removal from Wastewater, Rome, pg. 349.

Radjai M., Hatch R.T. and T.W. Cadman, 1984. "Optimization of Amino Acid Production by Automatic Self-tuning Digital control of Redox Potential". Biotechnology and Bioengineering Symposium No. 14, John Wiley and Sons, p. 657.

Randall, C.W., Marshall, D.W. and P.H. King, 1970. "Phosphate Release in Activated Sludge Process". Journal of the Sanitary Engineering Division, In Proceedings of the American Society of Civil Engineers, SA 2, p.395.

Rich, L.G., 1982. "A Cost-Effective System for the Aerobic Stabilization and Disposal of Waste Activated Sludge Solids". Water Research, 16:535.

Rimkus, R.R., Ziols, R. and A. Shaikh, 1985. "Computer Control of Raw Sewage Chlorination for Odour Control". Instrumentation and Control in Water and Wastewater Treatment and Transport Systems, In Proceeding 4th IAWPRC Workshop, 27 April-4 May, Houston and Denver, USA., p. 297.

Roberts, F.W. and D.A. Rudd, 1963. "Applications of Oxidation Reduction Potential to Sewage Purification". Journal of Instrumentation and Sewage Purification. p. 227.

Rohlich, G.A., 1948. "Measurement and Control of Sewage Treatment Process Efficiency by Oxidation-Reduction Potential - A Discussion". Sewage Works Journal, 20(4):650.

Rudd, D.A., Roberts, F.W. and D.E. Brooks, 1961. "Oxidation - Reduction Potential Measurements in Sewage Purification". Instrument Engineer, 3(3):61.

Sekine, T., Iwahorik, K., Fujimoto, E. and Y. Inamori, 1985. "Advanced Control Strategies for the Activated Sludge Process". Instrumentation and Control of Water and Wastewater Treatment and Transport Systems, In Proceedings 4th IAWPRC Workshop, 27 April - 4 May, Houston and Denver, USA., p269.

Shammas, N.M., 1988. "The BASIC Revival". BYTE Magazine, 13(9):295.

Shapiro, J., Levin, G.V. and Z.G. Humberto, 1967. "Anoxically Induced Release of Phosphate in Wastewater Treatment". Journal Water Pollution Control Federation, 39(11):1810.

Shibai H., Ishizaki A., Kobayashi, K. and Y. Hirose, 1974. "Simultaneous Measurement of Dissolved Oxygen and Oxidation Reduction Potentials in the Aerobic Culture". Journal of Agricultural and Biological Chemistry, 38(12):2407.

Siebritz, I.P., Ekama, G.A. and G.v.R. Marais, 1983. " A Parametric Model for Biological Excess Phosphorus Removal". IAWPRC, Capetown, Water Science Technology, 15:127.

Silverstein, J. and E.D. Schroeder, 1983. "Performance of SBR Activated Sludge Processes with Nitrification Denitrification". Journal Water Pollution Control Federation, 55(4):377.

Smith, D., 1978. "Wastage Rates Determined by SRT Method". Water and Sewage Works, 125(9):68.

Snoeyink, V.L. and D. Jenkins, 1980. Water Chemistry., John Wiley and Sons Inc., New York, N.Y., 463p.

Stumm, W. 1966. "Redox Potential as an Environmental Parameter: Conceptual Significance and Operational Limitation". Advances in Water Pollution Research, Vol. 1, In, Proceedings of 3rd International Conference of Int. Ass. on Water Pollution Research., Munich, Germany, p. 283.

Tortora, G.J., Funke, B.R. and C.L. Case, 1982. Microbiology: An Introduction, (2nd Ed.), Benjamin/Cummings Pub. Co. Inc. 772p.

Tracy, K.D. and A. Flammino, 1985. "Kinetics of Biological Phosphorus Removal". Presented at the 58th Annual Water Pollution Control Federation Conference, Kansas City, Missouri.

Tracy, K.D. and A. Flammino, 1987. "Biochemistry and Energetics of Biological Phosphorus Removal". In Advances in Water Pollution Control, R. Ramadori (ed.), Pergamon Press, London, pg. 15.

U.S. Environmental Protection Agency, 1986. "Summary Report: Sequencing Batch Reactors". Report No. EPA-625-8-86-011, Office of Technology Transfer, Cincinatti, Ohio, 23p.

U.S. Environmental Protection Agency, 1987. "Design Manual: Phosphorus Removal". Report No. EPA-625-1-87-001, Office of Technology Transfer, Cincinatti, Ohio, 116p.

Vaccari, D.A., Cooper, A. and C. Christodoulatos, 1988. "Feedback Control of Activated Sludge Waste Rate". Journal Water Pollution Control Federation, 60(11):1979.

Van Haandel, A.C., Ekama, G.A. and G.v.R. Marais, 1981. "The Activated Sludge Process Part 3 - Single Sludge Denitrification". Water Research, 15:1135.

Vlekke, G.J.F.M., Comeau, Y. and W.K. Oldham, 1988. "Biological Phosphate Removal from Wastewater with Oxygen or Nitrate in Sequencing Batch Reactors". Environmental Technology Letters, 9(8):791.

Wang, N.S. and G.M. Stephanopoulos, 1987. "Computer Applications to Fermentation Processes". In CRC Critical Reviews in Biotechnology, 2(1), p.30.

Warner, A.P.C., Ekama, G.A. and G.v.R. Marais, 1985. "The Activated Sludge Process: Part 4 - Application of the the General Kinetic Model to Anoxic-Aerobic Digestion of Waste Activated Sludge". IAWPRC, Paris, Water Science Technology, 17(8):1475.

Watanabe, S., Baba, K. and S. Nogita, 1985. "Basic Studies of an ORP/External Carbon Source Control System for the Biological Denitrification Process". Instrumentation and Control of Water and Wastewater Treatment and Transport Systems, In Proceedings 4th IAWPRC Workshop, 27 April - 4 May, Houston and Denver, USA, p. 641.

Weber, L.J. and D.I. McLean, 1979. Electrical Measurement Systems for Biological and Physical Scientists, Addison -Wesley Publishing Company, 399p.

Westcott, C.C., 1976. "Oxidation-Reduction Potential with Beckman Metallic Electrodes". Technical Information Bulletin, No. 952-EC-76-GT, Scientific Instruments Division, Irvine, California 92713, p. 13.

Whitfield, M., 1969. "Eh as an Operational Parameter in Estuarine Studies". Limnology and Oceanography, 14(4):547.

Williams, D.S., Burgarino, A.E. and J.R. Fernandez, 1986. "Process Control and Management Information Processing at a Municipal Wastewater Treatment Plant". Journal Water Pollution Control Federation, 58(10):949.

Wimpenny, J.W.T., 1969. "The Effect of Eh on Regulatory Processes in Facultative Anaerobes". Biotechnology and Bioengineering, 11(4):623.

Wimpenny, J.W.T. and D.K. Necklen, 1971. "The Redox Environment and Microbial Physiology: The Transition from Anaerobiosis to Aerobiosis in Continuous Cultures of Facultative Anaerobes". Biochimica et Biophysica Acta, 253:352.

Zhou, J., 1991. "Applicability Study of ORP Probes in the Biological Phosphorus Removal Process". M.A.Sc. Thesis University of British Columbia, Vancouver, B.C.

APPENDIX A

APPENDIX A

Derivation of the Nernst Equation

For the general reaction.. $aA + bB \Leftrightarrow cC + dD$ (1)

The Van't Hoff Equation.. $\Delta G = \Delta G^{o} + RT \log\left[\frac{\{C\}^{c}\{D\}^{d}}{\{A\}^{a}\{B\}^{b}}\right]$ (2)

Thus for the equation .. $ox + ne^{-} \Leftrightarrow red$ (3)

The Van't Hoff Equation.. $\Delta G = \Delta G^{o} + RT \log\left[\frac{\{red\}}{\{ox\}}\right]$ (4)

Now...

"The reduction of one mole of oxidant to its reduced form requires the passage of nF coulombs of electricity against a potential difference of E volts, so the electrical work done by the system at constant temperature and pressure is nEF joules. This is equal to the decrease in free energy of the system" (Eilbeck and Mattock, (1987)).

The Gibbs Free Energy Equation $\Delta G = -nEF$ (5)

at Standard State $\Delta G^{o} = -nE^{o}F$ (6)

Substituting (5) and (6) into (4)

Gives.... $-nEF = -nE^{o}F + RT \log\left[\frac{\{red\}}{\{ox\}}\right]$ (7)

Or... $E = E^{o} - \frac{RT}{nF} \log\left[\frac{\{red\}}{\{ox\}}\right]$ (8)

which is the Nernst Equation.

APPENDIX B

APPENDIX B

Intracellular Redox and Energy Calculation

A Oxygen as a Terminal Electron Acceptor

Consider the oxygen terminal electron acceptor with E^o adjusted to an E value associated with a pH of 7.0, T = 25°C) .

$O_{2(aq)} + 4H^+ + 4e^- \Leftrightarrow 2H_2O$ $E^o = +1.27$ (Snoeyink & Jenkins, 1980)

@ pH = 7 $E = E^o + \frac{.0592}{n} \log \{H^+\}^4$

$$E = 1.27 + \frac{.0592}{4} \log \{10^{-7}\}^4$$

$$E = 1.27 + (-.42) = 0.85 \text{ volts}$$

when coupled with... (Dyson, 1974, T = 25°C)

$NAD^+ + H^+ + 2e^- \Leftrightarrow NADH$ $E^o = -0.32$ @ pH = 7

gives the equation

$$1/2\ O_{2(aq)} + H^+ + NADH \Leftrightarrow NAD^+ + H_2O$$

and since $\Delta G = -nEF$

$$\Delta G = -2\left(23000 \frac{\text{calories}}{\text{volts}}\right)[(-0.32)-(0.85)] \text{ volts}$$

$$\Delta G = -46000 \times (-1.17) = -53{,}820 \text{ cal/mole} = -53.8 \text{ kcal/mole}$$

B ATP

The Free energy of hydrolysis of ATP is approximately - 7000 cal/mole and there are 3 ATP molecules generated in one pass of the ETC with oxygen as the terminal electron acceptor. Thus...

$$\text{Efficiency} = \frac{(3)(7000)}{53820} \times 100\ \% = 39\ \%\ \text{capture.}$$

C Oxidative Phosphorylation

Generates 38 ATP and with potential glucose oxidation of 686,000 cal/mole.

$$\text{Efficiency} = \frac{(38)(7000)}{686000} \times 100\ \% = 39\ \%\ \text{efficiency}$$

APPENDIX C

SOFTWARE FLOWCHARTS - AASD AND BIO-P

Figure Page

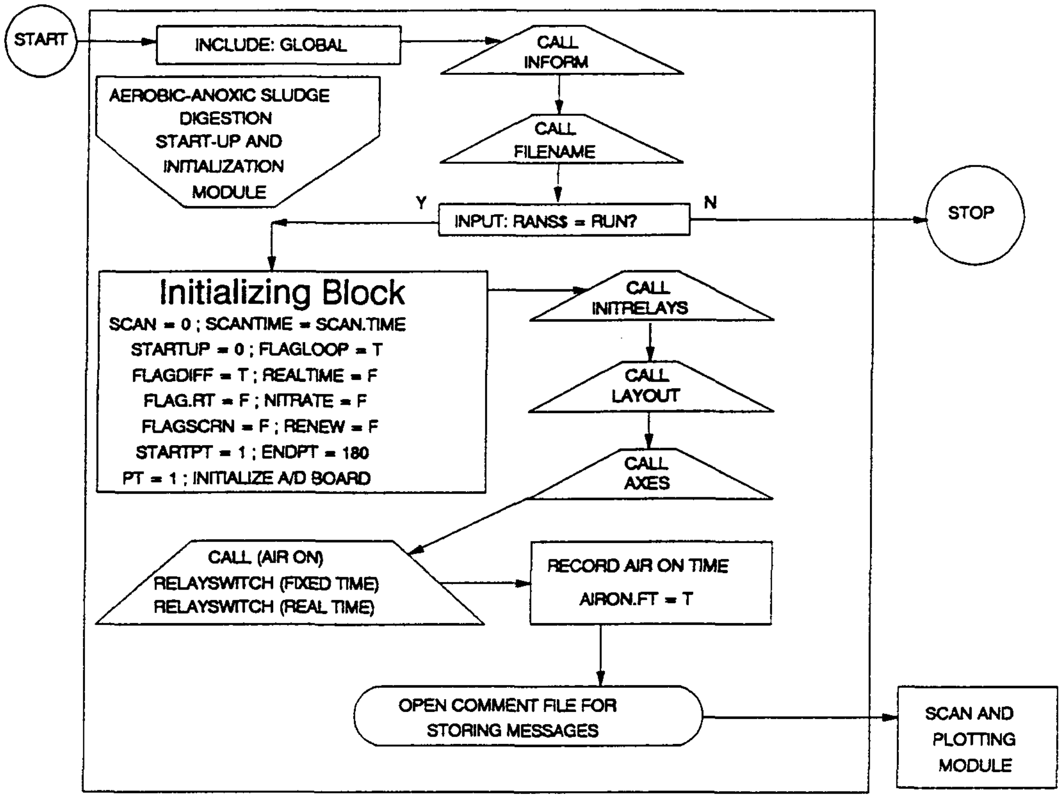


FIGURE C.1 AASD START-UP AND INITIALIZATION MODULE

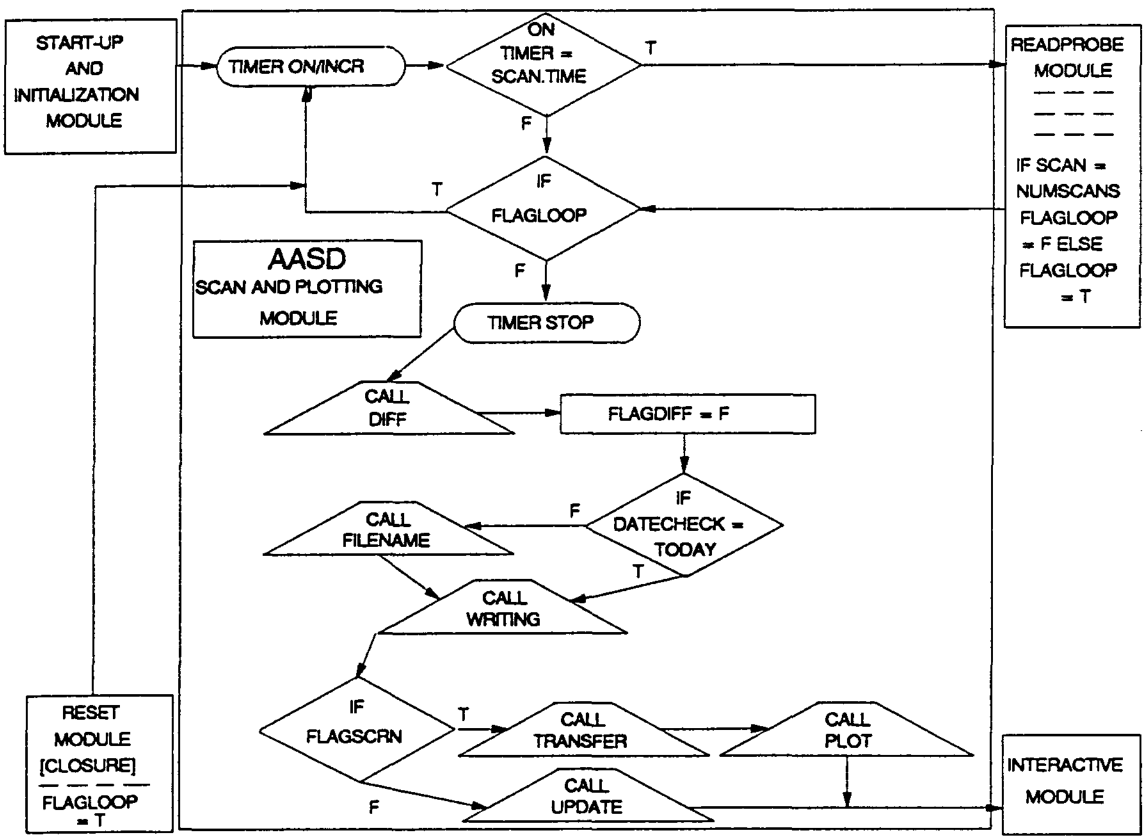


FIGURE C.2 AASD SCAN AND PLOTTING MODULE

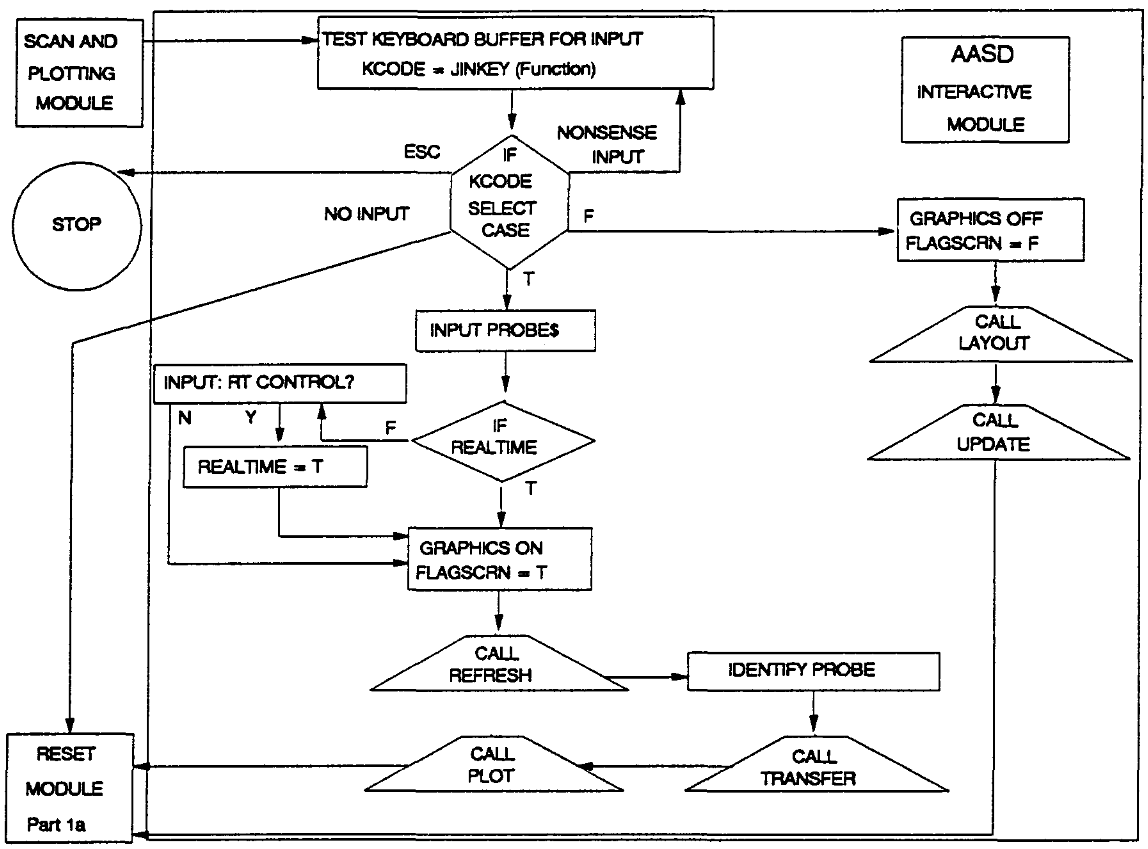


FIGURE C.3 AASD INTERACTIVE MODULE

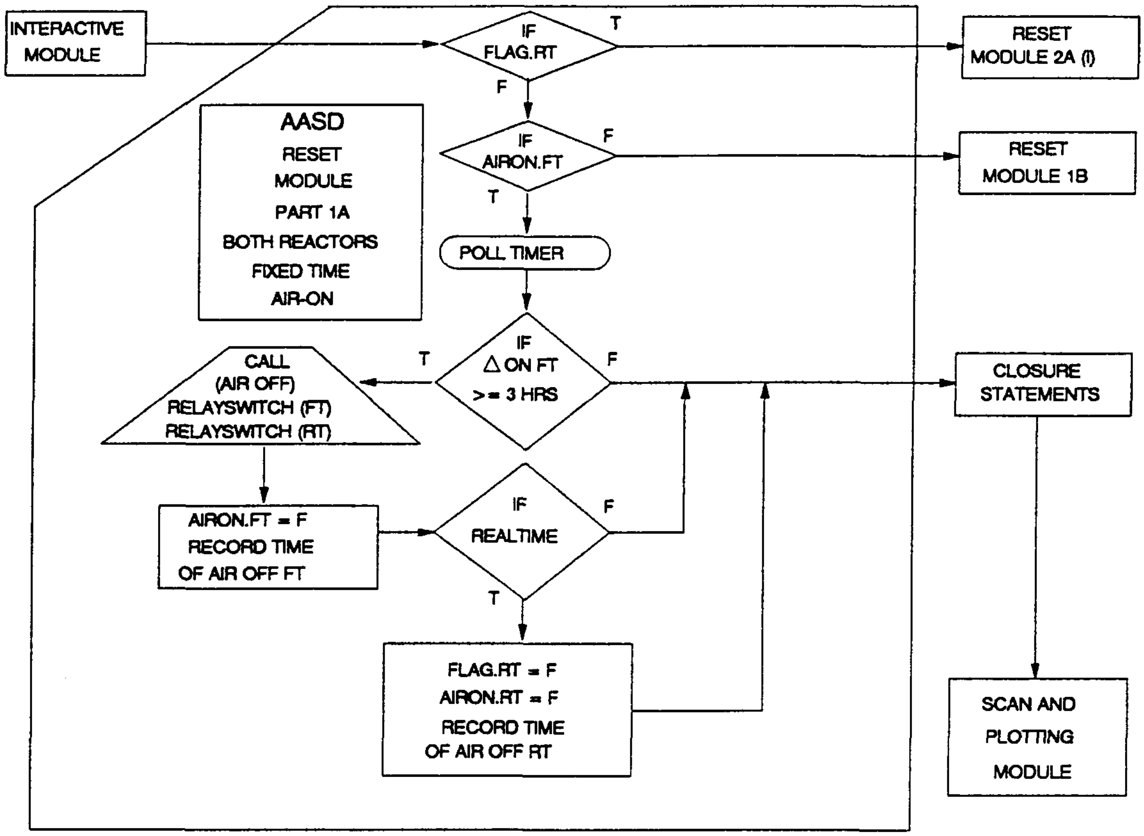


FIGURE C.4 AASD RESET MODULE - 1A - BOTH RCTRS FT - AIR ON

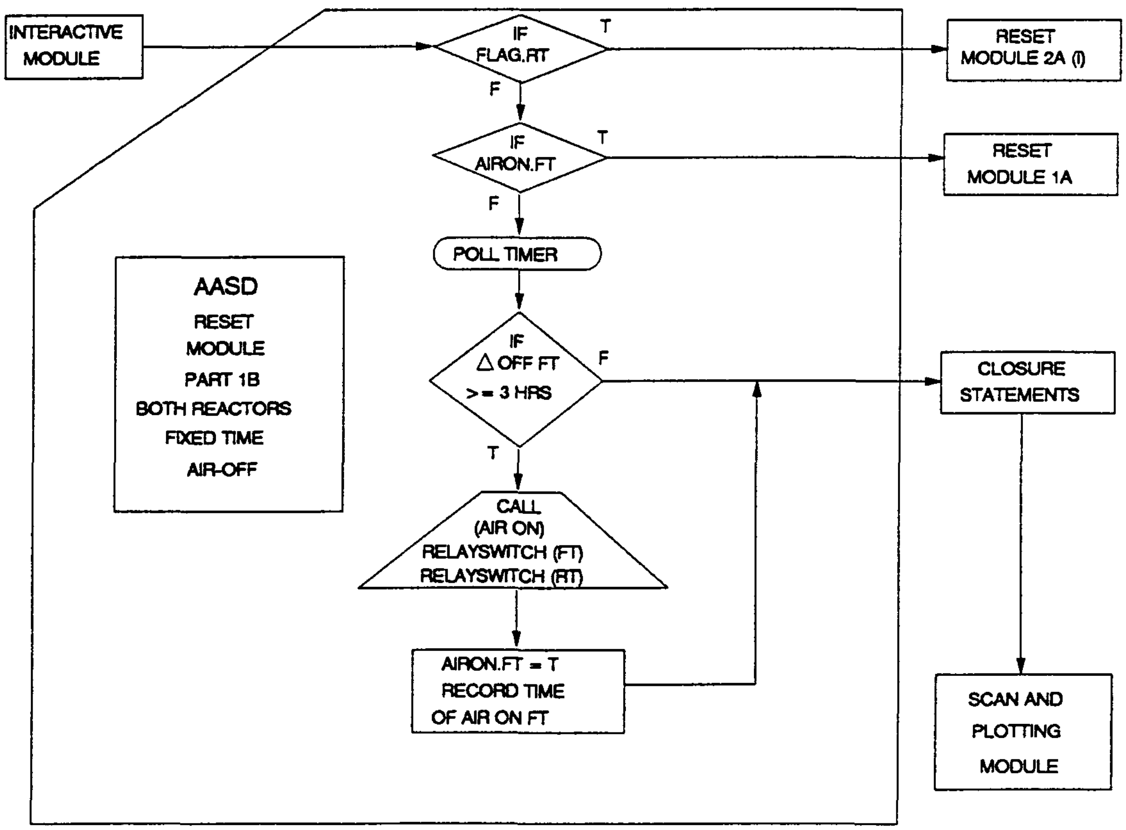


FIGURE C.5 AASD RESET MODULE - 1B - BOTH RCTRS FT - AIR OFF

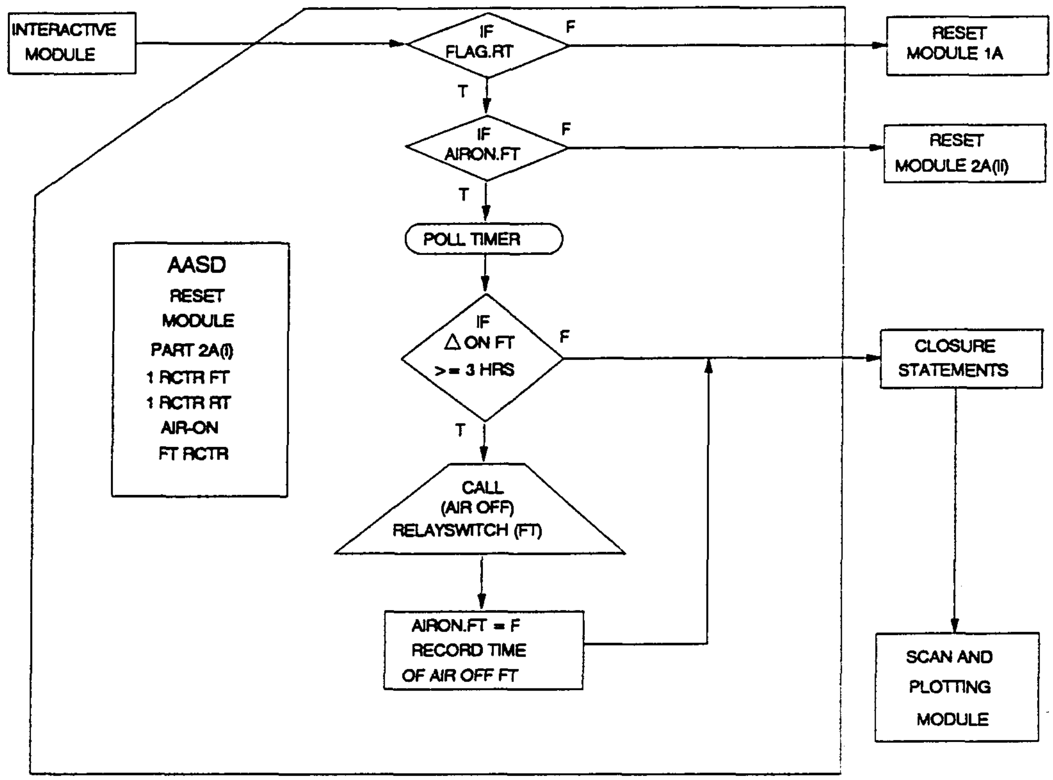


FIGURE C.6 AASD RESET MODULE - 2A(i) - RT CONTROL - AIR ON FT

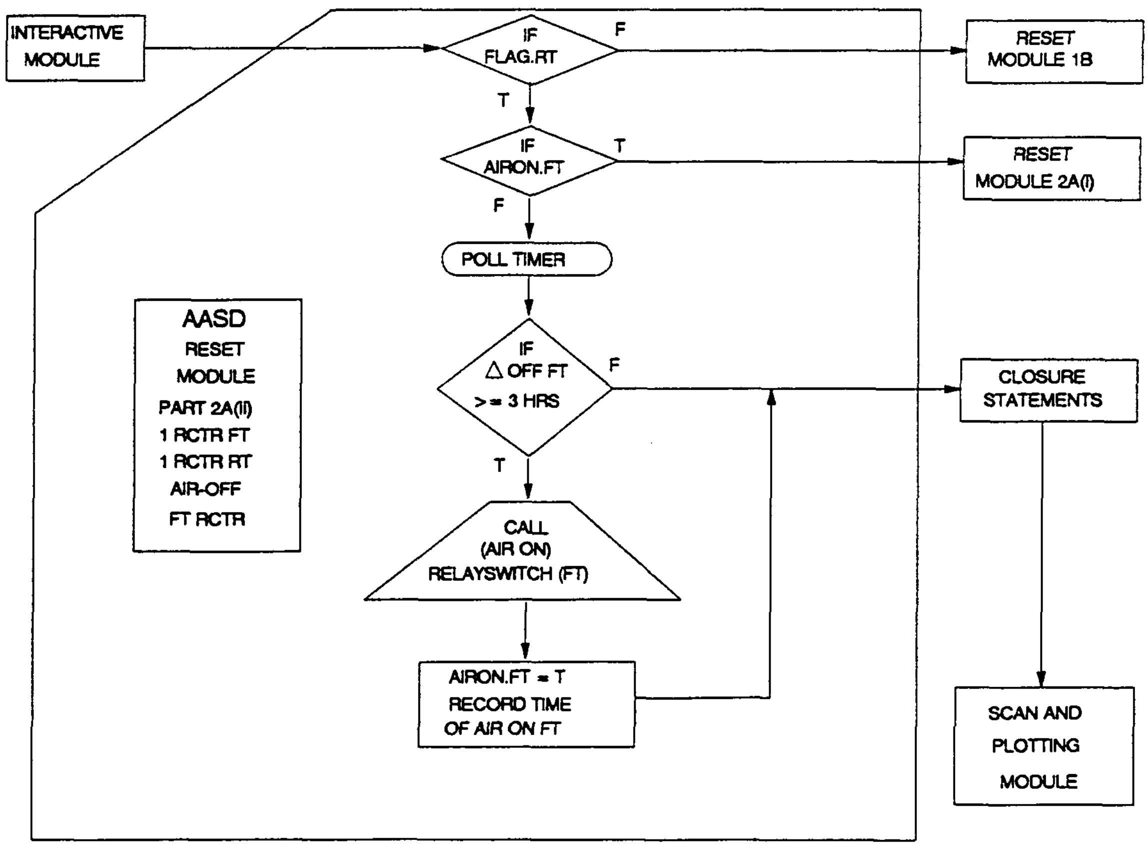


FIGURE C.7 AASD RESET MODULE - 2A(ii) - RT CONTROL - AIR OFF FT

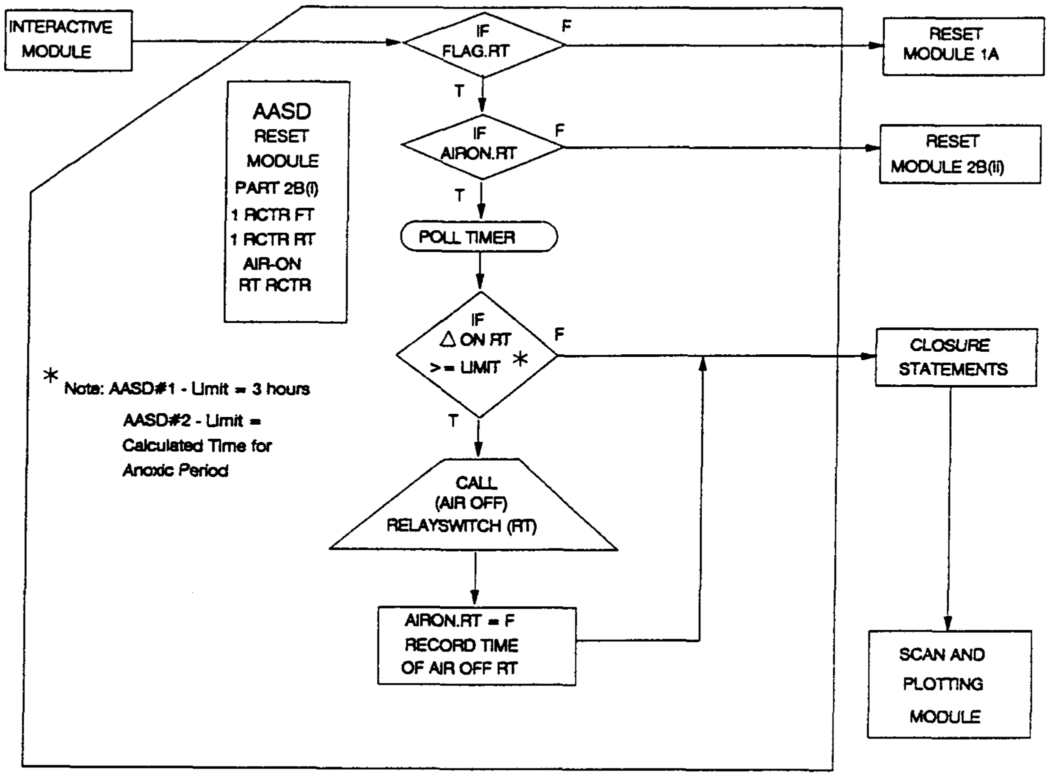


FIGURE C.8 AASD RESET MODULE - 2B(i) - RT CONTROL - AIR ON RT

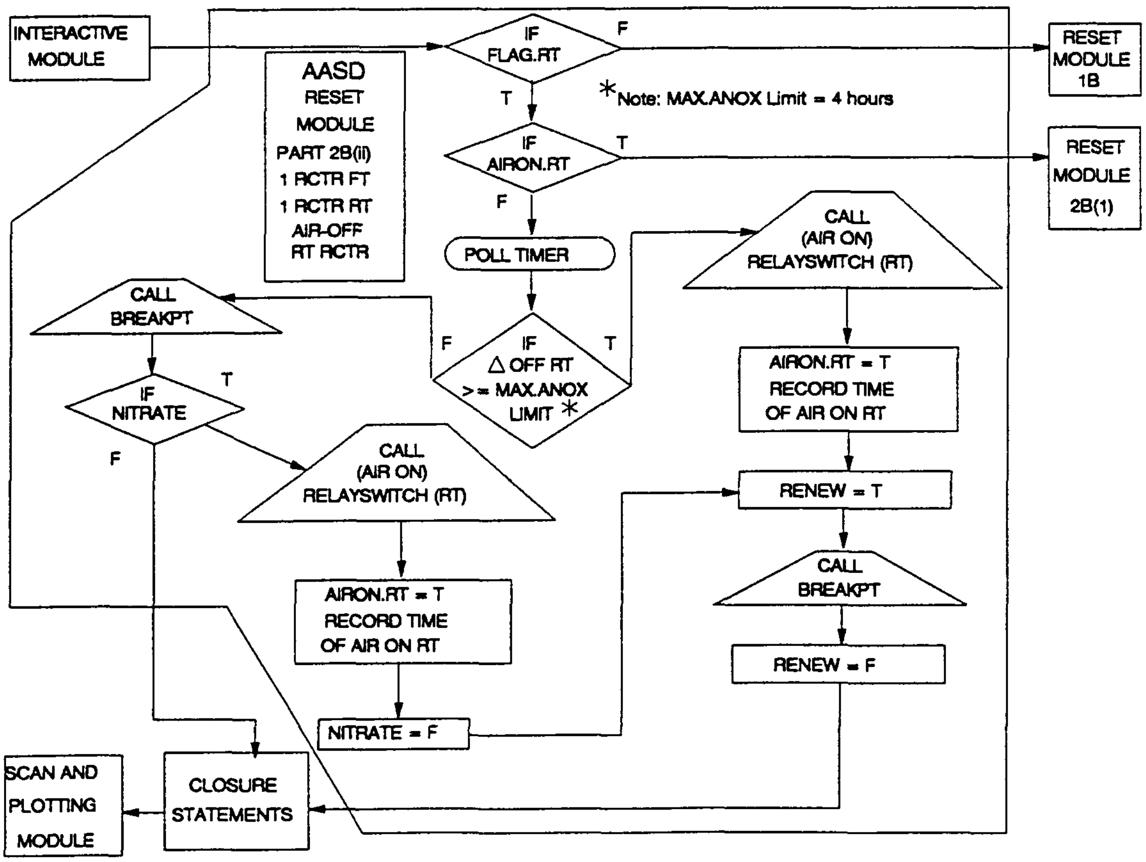


FIGURE C.9 AASD RESET MODULE - 2B(ii) - RT CONTROL - AIR OFF RT

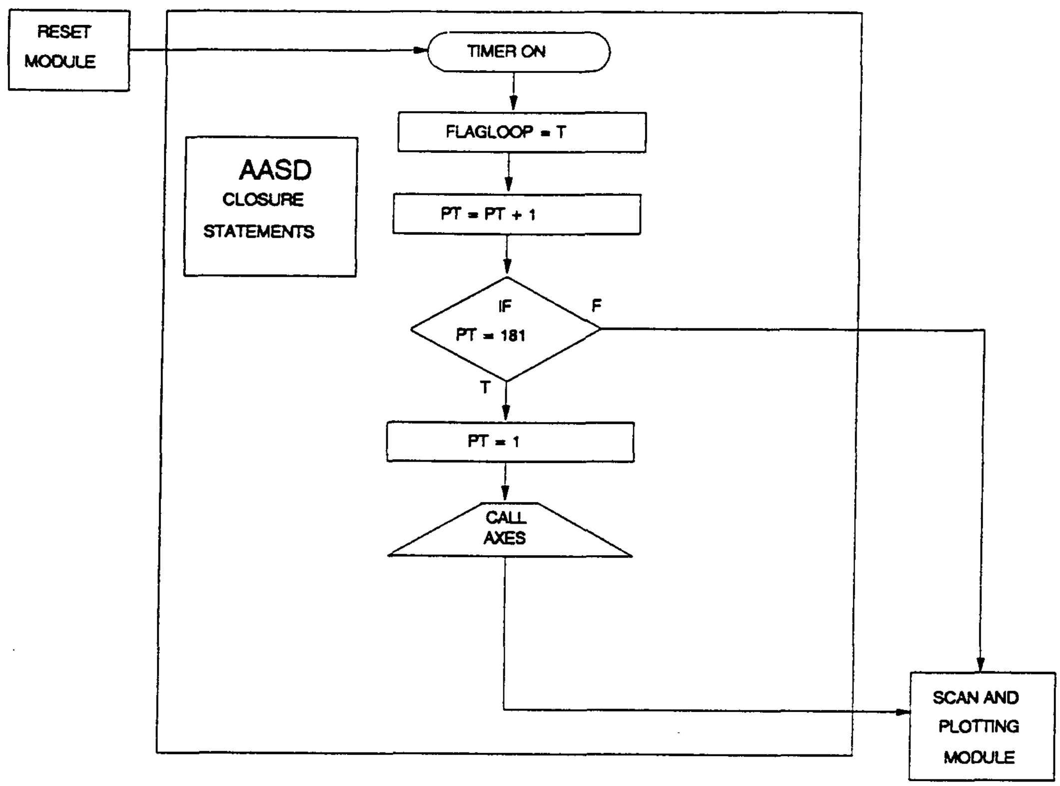


FIGURE C.10 AASD CLOSURE STATEMENTS

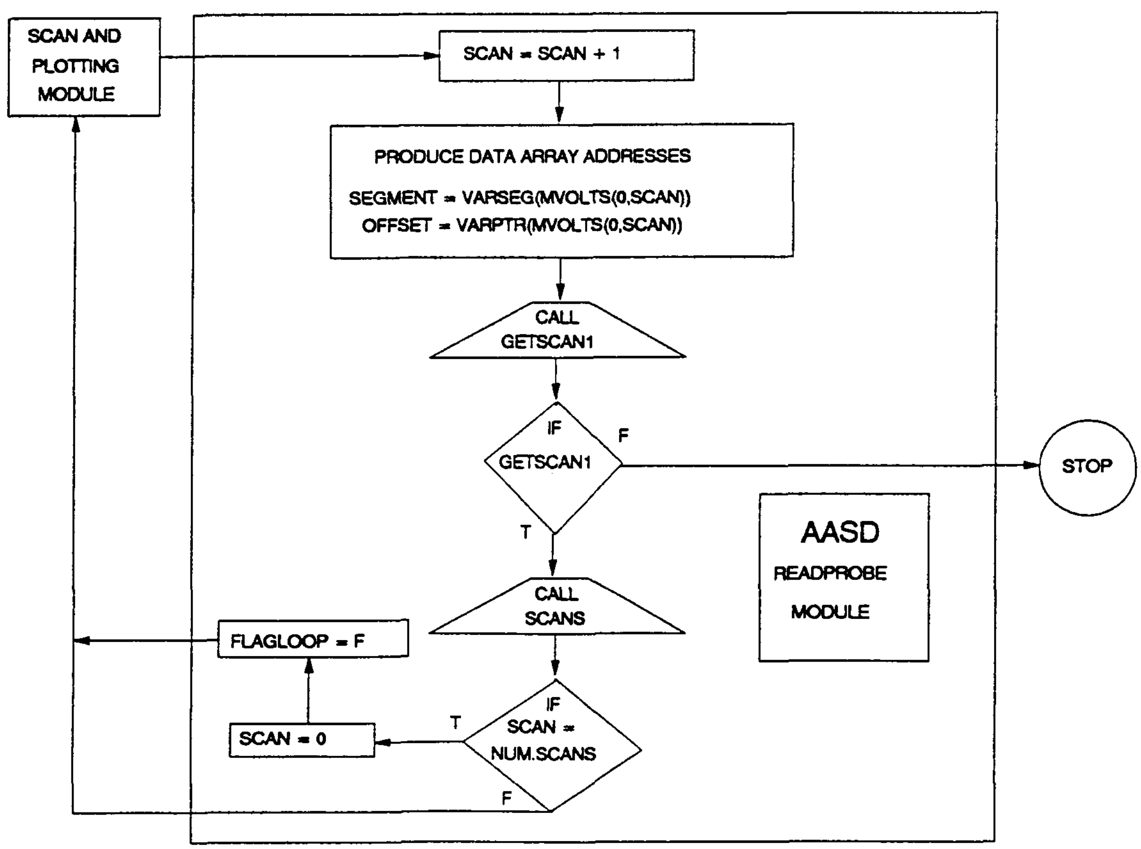


FIGURE C.11 AASD READPROBE MODULE

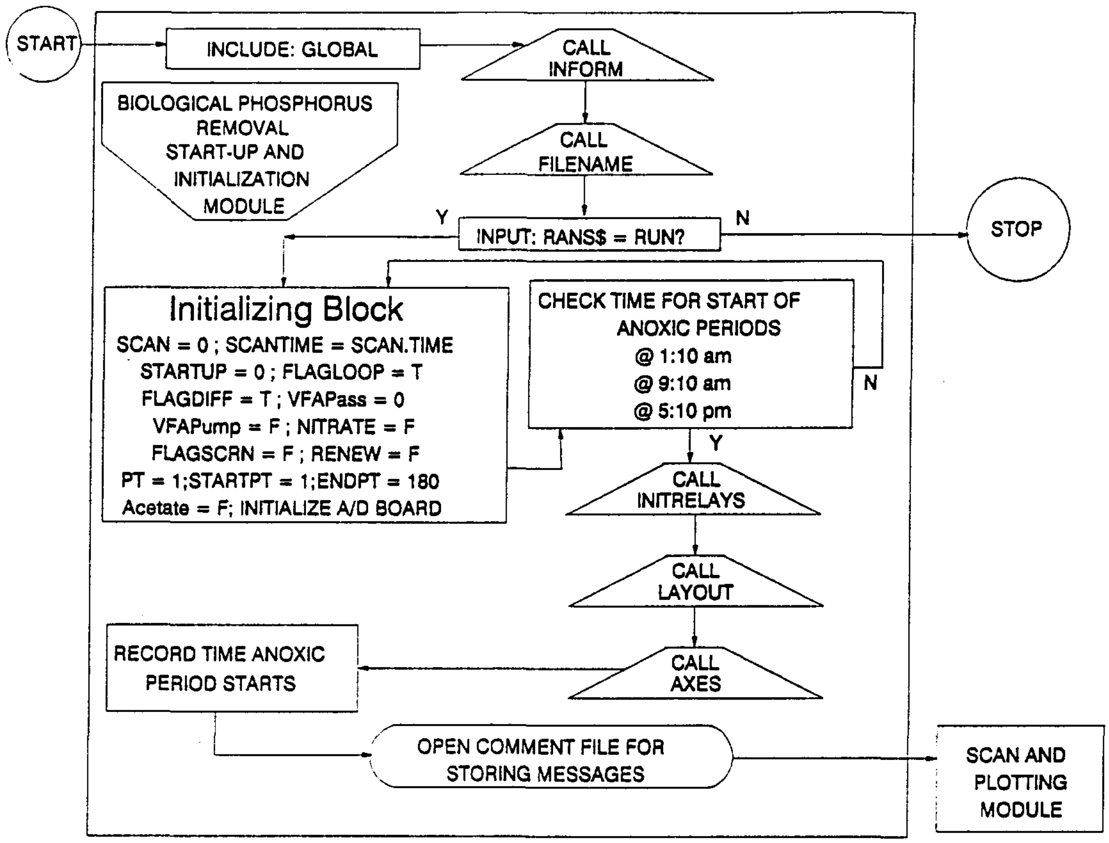


FIGURE C.12 BIO-P START-UP AND INITIALIZATION MODULE

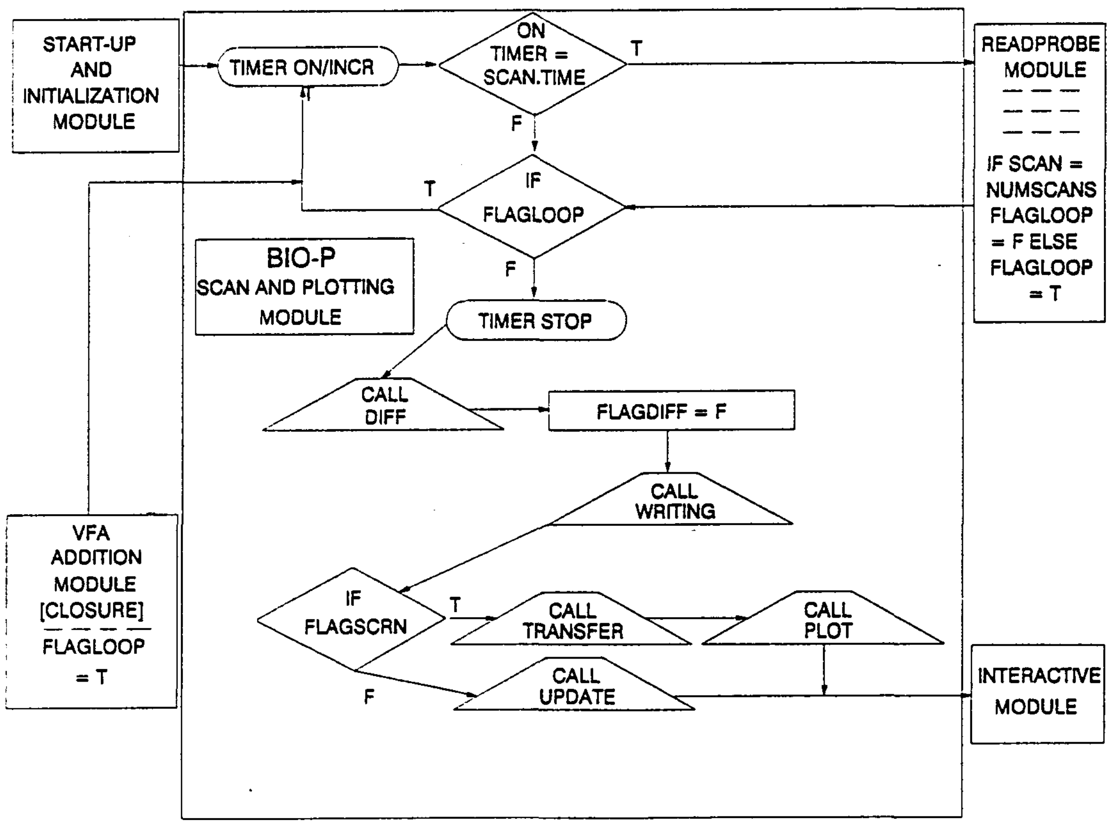


FIGURE C.13 BIO-P SCAN AND PLOTTING MODULE

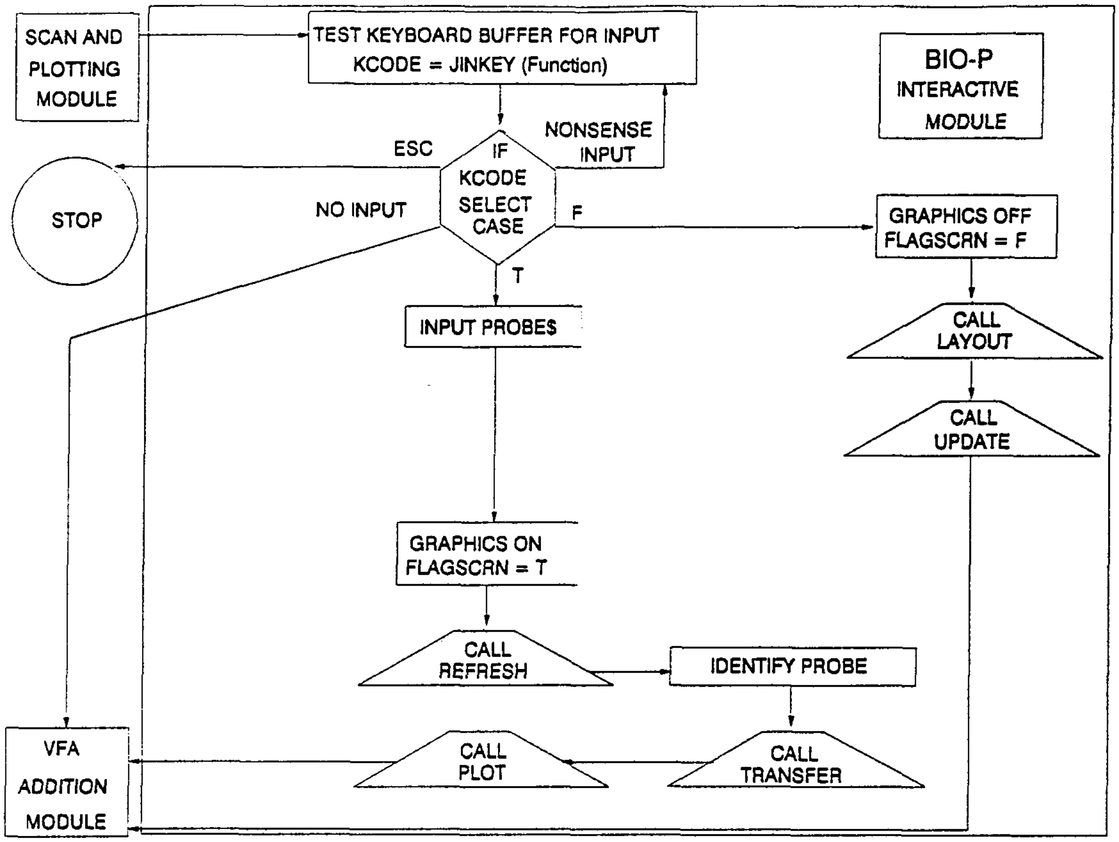


FIGURE C.14 BIO-P INTERACTIVE MODULE

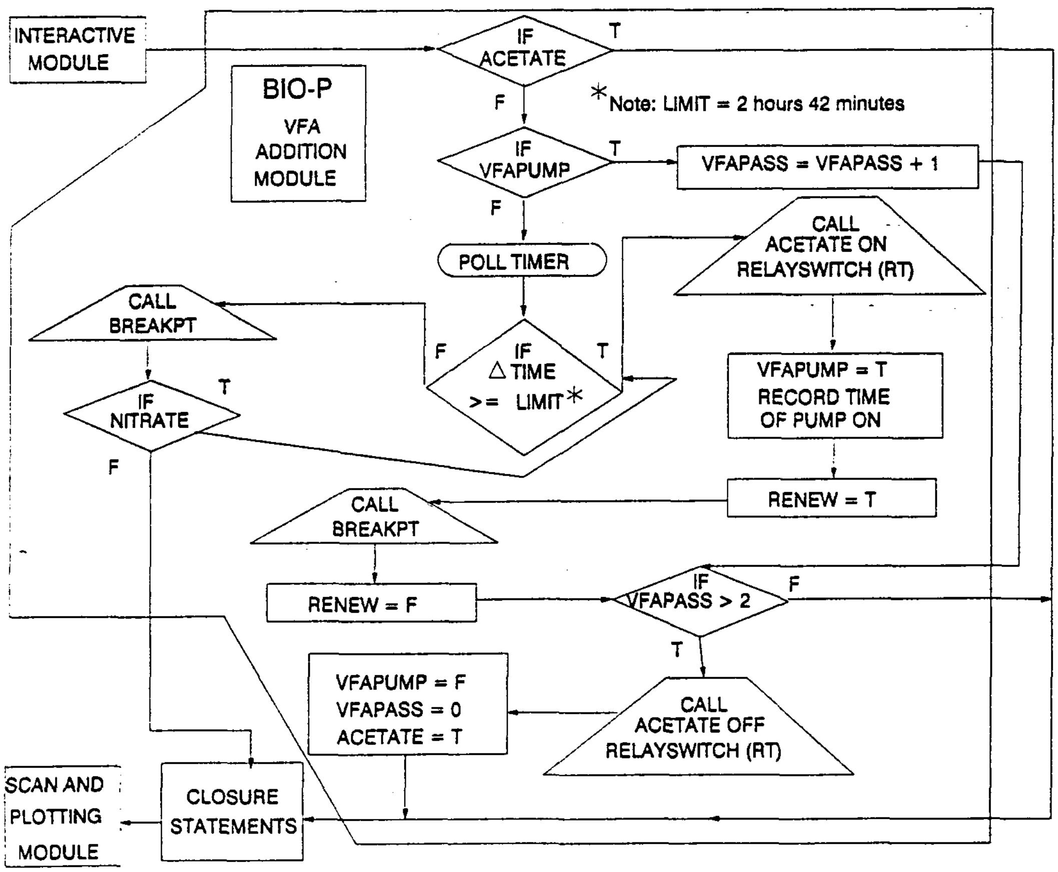


FIGURE C.15 BIO-P VFA ADDITION TO REAL-TIME REACTOR MODULE

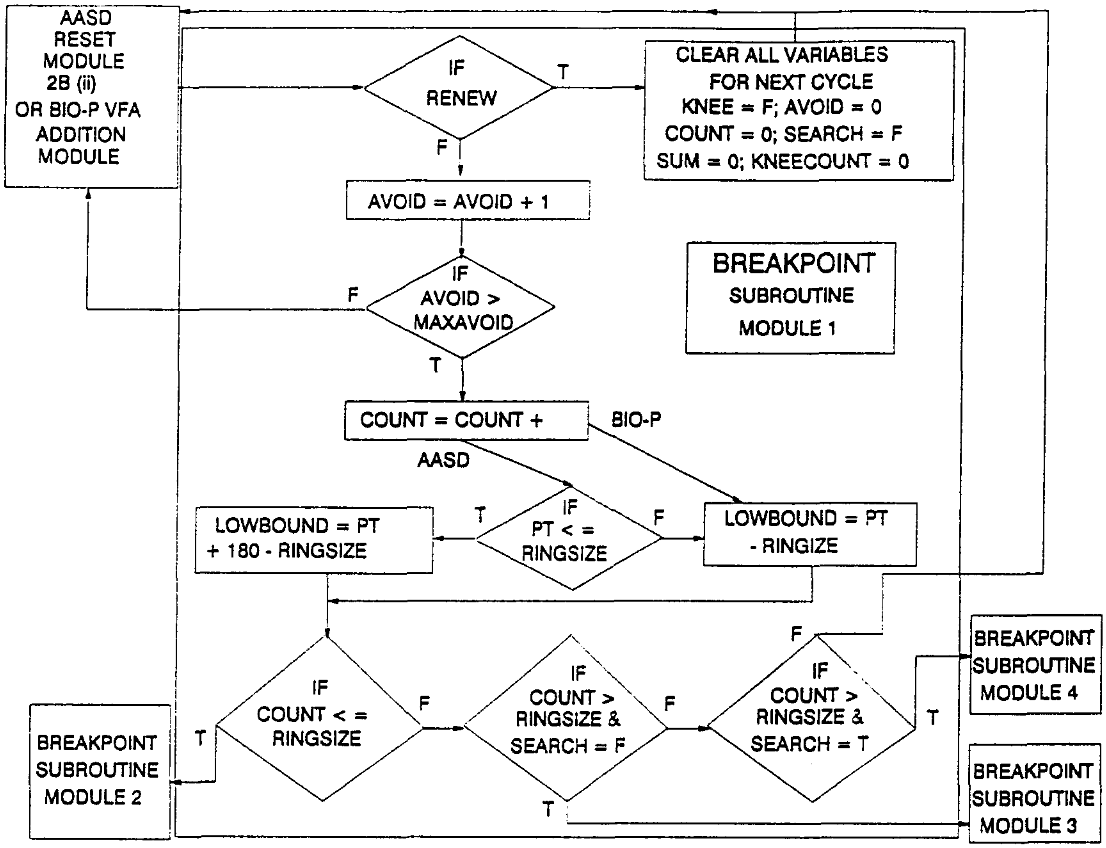


FIGURE C.16 BREAKPOINT SUBROUTINE - MODULE 1

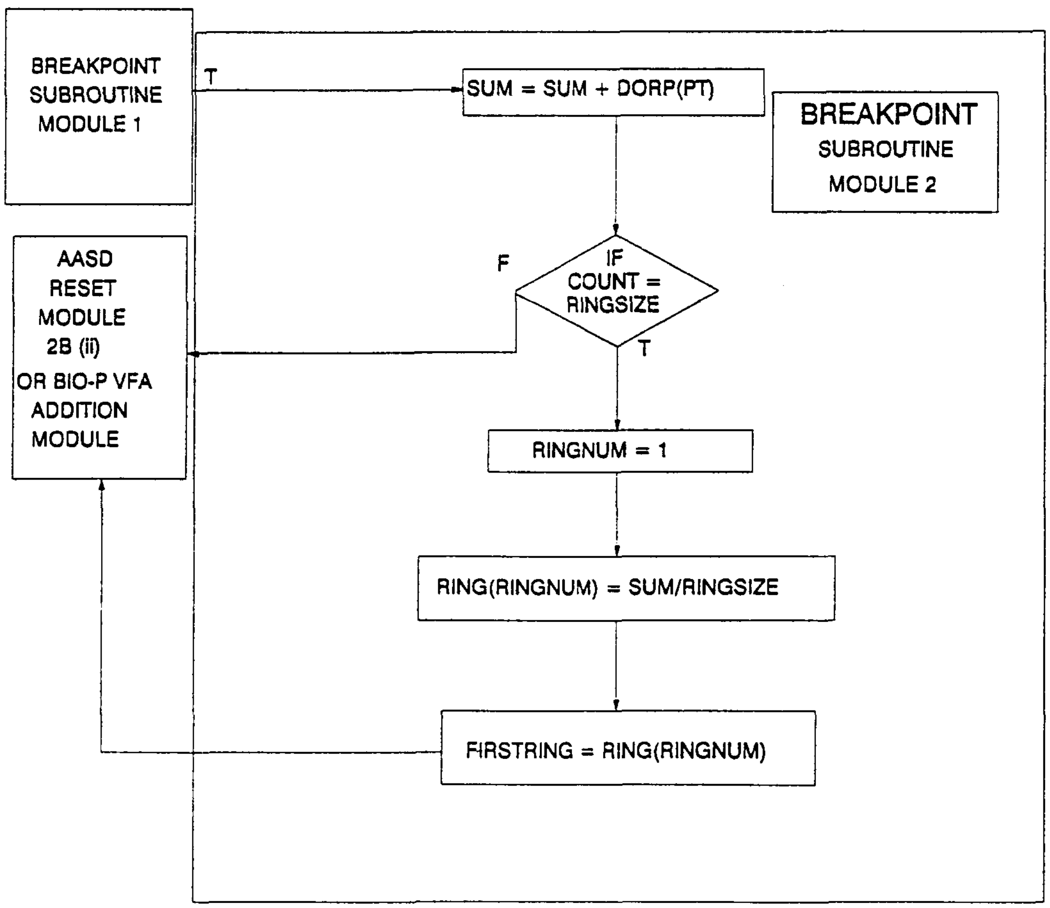


FIGURE C.17 BREAKPOINT SUBROUTINE - MODULE 2

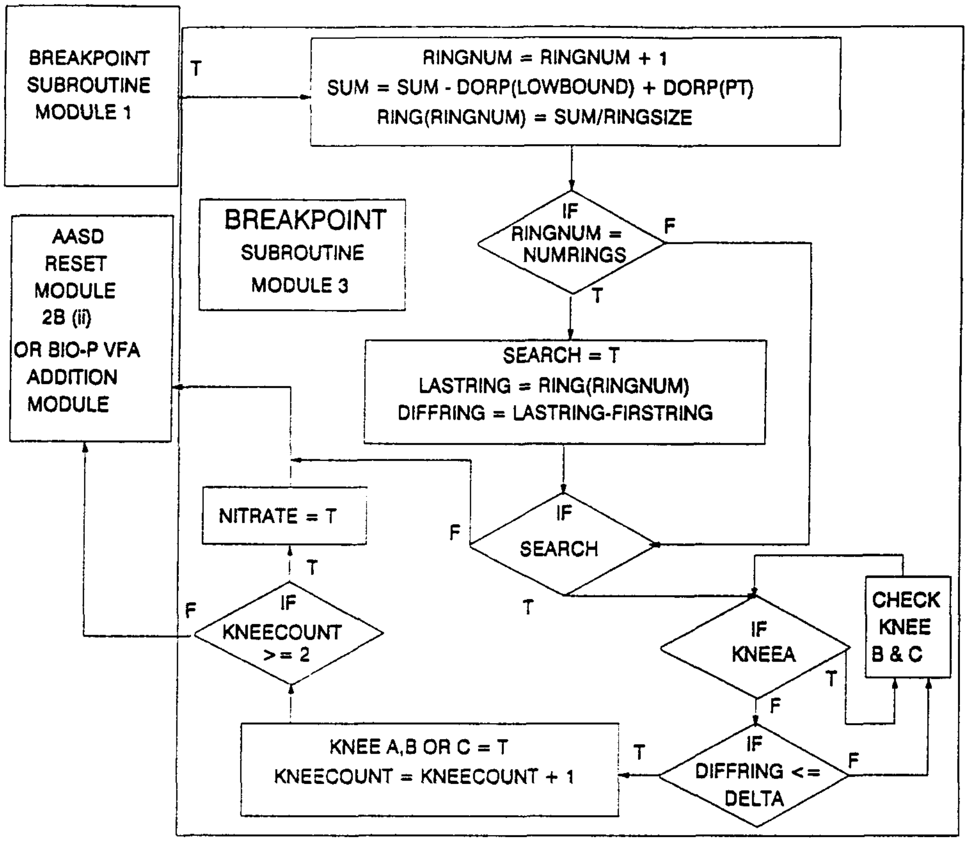


FIGURE C.18 BREAKPOINT SUBROUTINE - MODULE 3

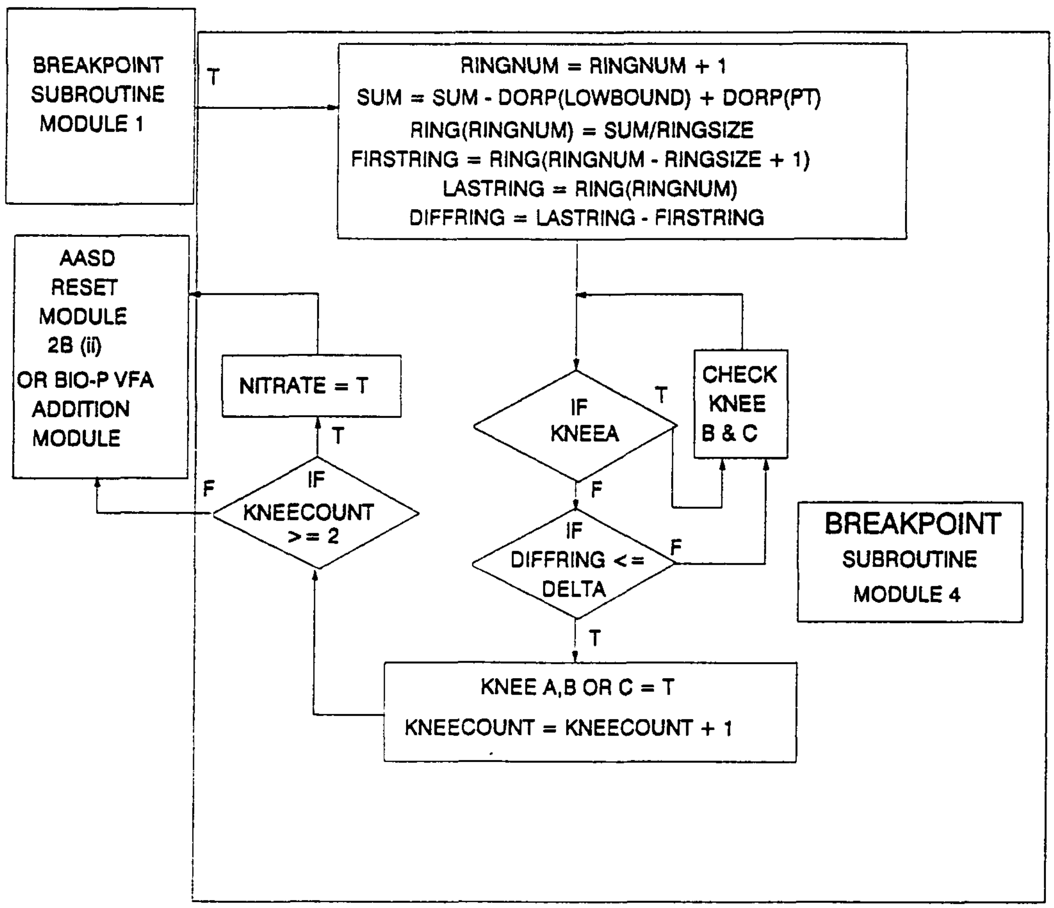


FIGURE C.19 BREAKPOINT SUBROUTINE - MODULE 4

APPENDIX D

SOFTWARE CODE - AASD#1, AASD#2 AND BIO-P

```
'--------------------------------- GLOBAL.BI -----------------------------
DEFINT A-Z
'-------------------------Declaration of Subroutines---------------------
DECLARE SUB INFORM ()
DECLARE SUB RELAYSWITCH (Relaynum%)
DECLARE SUB INITRELAYS ()
DECLARE SUB FILENAME (FTout$, RTout$, Commout$, FTnum, RTnum, Commnum)
DECLARE SUB REFRESH (Probe$)
DECLARE SUB ORPSCRN ()
DECLARE SUB AXES ()
DECLARE SUB PAXIS ()
DECLARE SUB SCANS (SCAN, Pt)
DECLARE SUB DIFF (Flagdiff, Pt)
DECLARE SUB WRITING (Pt, FTout$, RTout$, FTnum, RTnum)
DECLARE SUB TRANSFER (ProbeID$, Pt)
DECLARE SUB PLOT (Pt)
DECLARE SUB BREAKPT (Commnum, Pt, Nitrate, Renew)
DECLARE SUB LAYOUT ()
DECLARE SUB UPDATE (Pt)
'-------------------------Declaration of Functions------------------------
DECLARE FUNCTION TYPROBE$ (Probe$)
DECLARE FUNCTION jinkey% ()
DECLARE FUNCTION getscan1% (iobase%, first%, last%, BYVAL segaddr%, BYVAL offaddr%)
'-----------------------Declaration of Constants------------------------
CONST SCAN.TIME = 2         'The scanning time is 2 seconds.
CONST NUM.CHANNELS = 16     'The number of channels to be scanned.
CONST NUM.SCANS = 60        'Number of scans in two minute interval.
CONST NUM.PTS = 181         'For dimensioning purposes.
CONST MAX.ANOX = 14400      'Currently a Four Hours Maximum Anoxic Limit
CONST KY.LY = &H79          'For <Yes> decision in selecting other probes.
CONST KY.LN = &H6E          'For <No> decision finished viewing probes.
CONST KY.ESC = &H1B         'For escaping from program.
CONST chan0% = 0            'The first channel - lower bound.
CONST chan15% = 15          'The last channel - upper bound.
CONST baseaddr% = &H220     'The base address of the A/D board.
CONST ioaddr% = &H300       'The base address of the relay board.
CONST FALSE = 0             'Mostly used for flag settings.
CONST TRUE = 1              'Mostly used for flag settings.
CONST RINGSIZE = 5          'The Width of the Ring.
CONST NUMRINGS = 5          'The number of Rings in the Buffer.
CONST DELTA2A! = -1.25      'The difference in slope between the first and last
CONST DELTA2B! = -1.25      'rings of the Ringbuffer for the Real Time
CONST DELTA2C! = -1.25      'ORP Probes.
CONST MAXAVOID = 15         'Safety Factor to allow stability after air ceases.
'-------------------Dimensioning of Arrays------------------------------
DIM MVolts(NUM.CHANNELS, NUM.SCANS)
DIM ORP1a(NUM.PTS) AS SINGLE, ORP1b(NUM.PTS) AS SINGLE
DIM ORP1c(NUM.PTS) AS SINGLE, ORP2a(NUM.PTS) AS SINGLE
DIM ORP2b(NUM.PTS) AS SINGLE, ORP2c(NUM.PTS) AS SINGLE
DIM DOx1(NUM.PTS) AS SINGLE, DOx2(NUM.PTS)  AS SINGLE
DIM ORP(NUM.PTS)
DIM DORP1a(NUM.PTS) AS SINGLE, DORP1b(NUM.PTS) AS SINGLE
DIM DORP1c(NUM.PTS) AS SINGLE, DORP2a(NUM.PTS) AS SINGLE
DIM DORP2b(NUM.PTS) AS SINGLE, DORP2c(NUM.PTS) AS SINGLE
DIM RING2a(NUM.PTS) AS SINGLE, RING2b(NUM.PTS) AS SINGLE
DIM RING2c(NUM.PTS) AS SINGLE
'-----------Variables shared between Modules----------------------------
COMMON SHARED ORP1a() AS SINGLE, ORP1b() AS SINGLE, ORP1c() AS SINGLE
COMMON SHARED ORP2a() AS SINGLE, ORP2b() AS SINGLE, ORP2c() AS SINGLE
COMMON SHARED DOx1() AS SINGLE, DOx2() AS SINGLE
COMMON SHARED ORP(), MVolts()
COMMON SHARED DORP1a() AS SINGLE, DORP1b() AS SINGLE, DORP1c() AS SINGLE
COMMON SHARED DORP2a() AS SINGLE, DORP2b() AS SINGLE, DORP2c() AS SINGLE
COMMON SHARED RING2a() AS SINGLE, RING2b() AS SINGLE, RING2c() AS SINGLE
COMMON SHARED Startpt, Endpt, ONOFFmap&, Digit01, Digit02, Digit21, Digit22
COMMON SHARED Digit41, Digit42, Digit61, Digit62, Digit3, Digit4
```

```
'------------------------------- AASD1.BAS ------------------------------
                                  and
'------------------------------- AASD2.BAS ------------------------------
DEFINT A-Z

'===========================================================================
'                        STARTUP AND INITIALIZATION MODULE
'=========================================================================
'This module introduces the user to the mechanics of the program, initializes
'some parameters, and declares global parameters.

'$INCLUDE: 'GLOBAL.BI'

 CLS

 CALL INFORM                 'Call the information for the program mechanics.

 CALL FILENAME(FTout$, RTout$, Commout$, FTnum, RTnum, Commnum)'Set disk Files

Runprompt:

   LOCATE 21, 15:  INPUT ; "Do you want to run the program? (Y/N)   ", RAns$
                           RAns$ = UCASE$(RAns$)

   IF RAns$ = "Y" THEN
      GOTO Initialize
   ELSEIF RAns$ = "N" THEN
      GOTO Theend
   ELSE
      GOTO Runprompt
   END IF

Initialize:

 SCAN = 0                    'Set the Scan counter to zero to start the scans.
 Scantime = SCAN.TIME        'The Scan time is currently every 2 seconds.

 OUT baseaddr%, &H0          '
 FOR x = 1 TO 100: NEXT x    'Initialize the DT2814 A/D Board
  i = INP(baseaddr% + 1)     'as per the DT2814 manual on pg. 5-9
  i = INP(baseaddr% + 1)     '

 CALL INITRELAYS             'Initialize the relay board - set all relays off.

 Startup = 0                 'Used to control the Scanning Loop
 Flagloop = TRUE             'Flag for breaking out of and into Scanning Loop.
 Flagdiff = TRUE             'Flag to signify no preceeding point in Diff Sub.
 Realtime = FALSE            'Initially no Real Time Control of Reactor # 2
 Flag.RT = FALSE             'Real-time indicated - wait for anoxic cycle
 Nitrate = FALSE             'No Nitrate Breakpoint Detected as of yet.
 Renew = FALSE               'Flag used to clear/reset Breakpt Sub variables.
 Flagscrn = FALSE            'Flag indicating whether graphics is invoked

  Pt = 1                     'Assign initial point of the start of cycle.
  Startpt = 1                'Storage of initial Pt value.
  Endpt = 180                'There are 180 points in a Six Hour Cycle.

 CALL LAYOUT                 'Layout the Text mode information.
 CALL AXES                   'Calculate the relevant time axis.

                                              'Air on for 3 hours of Aeration
 Relaynum% = 0: CALL RELAYSWITCH(Relaynum%)  'Air.FT is switched on
 Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)  'Air.RT is switched on
 StartAer.FT& = TIMER                         'Poll the TIMER Function
 AirOn.FT = TRUE

 OPEN Commout$ FOR APPEND AS #Commnum         'Write to the comment file
 PRINT #Commnum, "AirFT On at "; TIME$
 PRINT #Commnum, "AirRT On at "; TIME$
```

```
'==============================================================================
'                          SCAN AND PLOTTING MODULE
'==============================================================================
'This module scans the ORP probes every 2 seconds and then  every  2 minutes
'an average for each probe is calculated and plotted if graphics is invoked
'else an update is written to the screen in text mode.

Scanning:

ON TIMER(Scantime) GOSUB Readprobe  'Every 2 sec. go to the Readprobe Module

   TIMER ON         'Enable On Timer event-handling trapping routine

DO                  'Loop enclosing the entire program - to exit press <Escape>

IF Flagloop = FALSE THEN                   'Break out of the Scanning Loop

   TIMER STOP

   CALL DIFF(Flagdiff, Pt)                 'Calculate the First Difference

    Flagdiff = FALSE                       'Now Preceeding Pts are available

    Datecheck = VAL(MID$(DATE$, 4, 2))     'Perform Date check on the Data
    IF Datecheck <> FTnum THEN             'If past midnight (ie. new day)
       CLOSE #Commnum                      'Close comment file - open data
       CALL FILENAME(FTout$, RTout$, Commout$, FTnum, RTnum, Commnum)  'file
       OPEN Commout$ FOR APPEND AS #Commnum  'Open new comment file
    END IF

   CALL WRITING(Pt, FTout$, RTout$, FTnum, RTnum)  'Write data to disk

   IF Flagscrn = FALSE THEN CALL UPDATE(Pt) 'Update the information screen

   IF Flagscrn = TRUE THEN
      CALL TRANSFER(ProbeID$, Pt)          'Transfer the array of points
      CALL PLOT(Pt)                        'Plot history of points to present
   END IF




'==============================================================================
'                             READPROBE MODULE
'==============================================================================
'This module does the actual reading of the probes by calling the SCAN Sub

Readprobe:

        SCAN = SCAN + 1                    'Increment the SCAN Counter

        LOCATE 23, 42: PRINT USING "###"; SCAN

        segment% = VARSEG(MVolts(0, SCAN))  'Produce the requisite FAR
        offset% = VARPTR(MVolts(0, SCAN))   'Pointer to the data array

        'Call the function returning an error code

        errnum% = getscan1%(baseaddr%, chan0%, chan15%, segment%, offset%)

        IF errnum% <> 0 THEN
           PRINT #Commnum, "Getscan returned an error code at "; TIME$
           GOTO Theend
        END IF

           CALL SCANS(SCAN, Pt)            'Call the SCAN Subroutine

        IF SCAN = NUM.SCANS THEN           '60 Scans (2 min) elapsed
           SCAN = 0
           Flagloop = FALSE                'Break out of scanning loop
        END IF

RETURN
```

```
'=========================================================================
'                            INTERACTIVE MODULE
'=========================================================================
'This module allows the user to interact with the process allowing him to
'select any of the probes which he desires to observe on a real-time basis.

kcode = jinkey%                      'Test for Keystroke in the Keyboard buffer.

IF kcode THEN                        'Determine what the keystroke is.

 SELECT CASE kcode

   CASE KY.ESC

        EXIT DO

   CASE KY.LY

        GOTO Whichprobe              'Which probe has been selected.

Whichprobe:

        LOCATE 23, 48: INPUT "Which Probe? (Letter)"; Probe$
                                Probe$ = UCASE$(Probe$)

        IF Probe$ = "A" OR Probe$ = "B" OR Probe$ = "C" THEN GOTO RTprompt

        IF Probe$ = "D" OR Probe$ = "E" OR Probe$ = "F" THEN
           GOTO RTprompt
        ELSE
           GOTO Whichprobe
        END IF

RTprompt:

        IF Realtime = FALSE THEN        'Interested in Real Time Control?
           LOCATE 23, 48: INPUT "Real-time control RCTR 2? (Y)"; Ans.RT$
                                  Ans.RT$ = UCASE$(Ans.RT$)
        IF Ans.RT$ = "Y" THEN Realtime = TRUE
        END IF

        SCREEN 3                     'For Hercules Graphics capabilities

        Flagscrn = TRUE              'Do not overlay text mode on graphics

        CALL REFRESH(Probe$)                 'Refresh the screen
        ProbeID$ = TYPROBE$(Probe$)          'Identify the Selected probe
        CALL TRANSFER(ProbeID$, Pt)          'Transfer the array of points
        CALL PLOT(Pt)                        'Plot history of points to present
        LOCATE 23, 27: PRINT "Scan Number - "

   CASE KY.LN

        SCREEN 0                     'Turn off Hercules Graphics

        Flagscrn = FALSE             'Invoke Text mode again

        CALL LAYOUT                  'Layout the text information

        CALL UPDATE(Pt)              'Update the screen information

   CASE ELSE                         'Do nothing

 END SELECT                          'Closes Select Case kcode Structure.

END IF                               'Closes IF kcode Decision Block.
```

```
'==========================================================================
'            RESET MODULE: Part 1 - Both Reactors Fixed time
'==========================================================================
'This module resets some flags to break out of loops at the appropriate
'times.

IF Flag.RT = FALSE THEN     'Real time not implemented yet.

'--------------------------- Part 1a Air On ---------------------------------

IF AirOn.FT = TRUE THEN     'Check for finish of 3 hr aeration  period

 FinishAer.FT& = TIMER      'Poll the TIMER Function

 'Check if 3 hr air on period overlaps into next day
 IF FinishAer.FT& < 10920 AND StartAer.FT& >= 75480 THEN
    FinishAer.FT& = FinishAer.FT& + 86400
 END IF

 IF (FinishAer.FT& - StartAer.FT&) >= 10800 THEN  'Aerated for 3 hours
    Relaynum% = 0: CALL RELAYSWITCH(Relaynum%)     'Air.FT is switched off
    Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)     'Air.RT is switched off
    StartAnox.FT& = TIMER                          'Poll the TIMER Function
    AirOn.FT = FALSE
    PRINT #Commnum, "AirFT Off at "; TIME$         'Write to the comment file
    PRINT #Commnum, "AirRT Off at "; TIME$

    IF Realtime = TRUE THEN                        'User wants Realtime control
       Flag.RT = TRUE                              'Avoid Part 1 - no Real Time
       StartAnox.RT& = TIMER                       'Poll the TIMER Function
       AirOn.RT = FALSE
       PRINT #Commnum, "Real-Time started at "; TIME$
    END IF

 END IF                  'Closes 3 Hour Aeration Block

END IF                   'Closes If AirOn.FT = TRUE Part 1a Decision Block

'--------------------------- Part 1b Air Off --------------------------------

IF AirOn.FT = FALSE THEN   'Check for Finish of 3 hours air off period

 FinishAnox.FT& = TIMER    'Poll the TIMER Function

 'Check if 3 hour air off period overlaps into next day
 IF FinishAnox.FT& < 10920 AND StartAnox.FT& >= 75480 THEN
    FinishAnox.FT& = FinishAnox.FT& + 86400
 END IF

 IF (FinishAnox.FT& - StartAnox.FT&) >= 10800 THEN 'Anoxic for 3 hours
    Relaynum% = 0: CALL RELAYSWITCH(Relaynum%)      'Air.FT is switched on
    Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)      'Air.RT is switched on
    StartAer.FT& = TIMER                            'Poll the TIMER Function
    AirOn.FT = TRUE
    PRINT #Commnum, "AirFT On at "; TIME$           'Write to the comment file
    PRINT #Commnum, "AirRT On at "; TIME$
 END IF                  'Closes 3 hour Air Off Decision Block

END IF                   'Closes If AirOn.FT = FALSE Part 1b Decision Block
```

'Note: This is for the AASD#1 Program

```
'============================================================================
'        RESET MODULE: Part 2 - 1 RCTR Fixed Time / 1 RCTR Real time
'============================================================================

ELSEIF Flag.RT = TRUE THEN 'Real Time Control Implemented

'----------------------- Part 2a(i) - Fixed Time Air On --------------------

IF AirOn.FT = TRUE THEN    'Check for Finish of 3 hour aeration period

 FinishAer.FT& = TIMER     'Poll the TIMER Function

 'Check if 3 hr air on period overlaps into next day
 IF FinishAer.FT& < 10920 AND StartAer.FT& >= 75480 THEN
    FinishAer.FT& = FinishAer.FT& + 86400
 END IF

 IF (FinishAer.FT& - StartAer.FT&) >= 10800 THEN  'Aerated for 3 hours
    Relaynum% = 0: CALL RELAYSWITCH(Relaynum%)     'Air.FT is switched off.
    StartAnox.FT& = TIMER                          'Poll the TIMER Function
    AirOn.FT = FALSE
    PRINT #Commnum, "AirFT Off at "; TIME$         'Write to the comment file
 END IF

END IF                  'Closes If AirOn.FT = TRUE Part 2a(i) Decision Block

'---------------------- Part 2a(ii) - Fixed Time Air Off ------------------

IF AirOn.FT = FALSE THEN   'Check for finish of 3 hr air off period

FinishAnox.FT& = TIMER    'Poll the TIMER Function

'Check if 3 hour air off period overlaps into next day
IF FinishAnox.FT& < 10920 AND StartAnox.FT& >= 75480 THEN
   FinishAnox.FT& = FinishAnox.FT& + 86400
END IF

IF (FinishAnox.FT& - StartAnox.FT&) >= 10800 THEN 'Anoxic for 3 hours
   Relaynum% = 0: CALL RELAYSWITCH(Relaynum%)     'Air.FT is switched on.
   StartAer.FT& = TIMER                           'Poll the TIMER Function
   AirOn.FT = TRUE
   PRINT #Commnum, "AirFT On at "; TIME$          'Write to the comment file
END IF

END IF                  'Closes If AirOn.FT = FALSE Part 2a(ii) Decision Block

' ---------------------- Part 2b(i) - Real Time Air On ---------------------

IF AirOn.RT = TRUE THEN    'Check for finish of 3 hour air on period

 FinishAer.RT& = TIMER     'Poll the TIMER Function

 'Check if 3 hour air on period overlaps into next day
 IF FinishAer.RT& < 10920 AND StartAer.RT& >= 75480 THEN
    FinishAer.RT& = FinishAer.RT& + 86400
 END IF

 IF (FinishAer.RT& - StartAer.RT&) >= 10800 THEN  'Aerated for 3 hours
    Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)     'Air.RT is switched off.
    StartAnox.RT& = TIMER                          'Poll the TIMER Function
    AirOn.RT = FALSE
    PRINT #Commnum, "AirRT Off at "; TIME$         'Write to the comment file
 END IF

END IF                  'Closes If AirOn.RT = TRUE Part 2b(i) Decision Block
```

```
'------------------------ Part 2b(ii) - Real Time Air Off -----------------

IF AirOn.RT = FALSE THEN   'Check for Finish of Air Off Period

 FinishAnox.RT& = TIMER    'Poll the TIMER Function

 'Check if Maximum Anoxic limit overlaps into next day
 IF FinishAnox.RT& < MAX.ANOX AND StartAnox.RT& >= (86400 - MAX.ANOX) THEN
    FinishAnox.RT& = FinishAnox.RT& + 86400
 END IF

 IF (FinishAnox.RT& - StartAnox.RT&) >= MAX.ANOX THEN 'Anoxic limit exceeded
    Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)        'Air.RT is switched on.
    StartAer.RT& = TIMER                              'Poll the TIMER Function
    AirOn.RT = TRUE
    PRINT #Commnum, "Nitrate knee NOT detected on "; DATE$;
    PRINT #Commnum, " AirRT activated at "; TIME$

      Renew = TRUE                                  'Reset Breakpoint Subroutine
        CALL BREAKPT(Commnum, Pt, Nitrate, Renew)
      Renew = FALSE

 ELSE                                               'Search for Nitrate Breakpt

      CALL BREAKPT(Commnum, Pt, Nitrate, Renew)

         IF Nitrate = TRUE THEN
            Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)    'Air.RT switched on.
            StartAer.RT& = TIMER                         'Poll the TIMER Function
            AirOn.RT = TRUE
            PRINT #Commnum, "Nitrate knee detected on "; DATE$;
            PRINT #Commnum, " AirRT activated at "; TIME$

            Nitrate = FALSE

            Renew = TRUE                            'Reset Breakpoint Subroutine
               CALL BREAKPT(Commnum, Pt, Nitrate, Renew)
            Renew = FALSE
         END IF         'Closes If Nitrate = TRUE Decision Block

 END IF                 'Closes If Anoxic limit is > MAX.ANOX Decision Block

END IF                  'Closes If AirOn.RT = FALSE Part 2b(ii) Decision Block

END IF                  'Closes IF Flag.RT = FALSE Block - RESET MODULE

'------------------------ Closure Statements --------------------------------

   TIMER ON          'Enable the On Timer trapping  event-handling subroutine.

   Flagloop = TRUE   'Break back into the Scanning Loop.

   Pt = Pt + 1       'Increment point.

   IF Pt = 181 THEN  'Start of next 6 Hour Cycle
      Pt = 1         'Reset Pt to one
      CALL AXES      'Calculate the new time Axis
   END IF            'Closes IF Pt = 181 Decision Block.

END IF               'Closes IF Flagloop = FALSE Block Scanning Loop

LOOP WHILE Startup < 2                      'Closes DO LOOP Structure.

Theend:
      CLOSE #Commnum                        'Close the Comment File
      ONOFFmap& = &HFFFF                    'When exiting the program
      OUT (ioaddr%), ONOFFmap&              'turn off all the relay
      OUT (ioaddr% + 1), ONOFFmap&          'switches at both ports A and B
      CLS
END
```

```
'Note: This is for the AASD#2 Program

'==========================================================================
'        RESET MODULE: Part 2 - 1 RCTR Fixed Time / 1 RCTR Real time
'==========================================================================

ELSEIF Flag.RT = TRUE THEN 'Real Time Control Implemented

'----------------------- Part 2a(i) - Fixed Time Air On --------------------

IF AirOn.FT = TRUE THEN    'Check for Finish of 3 hour aeration period

 FinishAer.FT& = TIMER     'Poll the TIMER Function

 'Check if 3 hr air on period overlaps into next day
 IF FinishAer.FT& < 10920 AND StartAer.FT& >= 75480 THEN
    FinishAer.FT& = FinishAer.FT& + 86400
 END IF

 IF (FinishAer.FT& - StartAer.FT&) >= 10800 THEN  'Aerated for 3 hours
    Relaynum% = 0: CALL RELAYSWITCH(Relaynum%)    'Air.FT is switched off.
    StartAnox.FT& = TIMER                         'Poll the TIMER Function
    AirOn.FT = FALSE
    PRINT #Commnum, "AirFT Off at "; TIME$        'Write to the comment file
 END IF

END IF                  'Closes If AirOn.FT = TRUE Part 2a(i) Decision Block

'---------------------- Part 2a(ii) - Fixed Time Air Off ------------------

IF AirOn.FT = FALSE THEN   'Check for finish of 3 hr air off period
FinishAnox.FT& = TIMER    'Poll the TIMER Function

'Check if 3 hour air off period overlaps into next day
IF FinishAnox.FT& < 10920 AND StartAnox.FT& >= 75480 THEN
   FinishAnox.FT& = FinishAnox.FT& + 86400
END IF

IF (FinishAnox.FT& - StartAnox.FT&) >= 10800 THEN 'Anoxic for 3 hours
   Relaynum% = 0: CALL RELAYSWITCH(Relaynum%)     'Air.FT is switched on.
   StartAer.FT& = TIMER                           'Poll the TIMER Function
   AirOn.FT = TRUE
   PRINT #Commnum, "AirFT On at "; TIME$          'Write to the comment file
END IF

END IF                  'Closes If AirOn.FT = FALSE Part 2a(ii) Decision Block

' ---------------------- Part 2b(i) - Real Time Air On --------------------

IF AirOn.RT = TRUE THEN    'Check for finish of aeration period

 FinishAer.RT& = TIMER     'Poll the TIMER Function

 'Check if aeration period overlaps into next day
 IF FinishAer.RT& < 10920 AND StartAer.RT& >= 75480 THEN
    FinishAer.RT& = FinishAer.RT& + 86400
 END IF

 AerPeriod.RT& = FinishAer.RT& - StartAer.RT&     'Calculate Aeration Period

 IF (AerPeriod.RT&) >= AerLength.RT& THEN         'Aerated for anoxic period
    Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)    'Air.RT is switched off.
    StartAnox.RT& = TIMER                         'Poll the TIMER Function
    AirOn.RT = FALSE
    PRINT #Commnum, "AirRT Off at "; TIME$        'Write to the comment file
    PRINT #Commnum, "RT Aeration Period for "; AerPeriod.RT&
 END IF

END IF                  'Closes If AirOn.RT = TRUE Part 2b(i) Decision Block
```

```
'------------------------ Part 2b(ii) - Real Time Air Off -----------------

IF AirOn.RT = FALSE THEN   'Check for Finish of Air Off Period

 FinishAnox.RT& = TIMER    'Poll the TIMER Function

 'Check if Maximum Anoxic limit overlaps into next day
 IF FinishAnox.RT& < MAX.ANOX AND StartAnox.RT& >= (86400 - MAX.ANOX) THEN
    FinishAnox.RT& = FinishAnox.RT& + 86400
 END IF

 AnoxPeriod.RT& = FinishAnox.RT& - StartAnox.RT&      'Air off length of time

 IF (AnoxPeriod.RT&) >= MAX.ANOX THEN                 'Anoxic limit exceeded
    Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)        'Air.RT is switched on.
    StartAer.RT& = TIMER                              'Poll the TIMER Function
    AirOn.RT = TRUE
    AerLength.RT& = AnoxPeriod.RT&                    'Assign aeration time
    PRINT #Commnum, "Nitrate knee NOT detected on "; DATE$;
    PRINT #Commnum, " AirRT activated at "; TIME$

      Renew = TRUE                                   'Reset Breakpoint Subroutine
        CALL BREAKPT(Commnum, Pt, Nitrate, Renew)
      Renew = FALSE

 ELSE                                                'Search for Nitrate Breakpt
      CALL BREAKPT(Commnum, Pt, Nitrate, Renew)

         IF Nitrate = TRUE THEN
            Relaynum% = 1: CALL RELAYSWITCH(Relaynum%)  'Air.RT switched on.
            StartAer.RT& = TIMER                      'Poll the TIMER Function
            AirOn.RT = TRUE
            AerLength.RT& = AnoxPeriod.RT&              'Assign aeration time
            PRINT #Commnum, "Nitrate knee detected on "; DATE$;
            PRINT #Commnum, " AirRT activated at "; TIME$

            Nitrate = FALSE

            Renew = TRUE                         'Reset Breakpoint Subroutine
                CALL BREAKPT(Commnum, Pt, Nitrate, Renew)
            Renew = FALSE
         END IF        'Closes If Nitrate = TRUE Decision Block

 END IF                'Closes If Anoxic limit is > MAX.ANOX Decision Block

END IF                 'Closes If AirOn.RT = FALSE Part 2b(ii) Decision Block

END IF                 'Closes IF Flag.RT = FALSE Block - RESET MODULE

'----------------------- Closure Statements -------------------------------

   TIMER ON          'Enable the On Timer trapping  event-handling subroutine.

   Flagloop = TRUE   'Break back into the Scanning Loop.

   Pt = Pt + 1       'Increment point.

   IF Pt = 181 THEN  'Start of next 6 Hour Cycle
      Pt = 1         'Reset Pt to one
      CALL AXES      'Calculate the new time Axis
   END IF            'Closes IF Pt = 181 Decision Block.

END IF               'Closes IF Flagloop = FALSE Block Scanning Loop

LOOP WHILE Startup < 2                      'Closes DO LOOP Structure.

Theend:
      CLOSE #Commnum                        'Close the Comment File
      ONOFFmap& = &HFFFF                    'When exiting the program
      OUT (ioaddr%), ONOFFmap&              'turn off all the relay
      OUT (ioaddr% + 1), ONOFFmap&          'switches at both ports A and B
      CLS
END
```

```
'-------------------------------- BIOP.BAS ----------------------------
DEFINT A-Z

'========================================================================
'                       STARTUP AND INITIALIZATION MODULE
'========================================================================
'This module introduces the user to the mechanics of the program, initializes
'some parameters, and declares global parameters.

'$INCLUDE: 'GLOBAL.BI'

 CLS

 CALL INFORM               'Display the information for the program mechanics.

 CALL FILENAME(FTout$, RTout$, Commout$, FTnum, RTnum, Commnum)'Set disk Files

Runprompt:

   LOCATE 23, 15:  INPUT ; "Do you want to run the program? (Y/N)   ", RAns$
                            RAns$ = UCASE$(RAns$)

   IF RAns$ = "Y" THEN
      GOTO Setscreen
   ELSEIF RAns$ = "N" THEN
      GOTO Theend
   ELSE
      GOTO Runprompt
   END IF

Setscreen:

 CLS

 LOCATE 10, 14: PRINT "The reactors are not in an anoxic mode."
 LOCATE 11, 14: PRINT "Anoxic Sequence Starting Times are the"
 LOCATE 12, 14: PRINT "following ... 1:10 am, 9:10 am and 5:10 pm."

Initialize:

 FOR x = 1 TO 5000
  FOR y = 1 TO 100: NEXT y  'Delay to slow down the timer loop
 NEXT x

 Checktime& = TIMER         'Poll the timer function

 SCAN = 0                   'Set the Scan counter to zero to start the scans.
 Scantime = SCAN.TIME       'The Scan time is currently every 2 seconds.

 Startup = 0                'Used to control the Scanning Loop
 Flagloop = TRUE            'Flag for breaking out of and into Scanning Loop.
 Flagdiff = TRUE            'Flag to signify no preceeding point in Diff Sub.
 Nitrate = FALSE            'No Nitrate Breakpoint Detected as of yet.
 Renew = FALSE              'Flag used to clear/reset Breakpt Sub variables.
 Flagscrn = FALSE           'Flag indicating whether graphics is invoked


 VFAPass = 0                'The VFA counter to time the pump operation.
 VFAPump = FALSE            'The RT Acetate Pump is off
 Acetate = FALSE            'Acetate not added to the RT reactor yet

 Pt = 1                     'Assign initial point of the start of graph.
 Startpt = 1                'Storage of initial Pt value.
 Endpt = 180                'There are 180 points in a Six Hour Graph.
```

```
 IF Checktime& > 0 THEN AnoxStart& = 4200        'Time: 1:10 am

    Datecheck = VAL(MID$(DATE$, 4, 2))        'Perform Date check on the Data
    IF Datecheck <> FTnum THEN                'If past midnight (ie. new day)
       CALL FILENAME(FTout$, RTout$, Commout$, FTnum, RTnum, Commnum)  'file
    END IF

IF Checktime& > 4200 THEN AnoxStart& = 33000    ' Time: 9:10 am
IF Checktime& > 33000 THEN AnoxStart& = 61800   ' Time: 5:10 pm
IF Checktime& > 61800 THEN GOTO Initialize

SamplingTime:

 Polltime& = TIMER                  'Poll the timer function

 IF Polltime& > AnoxStart& THEN     'The anoxic cycle commences
    GOTO StartRecording             'Start Recording the ORP values
 ELSE
    GOTO SamplingTime               'Return and poll the timer function again
 END IF

StartRecording:

 OUT baseaddr%, &H0          '
 FOR x = 1 TO 100: NEXT x    'Initialize the DT2814 A/D Board
  i = INP(baseaddr% + 1)     'as per the DT2814 manual on pg. 5-9
  i = INP(baseaddr% + 1)     '

 CALL INITRELAYS             'Initialize the relay board - set all relays off.

 OPEN Commout$ FOR APPEND AS #Commnum                    'Write to the
 PRINT #Commnum, "Anoxic Period Started at "; TIME$      'comment file
 StartAnox& = Polltime&
 Oper$ = "Acetate not added yet"

 CLS
 CALL LAYOUT                 'Layout the text information.
 CALL AXES                   'Calculate the relevant time axis.

'============================================================================
'                          SCAN AND PLOTTING MODULE
'============================================================================
'This module scans the ORP probes every 2 seconds and then every 2 minutes
'an average for each probe is calculated and plotted if graphics is invoked
'else an update is written to the screen in text mode.

Scanning:

ON TIMER(Scantime) GOSUB Readprobe  'Every 2 sec. go to the Readprobe Module

   TIMER ON         'Enable On Timer event-handling trapping routine

DO                  'Loop enclosing the entire program - to exit press <Escape>

IF Flagloop = FALSE THEN                        'Break out of the Scanning Loop

   TIMER STOP

   CALL DIFF(Flagdiff, Pt)                      'Calculate the First Difference

    Flagdiff = FALSE                            'Now Preceeding Pts are available

   CALL WRITING(Pt, FTout$, RTout$, FTnum, RTnum)  'Write data to disk

   IF Flagscrn = FALSE THEN
      CALL UPDATE(Pt)                           'Update the information screen
      LOCATE 14, 46: PRINT Oper$

   END IF

   IF Flagscrn = TRUE THEN
      CALL TRANSFER(ProbeID$, Pt)              'Transfer the array of points
      CALL PLOT(Pt)                            'Plot history of points to present
   END IF
```

```
'=========================================================================
'                         INTERACTIVE MODULE
'=========================================================================
'This module allows the user to interact with the process allowing him to
'select any of the probes which he desires to observe on a real-time basis.

kcode = jinkey%                    'Test for Keystroke in the Keyboard buffer.

IF kcode THEN                      'Determine what the keystroke is.

 SELECT CASE kcode

   CASE KY.ESC

        EXIT DO                    'Exit from the program

   CASE KY.LY

        GOTO Whichprobe            'Which probe has been selected.

Whichprobe:

        LOCATE 23, 48: INPUT "Which Probe? (Letter)"; Probe$
                             Probe$ = UCASE$(Probe$)

        IF Probe$ = "A" OR Probe$ = "B" OR Probe$ = "C" THEN GOTO Startplot

        IF Probe$ = "D" OR Probe$ = "E" OR Probe$ = "F" THEN
           GOTO Startplot
        ELSE
           GOTO Whichprobe
        END IF

Startplot:

        SCREEN 3                   'For Hercules Graphics capabilities

        Flagscrn = TRUE            'Do not overlay text mode on graphics

        CALL REFRESH(Probe$)               'Refresh the screen
        ProbeID$ = TYPROBE$(Probe$)        'Identify the Selected probe
        CALL TRANSFER(ProbeID$, Pt)        'Transfer the array of points
        CALL PLOT(Pt)                      'Plot history of points to present
        LOCATE 23, 27: PRINT "Scan Number - "

   CASE KY.LN

        SCREEN 0                   'Turn off Hercules Graphics

        Flagscrn = FALSE           'Invoke Text mode again

        CALL LAYOUT                'Layout the text information
        LOCATE 14, 46: PRINT Oper$
        CALL UPDATE(Pt)            'Update the screen information

   CASE ELSE                       'Do nothing

 END SELECT                        'Closes Select Case kcode Structure.
END IF                             'Closes IF kcode Decision Block.
```

```
'=========================================================================
'                  VFA ADDITION TO REAL-TIME REACTOR MODULE
'=========================================================================

IF Acetate = FALSE THEN                 'Acetate not added as of yet

  VFAddtime& = TIMER                    'Poll the TIMER Function

  IF VFAPump = FALSE THEN               'The pump is not currently on

  'If nitrate knee was not detected - Acetate added after 2 hr 42 minutes
  '(ie. 6 minutes (3 passes) plus 2 minutes spare) prior to commencement
  'of aeration period

  IF (VFAddtime& - StartAnox&) >= 9720 THEN   'Time is > than 2 hr 42 min.
       Relaynum% = 0
       CALL RELAYSWITCH(Relaynum%)            'Acetate added to RT Reactor
       VFAPump = TRUE                         'VFA RT pump is on
     PRINT #Commnum, "No Nitrate knee detected on "; DATE$
     PRINT #Commnum, "Acetate pumped to RT reactor starting at "; TIME$
     Oper$ = "Acetate RT Feed Pump On"
     IF Flagscrn = FALSE THEN LOCATE 14, 46: PRINT Oper$

     Renew = TRUE                               'Clear/Reset Breakpoint Sub
       CALL BREAKPT(Commnum, Pt, Nitrate, Renew)
     Renew = FALSE

  ELSE                                          'Search for nitrate breakpoint

     CALL BREAKPT(Commnum, Pt, Nitrate, Renew)

       IF Nitrate = TRUE THEN
            Relaynum% = 0
            CALL RELAYSWITCH(Relaynum%)         'Acetate added to RT Reactor
            VFAPump = TRUE                      'VFA RT pump is on
          PRINT #Commnum, "Nitrate knee detected at "; TIME$
          PRINT #Commnum, "Acetate started to RT reactor at "; TIME$
          Oper$ = "Acetate RT Feed Pump On"
          IF Flagscrn = FALSE THEN LOCATE 14, 46: PRINT Oper$

          Renew = TRUE                          'Clear/Reset the Breakpt Sub
            CALL BREAKPT(Commnum, Pt, Nitrate, Renew)
          Renew = FALSE

       END IF       'Closes IF Nitrate = TRUE Decision Block

  END IF  'Closes Real Time Acetate Addition Decision Block

  ELSE                                          'Since RT Acetate Pump is on
     VFAPass = VFAPass + 1                      'Increment Pass Counter by 1
     IF VFAPass > 2 THEN                        '6 min (3 passes) have elapsed
        Relaynum% = 0
        CALL RELAYSWITCH(Relaynum%)             'Turn off RT Acetate pump
        VFAPump = FALSE                         'Reset Pump Variable
        VFAPass = 0                             'Reset Pass Counter
        Acetate = TRUE                          'Reset Acetate Variable
        PRINT #Commnum, "Acetate finished to RT reactor at "; TIME$
        Oper$ = "RT Acetate has finished pumping"
        IF Flagscrn = FALSE THEN LOCATE 14, 46: PRINT Oper$
     END IF
  END IF   'Closes IF VFAPump = FALSE Decision Block

END IF     'Closes IF Acetate = FALSE Decision Block
```

```
'----------------------- Closure Statements -------------------------------

   TIMER ON          'Enable the On Timer trapping  event-handling subroutine.

   Flagloop = TRUE   'Break back into the Scanning Loop.

   Pt = Pt + 1       'Increment point.

END IF               'Closes IF Flagloop = FALSE Block Scanning Loop

   IF Pt = 181 THEN Startup = 3              'Breakout of the Loop

LOOP WHILE Startup < 2                       'Closes DO LOOP Structure.

Theend:
      TIMER OFF
      CLOSE #Commnum                         'Close the Comment File
      ONOFFmap& = &HFFFF                     'When exiting the program
      OUT (ioaddr%), ONOFFmap&               'turn off all the relay
      OUT (ioaddr% + 1), ONOFFmap&           'switches at both ports A and B
      CLS

IF Startup = 3 THEN GOTO Setscreen

END

'===========================================================================
'                           READPROBE MODULE
'===========================================================================
'This module does the actual reading of the probes by calling the SCAN Sub

Readprobe:

        SCAN = SCAN + 1                      'Increment the SCAN Counter

        LOCATE 23, 42: PRINT USING "###"; SCAN

        segment% = VARSEG(MVolts(0, SCAN))   'Produce the requisite FAR
        offset% = VARPTR(MVolts(0, SCAN))    'Pointer to the data array

        'Call the function returning an error code

        errnum% = getscan1%(baseaddr%, chan0%, chan15%, segment%, offset%)

        IF errnum% <> 0 THEN
           PRINT #Commnum, "Getscan returned an error code at "; TIME$
           GOTO Theend
        END IF

           CALL SCANS(SCAN, Pt)              'Call the SCAN Subroutine

        IF SCAN = NUM.SCANS THEN             '60 Scans (2 min) elapsed
           SCAN = 0
           Flagloop = FALSE                  'Break out of scanning loop
        END IF

RETURN
```

```
'------------------------------- INFORM.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for the AASD#1 Program

'========================================================================
'          THIS SUBROUTINE DETAILS THE MECHANICS OF THE PROGRAM
'========================================================================
SUB INFORM STATIC

LOCATE 2, 23: PRINT "COMPUTER CONTROLLED SLUDGE DIGESTION "
LOCATE 3, 23: PRINT "USING OXIDATION-REDUCTION POTENTIAL"
LOCATE 5, 20: PRINT "This program allows the user to select and watch"
LOCATE 6, 15: PRINT "each of the individual ORP probes associated with "
LOCATE 7, 15: PRINT "both the Fixed-Time (#1) (3 hr air on / 3 hr air off) "
LOCATE 8, 15: PRINT "and the Real-Time (#2) (3 hr air on / variable time air"
LOCATE 9, 15: PRINT " off - depending upon nitrate breakpoint) Reactors. "
LOCATE 10, 20: PRINT "Each probe has been assigned a capital letter and "
LOCATE 11, 15: PRINT "for distinguishing purposes the ORP probes have been "
LOCATE 12, 15: PRINT "given the appendages a, b, and c to denote the front,"
LOCATE 13, 15: PRINT "side and back probes respectively"
LOCATE 15, 27: PRINT "ORP1a - A    ORP2a - D "
LOCATE 16, 27: PRINT "ORP1b - B    ORP2b - E "
LOCATE 17, 27: PRINT "ORP1c - C    ORP2c - F "

END SUB

'------------------------------- INFORM.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for the AASD#2 Program
'========================================================================
'          THIS SUBROUTINE DETAILS THE MECHANICS OF THE PROGRAM
'========================================================================
SUB INFORM STATIC

LOCATE 2, 23: PRINT "COMPUTER CONTROLLED SLUDGE DIGESTION "
LOCATE 3, 23: PRINT "USING OXIDATION-REDUCTION POTENTIAL"
LOCATE 5, 20: PRINT "This program allows the user to select and watch"
LOCATE 6, 15: PRINT "each of the individual ORP probes associated with "
LOCATE 7, 15: PRINT "both the Fixed- (#1) (3 hr air on / 3 hr air off) and "
LOCATE 8, 15: PRINT "Real-Time (#2) (50/50 variable times of air on and"
LOCATE 9, 15: PRINT " off, depending upon the nitrate breakpoint) Reactors. "
LOCATE 10, 20: PRINT "Each probe has been assigned a capital letter and "
LOCATE 11, 15: PRINT "for distinguishing purposes the ORP probes have been "
LOCATE 12, 15: PRINT "given the appendages a, b, and c to denote the front,"
LOCATE 13, 15: PRINT "side and back probes respectively"
LOCATE 15, 27: PRINT "ORP1a - A    ORP2a - D "
LOCATE 16, 27: PRINT "ORP1b - B    ORP2b - E "
LOCATE 17, 27: PRINT "ORP1c - C    ORP2c - F "

END SUB

'------------------------------- INFORM.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for the BIO-P Program

'========================================================================
'          THIS SUBROUTINE DETAILS THE MECHANICS OF THE PROGRAM
'========================================================================
SUB INFORM STATIC

LOCATE 1, 22: PRINT "EXCESS BIOLOGICAL PHOSPHORUS REMOVAL USING"
LOCATE 2, 22: PRINT "OXIDATION REDUCTION POTENTIAL DETECTION OF"
LOCATE 3, 27: PRINT "THE DISSAPPEARANCE OF NITRATES"
LOCATE 5, 16: PRINT "This program demonstrates the use of ORP as a control"
LOCATE 6, 14: PRINT "parameter for bio-p processes in a sequencing batch "
LOCATE 7, 14: PRINT "reactor. Sodium Acetate is added to the Fixed Time "
LOCATE 8, 14: PRINT "Reactor (nr. rt.) at a preset time during the anoxic"
LOCATE 9, 14: PRINT "sequence, while the addition of VFAs to the Real Time"
LOCATE 10, 14: PRINT "Reactor (far rt,) is governed by the detection of the"
LOCATE 11, 14: PRINT "ORP breakpt. corresponding to nitrate dissappearance."
LOCATE 13, 16: PRINT "The user can select and watch any probe in the "
LOCATE 14, 14: PRINT "FT (#1) or RT(#2) reactors where each probe has been"
LOCATE 15, 14: PRINT "assigned a capitol letter and for distinguishing"
LOCATE 16, 14: PRINT "purposes an appendage a, b, or c to denote the front,"
LOCATE 17, 14: PRINT "side and back probes respectively"
LOCATE 19, 27: PRINT "ORP1a - A     ORP2a - D"
LOCATE 20, 27: PRINT "ORP1b - B     ORP2b - E"
LOCATE 21, 27: PRINT "ORP1c - C     ORP2c - F"

END SUB
```

```
'------------------------------- FILENAME.BAS -------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'===========================================================================
'      A SUBROUTINE WHICH GENERATES THE FILENAMES FOR THE DATA FILES
'===========================================================================
SUB FILENAME (FTout$, RTout$, Commout$, FTnum, RTnum, Commnum)

    Temp$ = DATE$
    Year$ = RIGHT$(Temp$, 2)
    Month$ = LEFT$(Temp$, 2)
    Day$ = MID$(Temp$, 4, 2)

    Composite$ = Year$ + "-" + Month$ + "-" + Day$

    FTout$ = Composite$ + ".FT"       'Fixed Time Filename
    RTout$ = Composite$ + ".RT"       'Real Time Filename
    Commout$ = Composite$ + ".msg     'The Comments Filename"

    FTnum = VAL(Day$)                 'Arbitrary numbering system
    RTnum = FTnum + 100               'Arbitrary numbering system
    Commnum = FTnum + 200             'Arbitrary numbering system

   OPEN FTout$ FOR APPEND AS #FTnum  'Print out file headings
     PRINT #FTnum, "  TIME    Seconds   ORP1a    ORP1b    ORP1c    ";
     PRINT #FTnum, " DOx1    DORP1a    DORP1b   DORP1c"
     PRINT #FTnum, ""
   CLOSE #FTnum

   OPEN RTout$ FOR APPEND AS #RTnum   'Print out file headings
     PRINT #RTnum, "  TIME    Seconds   ORP2a    ORP2b    ORP2c    ";
     PRINT #RTnum, " DOx2    DORP2a    DORP2b   DORP2c"
     PRINT #RTnum, ""
   CLOSE #RTnum

END SUB
```

```
'------------------------------- REFRESH.BAS -----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'===========================================================================
'      THIS SUBROUTINE REFRESHES THE SCREEN FOR THE NEXT PROBE'S PLOTS
'===========================================================================
SUB REFRESH (Probe$) STATIC

    CALL ORPSCRN                                      'Refresh the Screen with
    ProbeID$ = TYPROBE$(Probe$)                       'ORP Graph cooridinates
    LOCATE 23, 2: PRINT "Showing Probe - "; ProbeID$
    LOCATE 23, 48: PRINT "Select Another ? (Y/N)"'

END SUB
```

```
'------------------------------- INITREL.BAS -----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'==========================================================================
' A SUBROUTINE WHICH INITIALIZES THE SOLID STATE RELAY CONTROL IO BOARD
'==========================================================================
' This subroutine is designed to output 16 bits of data to control the solid
'state relays that are connected to Metrabyte's PIO-12 I/O Board for the
'the IBM PC.
'Port A Relays: 0 - 7      Relay Control Bits: 1 = OFF
'Port B Relays: 8 - 15                         0 = ON
'
'Note: In setting up the port configuration it initializes all relays
'      of ports A and B to OFF. To do this it leaves the global variable
'      ONOFFmap& = &HFFFF with all 32 bits set to 1. The global constant
'      ioaddr% is also used.
'
'
SUB INITRELAYS STATIC

    OUT (ioaddr% + 3), &H80        'Sets up all ports (A,B,C) as output
                                   'ports. Note: OUT (ioaddr% + 3), &H89
                                   'would be used for inputs to port C
    ONOFFmap& = &HFFFF             'Set global variables for all relays off
    OUT (ioaddr%), ONOFFmap&       'Set all port A relays off
    OUT (ioaddr% + 1), ONOFFmap&   'Set all port B relays off

END SUB


'-------------------------------- RELAY.BAS ------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'==========================================================================
' A SUBROUTINE WHICH FLIPS THE BIT TO CHANGE THE RELAY SWITCH STATUS
'==========================================================================
' Note: The subroutine scans the global variable ONOFFmap& which indicates
'       the present relay status and uses it to turn Relaynum% ON if OFF, or
'       OFF if ON. Again the Relay control bits are 1 = OFF and 0 = ON.
'
SUB RELAYSWITCH (Relaynum%)

    Smask& = 0
    Rmask& = ONOFFmap&                     'Get the present relay status
    Smask& = Smask& OR (2 ^ Relaynum%)     'Set relay bit Relaynum% = 1

    IF (ONOFFmap& AND Smask&) <> 0 THEN    'Relay Relaynum% is OFF
       Smask& = Smask& XOR &HFFFF          'Flip the lower 16 bits
       Rmask& = Rmask& AND Smask&          'Transfer the ON bit into the
                                           'Present Relay Status Word
    ELSE                                   'Relay Relaynum% is ON
       Rmask& = Rmask& OR Smask&           'Transfer the OFF bit into the
                                           'Present Relay Status Word
    END IF

    'Update the global relay status variable

    IF Rmask& = -65535 THEN Rmask& = 0
    IF Rmask& = 65535 THEN Rmask& = &HFFFF
    ONOFFmap& = Rmask&

    'Output the Updated relay status word to I/O ports A and B

    OUT (ioaddr%), Rmask&              'The lower byte to Port A
    Bmask% = Rmask&

    IF Bmask% < 0 THEN
       Bmask% = Bmask% XOR &HFFFF      'Flip the bits
       Bmask% = (Bmask% \ &H100)       'Shift Hi-byte Pattern into the Low-byte
       Bmask% = Bmask% XOR &HFFFF      'Flip the bits back again
    ELSE
       Bmask% = (Bmask% \ &H100)
    END IF

    OUT (ioaddr% + 1), Bmask%          'The higher byte to port B

END SUB
```

```
'---------------------------------- AXES.BAS -------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'===========================================================================
'      A SUBROUTINE WHICH CALCULATES  THE RELEVANT TIME SCALE AXIS
'===========================================================================
SUB AXES STATIC

 Seconds& = TIMER                                'Calculate the first two
 Hour0 = Seconds& \ 3600                         'digits of the starting time.
 Digit01 = Hour0 \ 10                            'First digit 0 hour
 Hourrem! = Seconds& / 3600
 Digitrem1! = Hour0 / 10
 Digit02 = ((Digitrem1! - Digit01) * 10)         'Second digit 0 hour

 Mintrunc! = (Hourrem! - Hour0) * 60             'Calc. third & fourth digits
 Digit3 = Mintrunc! \ 10                         'Third digit 0, 2, 4, 6 hours
 Digitrem2! = Mintrunc! / 10
 Digit4 = ((Digitrem2! - Digit3) * 10) \ 1       'Fourth digit 0, 2, 4, 6 hours

 Hour2 = Hour0 + 2
 Hour4 = Hour0 + 4
 Hour6 = Hour0 + 6
 IF Hour2 > 24 THEN Hour2 = Hour2 - 24           'Check if time scale extends
 IF Hour4 > 24 THEN Hour4 = Hour4 - 24           'into the next day.
 IF Hour6 > 24 THEN Hour6 = Hour6 - 24
 Digit21 = Hour2 \ 10                            'First digit 2 hour
 Digit41 = Hour4 \ 10                            'First digit 4 hour
 Digit61 = Hour6 \ 10                            'First digit 6 hour
 Digit22 = ((Hour2 / 10) - Digit21) * 10         'Second digit 2 hour
 Digit42 = ((Hour4 / 10) - Digit41) * 10         'Second digit 4 hour
 Digit62 = ((Hour6 / 10) - Digit61) * 10         'Second digit 6 hour

END SUB


'---------------------------------- PAXIS.BAS -------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'===========================================================================
'  A SUBROUTINE WHICH PRINTS OUT THE RELEVANT TIME SCALE AXIS
'===========================================================================
SUB PAXIS STATIC

 LOCATE 21, 17: PRINT USING "#"; Digit01; Digit02
 LOCATE 21, 19: PRINT ":"
 LOCATE 21, 20: PRINT USING "#"; Digit3; Digit4
 LOCATE 21, 31: PRINT USING "#"; Digit21; Digit22
 LOCATE 21, 33: PRINT ":"
 LOCATE 21, 34: PRINT USING "#"; Digit3; Digit4
 LOCATE 21, 44: PRINT USING "#"; Digit41; Digit42
 LOCATE 21, 46: PRINT ":"
 LOCATE 21, 47: PRINT USING "#"; Digit3; Digit4
 LOCATE 21, 58: PRINT USING "#"; Digit61; Digit62
 LOCATE 21, 60: PRINT ":"
 LOCATE 21, 61: PRINT USING "#"; Digit3; Digit4

END SUB
```

```
'------------------------------- SCANS.BAS ------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for all Programs

'=========================================================================
'          THIS SUBROUTINE SUMS AND AVERAGES THE PROBE READINGS
'=========================================================================
SUB SCANS (SCAN, Pt) STATIC

        'Sum the Scans
        MVolts1a& = MVolts1a& + MVolts(0, SCAN)
        MVolts1b& = MVolts1b& + MVolts(1, SCAN)
        MVolts1c& = MVolts1c& + MVolts(2, SCAN)
        MVolts2a& = MVolts2a& + MVolts(3, SCAN)
        MVolts2b& = MVolts2b& + MVolts(4, SCAN)
        MVolts2c& = MVolts2c& + MVolts(5, SCAN)
        MVoltDO1& = MVoltDO1& + MVolts(6, SCAN)
        MVoltDO2& = MVoltDO2& + MVolts(7, SCAN)


        IF SCAN = NUM.SCANS THEN

        '60 Scans therefore calculate 2 minute avg. reading for each probe

        ORP1a(Pt) = MVolts1a& / SCAN
        ORP1b(Pt) = MVolts1b& / SCAN
        ORP1c(Pt) = MVolts1c& / SCAN
        ORP2a(Pt) = MVolts2a& / SCAN
        ORP2b(Pt) = MVolts2b& / SCAN
        ORP2c(Pt) = MVolts2c& / SCAN
        DOx1(Pt) = MVoltDO1& / SCAN
        DOx2(Pt) = MVoltDO2& / SCAN

        'Convert digital numbers to millivoltages

        ORP1a(Pt) = ((ORP1a(Pt) - 2048) / 2048) * 500
        ORP1b(Pt) = ((ORP1b(Pt) - 2048) / 2048) * 500
        ORP1c(Pt) = ((ORP1c(Pt) - 2048) / 2048) * 500
        ORP2a(Pt) = ((ORP2a(Pt) - 2048) / 2048) * 500
        ORP2b(Pt) = ((ORP2b(Pt) - 2048) / 2048) * 500
        ORP2c(Pt) = ((ORP2c(Pt) - 2048) / 2048) * 500
        DOx1(Pt) = ((DOx1(Pt) - 2048) / 2048) * 500
        DOx2(Pt) = ((DOx2(Pt) - 2048) / 2048) * 500
        DOx1(Pt) = .082317 * (DOx1(Pt)) + .251
        DOx2(Pt) = .082317 * (DOx2(Pt)) + .251

        'Reset the millivoltage sum to zero

        MVolts1a& = 0: MVolts1b& = 0: MVolts1c& = 0
        MVolts2a& = 0: MVolts2b& = 0: MVolts2c& = 0
        MVoltDO1& = 0: MVoltDO2& = 0:

        END IF

END SUB
```

```
'-------------------------------- DIFF.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for AASD#1 and AASD#2 Programs

'=========================================================================
'  A SUBROUTINE WHICH CALCULATES THE FIRST DIFFERENCE OF THE ORP PROFILES
'=========================================================================
SUB DIFF (Flagdiff, Pt)

        Precpt = Pt - 1

IF Flagdiff = TRUE THEN

        ORP1a(Precpt) = ORP1a(Pt)  'At start up  of program the initial
        ORP1b(Precpt) = ORP1b(Pt)  'first difference point will be set
        ORP1c(Precpt) = ORP1c(Pt)  'equal to zero since there is no
        ORP2a(Precpt) = ORP2a(Pt)  'preceeding point.
        ORP2b(Precpt) = ORP2b(Pt)  '
        ORP2c(Precpt) = ORP2c(Pt)  '

END IF

IF Flagdiff = FALSE AND Pt = Startpt THEN

        ORP1a(Precpt) = ORP1a(Endpt)       'Store last point so it becomes
        ORP1b(Precpt) = ORP1b(Endpt)       'first point of the next cycle.
        ORP1c(Precpt) = ORP1c(Endpt)
        ORP2a(Precpt) = ORP2a(Endpt)
        ORP2b(Precpt) = ORP2b(Endpt)
        ORP2c(Precpt) = ORP2c(Endpt)
END IF

'Calculate the First Difference of the ORP (2 minute intervals)
        DORP1a(Pt) = (ORP1a(Pt) - ORP1a(Precpt)) / 2
        DORP1b(Pt) = (ORP1b(Pt) - ORP1b(Precpt)) / 2
        DORP1c(Pt) = (ORP1c(Pt) - ORP1c(Precpt)) / 2
        DORP2a(Pt) = (ORP2a(Pt) - ORP2a(Precpt)) / 2
        DORP2b(Pt) = (ORP2b(Pt) - ORP2b(Precpt)) / 2
        DORP2c(Pt) = (ORP2c(Pt) - ORP2c(Precpt)) / 2

END SUB


'-------------------------------- DIFF.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for the BIO-P Program

'=========================================================================
'  A SUBROUTINE WHICH CALCULATES THE FIRST DIFFERENCE OF THE ORP PROFILES
'=========================================================================
SUB DIFF (Flagdiff, Pt)

        Precpt = Pt - 1

IF Flagdiff = TRUE THEN

        ORP1a(Precpt) = ORP1a(Pt)  'At start up  of program the initial
        ORP1b(Precpt) = ORP1b(Pt)  'first difference point will be set
        ORP1c(Precpt) = ORP1c(Pt)  'equal to zero since there is no
        ORP2a(Precpt) = ORP2a(Pt)  'preceeding point.
        ORP2b(Precpt) = ORP2b(Pt)  '
        ORP2c(Precpt) = ORP2c(Pt)  '

END IF

'Calculate the First Difference of the ORP (2 minute intervals)
        DORP1a(Pt) = (ORP1a(Pt) - ORP1a(Precpt)) / 2
        DORP1b(Pt) = (ORP1b(Pt) - ORP1b(Precpt)) / 2
        DORP1c(Pt) = (ORP1c(Pt) - ORP1c(Precpt)) / 2
        DORP2a(Pt) = (ORP2a(Pt) - ORP2a(Precpt)) / 2
        DORP2b(Pt) = (ORP2b(Pt) - ORP2b(Precpt)) / 2
        DORP2c(Pt) = (ORP2c(Pt) - ORP2c(Precpt)) / 2

END SUB
```

```
'------------------------------ ORPSCRN.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'=======================================================================
'             A SUBROUTINE WHICH SETS UP THE ORP GRAPHING CO-ORDINATES
'=======================================================================
SUB ORPSCRN STATIC

    CLS

'Set up the Initial Boxes and Graph Dimensions
    LINE (0, 0)-(719, 335), , B
    LINE (110, 10)-(590, 270), , B
    LINE (110, 160)-(590, 160)

'Put in the  tick marks for the Time scale axis
    Pixtime = 110
    FOR i = 1 TO 9
      PSET (Pixtime, 271)
      PSET (Pixtime, 272)
      Pixtime = Pixtime + 60
    NEXT i

'Put in the tick marks for the ORP scale axis
    Pixorp = 10
    FOR j = 1 TO 11
      PSET (109, Pixorp)
      PSET (108, Pixorp)
      Pixorp = Pixorp + 25
    NEXT j

'Print out the Time Scale Axis
    CALL PAXIS
    LOCATE 22, 35: PRINT "Time (hrs)"

'Print out the ORP Scale Axis
    LOCATE 2, 9: PRINT "300"
    LOCATE 5, 9: PRINT "200"
    LOCATE 8, 9: PRINT "100"
    LOCATE 12, 9: PRINT "  0"
    LOCATE 16, 8: PRINT "-100"
    LOCATE 19, 8: PRINT "-200"
    LOCATE 6, 2: PRINT "  O"
    LOCATE 7, 2: PRINT "  R"
    LOCATE 8, 2: PRINT "  P"
    LOCATE 10, 2: PRINT " (mv)"

END SUB

'------------------------------ WRITING.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'=======================================================================
'             THIS SUBROUTINE WRITES THE DATA TO THE DISK FILE
'=======================================================================
SUB WRITING (Pt, FTout$, RTout$, FTnum, RTnum) STATIC

   'Write to the Fixed-Time Disk File

   OPEN FTout$ FOR APPEND AS FTnum
     PRINT #FTnum, TIME$; " ";
     PRINT #FTnum, USING "#####.## "; TIMER;
     PRINT #FTnum, USING "+###.##  "; ORP1a(Pt); ORP1b(Pt); ORP1c(Pt);
     PRINT #FTnum, USING " #.#    "; DOx1(Pt);
     PRINT #FTnum, USING "+###.##  "; DORP1a(Pt); DORP1b(Pt); DORP1c(Pt)
   CLOSE #FTnum

   'Write to the Real-Time Disk file

   OPEN RTout$ FOR APPEND AS RTnum
     PRINT #RTnum, TIME$; " ";
     PRINT #RTnum, USING "#####.## "; TIMER;
     PRINT #RTnum, USING "+###.##  "; ORP2a(Pt); ORP2b(Pt); ORP2c(Pt);
     PRINT #RTnum, USING " #.#    "; DOx2(Pt);
     PRINT #RTnum, USING "+###.##  "; DORP2a(Pt); DORP2b(Pt); DORP2c(Pt)
   CLOSE #RTnum

END SUB
```

```
'------------------------------ TRANSFER.BAS ------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'=========================================================================
'     A SUBROUTINE WHICH TRANSFERS THE PROBE READINGS TO A GENERAL ARRAY
'                          READY FOR PLOTTING
'=========================================================================
SUB TRANSFER (ProbeID$, Pt)

SELECT CASE ProbeID$

       CASE "ORP1a"
             FOR i = Startpt TO Pt
               ORP(i) = ORP1a(i)
             NEXT i

       CASE "ORP1b"
             FOR i = Startpt TO Pt
               ORP(i) = ORP1b(i)
             NEXT i

       CASE "ORP1c"
             FOR i = Startpt TO Pt
               ORP(i) = ORP1c(i)
             NEXT i

       CASE "ORP2a"
             FOR i = Startpt TO Pt
               ORP(i) = ORP2a(i)
             NEXT i

       CASE "ORP2b"
             FOR i = Startpt TO Pt
               ORP(i) = ORP2b(i)
             NEXT i

       CASE "ORP2c"
             FOR i = Startpt TO Pt
               ORP(i) = ORP2c(i)
             NEXT i

END SELECT

END SUB
```

```
'------------------------------ PLOT.BAS ------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'=========================================================================
'  A SUBROUTINE WHICH PLOTS THE PROBE READINGS UP TO THE PRESENT POINT
'=========================================================================
SUB PLOT (Pt)

          FOR j = Startpt TO Pt
          'Proportion to transform ORP values to pixels
              Mark1 = (ORP(j) / 50) * 25
              Pixel1 = 160 - Mark1
          'Plot the point
              PSET (168 + 2 * j, Pixel1)
          NEXT j

END SUB
```

```
'------------------------------- LAYOUT.BAS ------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for AASD#1 and AASD#2 Programs

'==========================================================================
'        THIS SUBROUTINE LAYS OUT THE TEXT INFORMATION SCREEN
'==========================================================================
SUB LAYOUT STATIC

    CLS

LOCATE 2, 23: PRINT "COMPUTER CONTROLLED SLUDGE DIGESTION "
LOCATE 3, 23: PRINT "USING OXIDATION-REDUCTION POTENTIAL "
LOCATE 5, 13: PRINT "RCTR #1 - FIXED TIME"
LOCATE 5, 46: PRINT "RCTR #2 - REAL TIME"
LOCATE 7, 13: PRINT "ORP1a    - "
LOCATE 7, 46: PRINT "ORP2a    - "
LOCATE 9, 13: PRINT "ORP1b    - "
LOCATE 9, 46: PRINT "ORP2b    - "
LOCATE 11, 13: PRINT "ORP1c    - "
LOCATE 11, 46: PRINT "ORP2c    - "
LOCATE 13, 13: PRINT "Time of Last Update - "
LOCATE 13, 46: PRINT "Point Number - "
LOCATE 15, 13: PRINT "Note: Hit <Y> - Yes - if desire to see ORP  plots"
LOCATE 16, 23: PRINT "<N> - No - when finished viewing plots"
LOCATE 17, 23: PRINT "<ESC> - Escape - to exit program"
LOCATE 19, 13: PRINT "Note: Time is updated every two minutes"
LOCATE 20, 19: PRINT "There are 60 scans (at 2 sec intervals) in 2 min"
LOCATE 21, 19: PRINT "There are 180 pts ( 2 min intervals) in a 6 hr cycle"
LOCATE 23, 30: PRINT "Scan number - "

END SUB


'------------------------------- LAYOUT.BAS ------------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for the BIO-P Program

'==========================================================================
'        THIS SUBROUTINE LAYS OUT THE TEXT INFORMATION SCREEN
'==========================================================================
SUB LAYOUT STATIC

    CLS

LOCATE 2, 15: PRINT "COMPUTER CONTROLLED ADDITION OF A VFA CARBON SOURCE"
LOCATE 3, 17: PRINT "BASED ON THE ORP-TIME VARIATION IN A BIO-P PROCESS "
LOCATE 5, 13: PRINT "RCTR #1 - FIXED TIME"
LOCATE 5, 46: PRINT "RCTR #2 - REAL TIME"
LOCATE 7, 13: PRINT "ORP1a    - "
LOCATE 7, 46: PRINT "ORP2a    - "
LOCATE 9, 13: PRINT "ORP1b    - "
LOCATE 9, 46: PRINT "ORP2b    - "
LOCATE 11, 13: PRINT "ORP1c    - "
LOCATE 11, 46: PRINT "ORP2c    - "
LOCATE 13, 13: PRINT "Time of Last Update - "
LOCATE 13, 46: PRINT "Point Number - "
LOCATE 14, 13: PRINT "Acetate Addition Status Report - "
LOCATE 16, 13: PRINT "Note: Hit <Y> - Yes - if desire to see ORP plots"
LOCATE 17, 23: PRINT "<N> - No - when finished viewing plots"
LOCATE 18, 23: PRINT "<ESC> - Escape - to exit program"
LOCATE 19, 13: PRINT "Note: Time is updated every two minutes"
LOCATE 20, 19: PRINT "There are 60 scans (at 2 sec intervals) in 2 min"
LOCATE 21, 19: PRINT "There are 180 pts ( 2 min intervals) in a 6 hr cycle"
LOCATE 23, 30: PRINT "Scan number - "

END SUB
```

```
'------------------------------ UPDATE.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs

'======================================================================
'   THIS SUBROUTINE UPDATES THE SCREEN LAYOUT EVERY TWO MINUTES
'======================================================================
SUB UPDATE (Pt) STATIC

LOCATE 7, 25: PRINT USING "+###.#"; ORP1a(Pt)
LOCATE 7, 57: PRINT USING "+###.#"; ORP2a(Pt)
LOCATE 9, 25: PRINT USING "+###.#"; ORP1b(Pt)
LOCATE 9, 57: PRINT USING "+###.#"; ORP2b(Pt)
LOCATE 11, 25: PRINT USING "+###.#"; ORP1c(Pt)
LOCATE 11, 57: PRINT USING "+###.#"; ORP2c(Pt)
LOCATE 13, 35: PRINT TIME$
LOCATE 13, 62: PRINT USING "###"; Pt

END SUB


'------------------------------ TYPROBE.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for ALL Programs


'======================================================================
'             A FUNCTION WHICH IDENTIFIES THE SELECTED PROBE
'======================================================================
FUNCTION TYPROBE$ (Probe$) STATIC

SELECT CASE Probe$

        CASE "A"
                TYPROBE$ = "ORP1a"
        CASE "B"
                TYPROBE$ = "ORP1b"
        CASE "C"
                TYPROBE$ = "ORP1c"
        CASE "D"
                TYPROBE$ = "ORP2a"
        CASE "E"
                TYPROBE$ = "ORP2b"
        CASE "F"
                TYPROBE$ = "ORP2c"
        CASE "G"
                TYPROBE$ = "D.O.#1"
        CASE "H"
                TYPROBE$ = "D.O.#2"
        CASE ELSE
                TYPROBE$ = "No such probe"

END SELECT

END FUNCTION


'======================================================================
'                             JINKEY FUNCTION
'======================================================================
'This function tests for a key stroke in the keyboard buffer.
FUNCTION jinkey%
        a$ = INKEY$
        IF a$ = "" THEN jinkey% = 0: EXIT FUNCTION  'Nothing there - exit
        IF LEN(a$) = 2 THEN                         'Something there - obtain
           jinkey% = ASC(MID$(a$, 2, 1)) + &H100    'ASCII Code
        ELSE
           jinkey% = ASC(a$)
        END IF

END FUNCTION
```

```
'------------------------------ BREAKPT.BAS ---------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for AASD#1 and AASD#2 Programs

'======================================================================
'          THIS SUBROUTINE FINDS THE NITRATE BREAKPOINT (KNEE)
'======================================================================
SUB BREAKPT (Commnum, Pt, Nitrate, Renew) STATIC

IF Renew = FALSE THEN       'Drop through Subroutine instead of resetting

   Avoid = Avoid + 1        'Increment ORP stability counter after feeding

   IF Avoid > MAXAVOID THEN               'ORP should have stabilized by now

      Count = Count + 1                   'Increment internal Ring counter

      IF Pt <= RINGSIZE THEN              'In Subsequent cycles the Ring
         LowBound = Pt + 180 - RINGSIZE   'Buffer may straddle two cycles
      ELSE
         LowBound = Pt - RINGSIZE
      END IF

      IF Count <= RINGSIZE THEN           'Ring is not full

      SumA! = SumA! + DORP2a(Pt)          'Sum the First Difference values
      SumB! = SumB! + DORP2b(Pt)
      SumC! = SumC! + DORP2c(Pt)

            IF Count = RINGSIZE THEN                'The Ring is full

               Ringnum = 1                          'Assign Ring Number

               RING2a(Ringnum) = SumA! / RINGSIZE   'Calculate the average
               RING2b(Ringnum) = SumB! / RINGSIZE   'Slope for the Ring
               RING2c(Ringnum) = SumC! / RINGSIZE

               FirstRingA! = RING2a(Ringnum)        'This becomes the first
               FirstRingB! = RING2b(Ringnum)        'Ring of the Ring Buffer
               FirstRingC! = RING2c(Ringnum)

            END IF

      ELSEIF Count > RINGSIZE AND Search = FALSE THEN 'Start filling next ring

            Ringnum = Ringnum + 1                    'Increment Ring Number

            SumA! = SumA! - DORP2a(LowBound) + DORP2a(Pt) 'Kick out First
            SumB! = SumB! - DORP2b(LowBound) + DORP2b(Pt) 'value and add in
            SumC! = SumC! - DORP2c(LowBound) + DORP2c(Pt) 'latest First Diff

            RING2a(Ringnum) = SumA! / RINGSIZE            'Calculate avg
            RING2b(Ringnum) = SumB! / RINGSIZE            'First Diff of
            RING2c(Ringnum) = SumC! / RINGSIZE            'this new Ring

            IF Ringnum = NUMRINGS THEN          'The Ring Buffer is Full

               Search = TRUE                    'Enable Search for Breakpoint

               LastRingA! = RING2a(Ringnum)     'The most recently calculated
               LastRingB! = RING2b(Ringnum)     'Ring becomes the last Ring
               LastRingC! = RING2c(Ringnum)     'in the Buffer

               DiffRingA! = LastRingA! - FirstRingA!  'Take the Diff between
               DiffRingB! = LastRingB! - FirstRingB!  'the first and last
               DiffRingC! = LastRingC! - FirstRingC!  'Rings in the Buffer
            END IF
```

```
        END IF

        IF Search = TRUE THEN       'Search for the Nitrate Breakpoint

           IF KneeA = FALSE THEN     'Knee ORP2a not detected as of yet
              IF DiffRingA! <= DELTA2A! THEN  'Arbitrary Constraint
                 KneeA = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeA detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF

           IF KneeB = FALSE THEN     'Knee ORP2b not detected as of yet
              IF DiffRingB! <= DELTA2B! THEN
                 KneeB = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeB detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF

           IF KneeC = FALSE THEN     'Knee ORP2c not detected as of yet
              IF DiffRingC! <= DELTA2C! THEN
                 KneeC = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeC detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF

           IF KneeCount >= 2 THEN Nitrate = TRUE '>= Two knees detected

        END IF       'Closes If Search = TRUE Decision Block

ELSEIF Count > RINGSIZE AND Search = TRUE THEN  'Ring Buffer moves along

        Ringnum = Ringnum + 1                   'Increment Ring Number

        SumA! = SumA! - DORP2a(LowBound) + DORP2a(Pt) 'Kick out First
        SumB! = SumB! - DORP2b(LowBound) + DORP2b(Pt) 'value and add in
        SumC! = SumC! - DORP2c(LowBound) + DORP2c(Pt) 'latest First Diff

        RING2a(Ringnum) = SumA! / RINGSIZE            'Calculate the
        RING2b(Ringnum) = SumB! / RINGSIZE            'average slope
        RING2c(Ringnum) = SumC! / RINGSIZE            'for the Ring

        FirstRingA! = RING2a(Ringnum - RINGSIZE + 1)  'Assign the
        FirstRingB! = RING2b(Ringnum - RINGSIZE + 1)  'First Ring of
        FirstRingC! = RING2c(Ringnum - RINGSIZE + 1)  'the new Buffer

        LastRingA! = RING2a(Ringnum)                   'The latest Ring
        LastRingB! = RING2b(Ringnum)                   'becomes the last
        LastRingC! = RING2c(Ringnum)                   'Ring of Buffer

        DiffRingA! = LastRingA! - FirstRingA!          'Calculate Diff
        DiffRingB! = LastRingB! - FirstRingB!          'between first
        DiffRingC! = LastRingC! - FirstRingC!          'and last Rings

           IF KneeA = FALSE THEN     'Knee ORP2a not detected as of yet
              IF DiffRingA! <= DELTA2A! THEN
                 KneeA = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeA detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF
```

```
                IF KneeB = FALSE THEN     'Knee ORP2b not detected as of yet
                   IF DiffRingB! <= DELTA2B! THEN
                      KneeB = TRUE
                      KneeCount = KneeCount + 1
                        PRINT #Commnum, "Nitrate KneeB detected on "; DATE$;
                        PRINT #Commnum, " at approximately "; TIME$
                   END IF
                END IF

                IF KneeC = FALSE THEN     'Knee ORP2c not detected as of yet
                   IF DiffRingC! <= DELTA2C! THEN
                      KneeC = TRUE
                      KneeCount = KneeCount + 1
                        PRINT #Commnum, "Nitrate KneeC detected on "; DATE$;
                        PRINT #Commnum, " at approximately "; TIME$
                   END IF
                END IF


                IF KneeCount >= 2 THEN Nitrate = TRUE '>= Two knees detected

          END IF         'Closes If Count <= Ringsize Decision Block

       END IF            'Closes If Avoid > MaxAvoid Decision Block

   ELSE

    KneeA = FALSE        'Clear and Reset all the Variables for next Cycle
    KneeB = FALSE
    KneeC = FALSE
    Avoid = 0
    Count = 0
    SumA! = 0
    SumB! = 0
    SumC! = 0
    Search = FALSE
    KneeCount = 0

   END IF                 'Closes Renew = FALSE Decision Block

   END SUB
```

```
'------------------------------ BREAKPT.BAS ----------------------------
'$INCLUDE: 'GLOBAL.BI'
'Note: This is for the BIO-P Program

'=========================================================================
'            THIS SUBROUTINE FINDS THE NITRATE BREAKPOINT (KNEE)
'=========================================================================
SUB BREAKPT (Commnum, Pt, Nitrate, Renew) STATIC

IF Renew = FALSE THEN      'Drop through Subroutine instead of resetting

   Avoid = Avoid + 1       'Increment ORP stability counter after feeding

   IF Avoid > MAXAVOID THEN              'ORP should have stabilized by now

      Count = Count + 1                  'Increment internal Ring counter

      LowBound = Pt - RINGSIZE           'Calculate lower bound of the Ring

      IF Count <= RINGSIZE THEN          'Ring is not full

      SumA! = SumA! + DORP2a(Pt)         'Sum the First Difference values
      SumB! = SumB! + DORP2b(Pt)
      SumC! = SumC! + DORP2c(Pt)

              IF Count = RINGSIZE THEN               'The Ring is full

                 Ringnum = 1                         'Assign Ring Number

                 RING2a(Ringnum) = SumA! / RINGSIZE  'Calculate the average
                 RING2b(Ringnum) = SumB! / RINGSIZE  'Slope for the Ring
                 RING2c(Ringnum) = SumC! / RINGSIZE

                 FirstRingA! = RING2a(Ringnum)       'This becomes the first
                 FirstRingB! = RING2b(Ringnum)       'Ring of the Ring Buffer
                 FirstRingC! = RING2c(Ringnum)

              END IF

      ELSEIF Count > RINGSIZE AND Search = FALSE THEN 'Start filling next ring

              Ringnum = Ringnum + 1                   'Increment Ring Number

              SumA! = SumA! - DORP2a(LowBound) + DORP2a(Pt) 'Kick out First
              SumB! = SumB! - DORP2b(LowBound) + DORP2b(Pt) 'value and add in
              SumC! = SumC! - DORP2c(LowBound) + DORP2c(Pt) 'latest First Diff

              RING2a(Ringnum) = SumA! / RINGSIZE            'Calculate avg
              RING2b(Ringnum) = SumB! / RINGSIZE            'First Diff of
              RING2c(Ringnum) = SumC! / RINGSIZE            'this new Ring

              IF Ringnum = NUMRINGS THEN         'The Ring Buffer is Full

                 Search = TRUE                   'Enable Search for Breakpoint

                 LastRingA! = RING2a(Ringnum)    'The most recently calculated
                 LastRingB! = RING2b(Ringnum)    'Ring becomes the last Ring
                 LastRingC! = RING2c(Ringnum)    'in the Buffer

                 DiffRingA! = LastRingA! - FirstRingA!  'Take the Diff between
                 DiffRingB! = LastRingB! - FirstRingB!  'the first and last
                 DiffRingC! = LastRingC! - FirstRingC!  'Rings in the Buffer

              END IF
```

```
        IF Search = TRUE THEN         'Search for the Nitrate Breakpoint

           IF KneeA = FALSE THEN      'Knee ORP2a not detected as of yet
              IF DiffRingA! <= DELTA2A! THEN  'Arbitrary Constraint
                 KneeA = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeA detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF

           IF KneeB = FALSE THEN      'Knee ORP2b not detected as of yet
              IF DiffRingB! <= DELTA2B! THEN
                 KneeB = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeB detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF

           IF KneeC = FALSE THEN      'Knee ORP2c not detected as of yet
              IF DiffRingC! <= DELTA2C! THEN
                 KneeC = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeC detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF

           IF KneeCount >= 2 THEN Nitrate = TRUE '>= Two knees detected

        END IF      'Closes If Search = TRUE Decision Block

ELSEIF Count > RINGSIZE AND Search = TRUE THEN  'Ring Buffer moves along

        Ringnum = Ringnum + 1                     'Increment Ring Number

        SumA! = SumA! - DORP2a(LowBound) + DORP2a(Pt) 'Kick out First
        SumB! = SumB! - DORP2b(LowBound) + DORP2b(Pt) 'value and add in
        SumC! = SumC! - DORP2c(LowBound) + DORP2c(Pt) 'latest First Diff

        RING2a(Ringnum) = SumA! / RINGSIZE            'Calculate the
        RING2b(Ringnum) = SumB! / RINGSIZE            'average slope
        RING2c(Ringnum) = SumC! / RINGSIZE            'for the Ring

        FirstRingA! = RING2a(Ringnum - RINGSIZE + 1)  'Assign the
        FirstRingB! = RING2b(Ringnum - RINGSIZE + 1)  'First Ring of
        FirstRingC! = RING2c(Ringnum - RINGSIZE + 1)  'the new Buffer

        LastRingA! = RING2a(Ringnum)                   'The latest Ring
        LastRingB! = RING2b(Ringnum)                   'becomes the last
        LastRingC! = RING2c(Ringnum)                   'Ring of Buffer

        DiffRingA! = LastRingA! - FirstRingA!          'Calculate Diff
        DiffRingB! = LastRingB! - FirstRingB!          'between first
        DiffRingC! = LastRingC! - FirstRingC!          'and last Rings

           IF KneeA = FALSE THEN      'Knee ORP2a not detected as of yet
              IF DiffRingA! <= DELTA2A! THEN
                 KneeA = TRUE
                 KneeCount = KneeCount + 1
                   PRINT #Commnum, "Nitrate KneeA detected on "; DATE$;
                   PRINT #Commnum, " at approximately "; TIME$
              END IF
           END IF
```

```
                IF KneeB = FALSE THEN     'Knee ORP2b not detected as of yet
                   IF DiffRingB! <= DELTA2B! THEN
                      KneeB = TRUE
                      KneeCount = KneeCount + 1
                        PRINT #Commnum, "Nitrate KneeB detected on "; DATE$;
                        PRINT #Commnum, " at approximately "; TIME$
                   END IF
                END IF

                IF KneeC = FALSE THEN     'Knee ORP2c not detected as of yet
                   IF DiffRingC! <= DELTA2C! THEN
                      KneeC = TRUE
                      KneeCount = KneeCount + 1
                        PRINT #Commnum, "Nitrate KneeC detected on "; DATE$;
                        PRINT #Commnum, " at approximately "; TIME$
                   END IF
                END IF


                IF KneeCount >= 2 THEN Nitrate = TRUE '>= Two knees detected

      END IF      'Closes If Count <= Ringsize Decision Block

   END IF         'Closes If Avoid > MaxAvoid Decision Block

ELSE

 KneeA = FALSE    'Clear and Reset all the Variables for next Cycle
 KneeB = FALSE
 KneeC = FALSE
 Avoid = 0
 Count = 0
 SumA! = 0
 SumB! = 0
 SumC! = 0
 Search = FALSE
 KneeCount = 0

END IF             'Closes Renew = FALSE Decision Block

END SUB
```

APPENDIX E

CHEMICAL DATA - AASD#1

AASD#1 FEED SUSPENDED SOLID CONCENTRATIONS

DAY	DATE	Approximate Time of Raw Sludge Collection (Hr:Min)	MLSS (mg/L)	MLVSS (mg/L)	SOLIDS RATIO
1	Jun/19/90	8:30 am	7108	5716	0.80
2	20	8:30 am	7852	6308	0.80
3	21	8:30 am	5188	4158	0.80
4	22	8:30 am	6198	4982	0.80
5	23	2:00 pm	5936	4740	0.80
6	24	12:00 pm	8104	6438	0.79
7	25	12:00 pm	9244	7318	0.79
8	26	8:30 am	7284	5772	0.79
9	27	12:00 pm	6370	5104	0.80
10	28	12:00 pm	9122	7214	0.79
11	29	8:30 am	7638	6056	0.79
12	30	2:00 pm	7052	5550	0.79
13	Jul/01/90	2:00 pm	6454	5084	0.79
14	02	8:30 am	6698	5186	0.77
15	03	8:30 am	6850	5366	0.78
16	04	8:30 am	6106	4798	0.79
17	05	8:30 am	8228	6442	0.78
18	06	8:30 am	9568	7516	0.79
19	07	12:00 pm	11866	9486	0.80
20	08	9:00 am	13550	10794	0.80
21	09	8:30 am	7216	5736	0.79
22	10	8:30 am	7286	5772	0.79
23	11	8:30 am	7656	6144	0.80
24	12	8:30 am	7308	5756	0.79
25	13	8:30 am	7624	6078	0.80
26	14	12:00 pm	6902	5472	0.79
27	15	12:00 pm	8034	6342	0.79
28	16	9:00 am	6530	5170	0.79
29	17	10:00 am	10540	8308	0.79
30	18	8:30 am	9318	7396	0.79
31	Jul/19/90	--------	-----	----	----
32	20	--------	-----	----	----
33	21	10:00 am	8070	6386	0.79
34	22	12:00 pm	11872	9568	0.81
35	23	8:30 am	6514	5228	0.80
36	24	12:00 pm	6858	5462	0.80
37	25	12:00 pm	6618	5230	0.79
38	26	12:00 pm	9594	7602	0.79
39	27	8:30 am	10068	7864	0.78
40	28	9:00 am	7818	6114	0.78
41	29	6:00 pm	7818	6168	0.79
42	30	7:00 am	8014	6288	0.78
43	31	--------	8042	6328	0.79
44	Aug/01/90	--------	8072	6372	0.79
45	02	8:30 am	9430	7344	0.78
46	03	8:30 am	7964	6214	0.78
47	04	12:00 pm	6940	5384	0.78
48	05	12:00 pm	9736	7608	0.78
49	06	9:15 am	7642	5912	0.77
50	07	8:30 am	6114	4728	0.77
51	08	11:00 am	7814	6008	0.77
52	09	8:30 am	9264	7168	0.77
53	10	8:30 am	9592	7512	0.78
54	11	9:00 am	5950	4556	0.77
55	12	7:30 am	5464	4202	0.77
56	13	7:30 am	7696	5910	0.77
57	14	10:30 am	6482	4944	0.76
58	15	9:00 am	7936	6114	0.77
59	16	8:15 am	5726	4400	0.77
60	17	7:30 am	6848	5256	0.77
Maximum			13550	10794	
Mean			7841	6174	
Minimum			5188	4158	
Std. Dev.			1626	1306	

AASD#2 FEED SUSPENDED SOLID CONCENTRATIONS

DAY	DATE	Approximate Time of Raw Sludge Collection Hr:Min	MLSS (mg/L)	MLVSS (mg/L)	SOLIDS RATIO
1	Oct/02/90	9:00 am	10610	8466	0.80
2	03	9:00 am	9596	7818	0.81
3	04	8:30 am	4040	3362	0.83
4	05	9:00 am	5986	4922	0.82
5	06	10:45 am	5384	4438	0.82
6	07	1:00 pm	5914	4832	0.82
7	08	9:00 am	6078	4958	0.82
8	09	8:00 am	7454	6092	0.82
9	10	10:30 am	10356	8442	0.82
10	11	11:30 am	9210	7510	0.82
11	12	10:00 am	6074	4984	0.82
12	13	11:00 am	7854	6476	0.82
13	14	1:00 pm	9562	7898	0.83
14	15	8:30 am	5190	4326	0.84
15	16	10:30 am	6380	5282	0.83
16	17	11:00 am	4924	4120	0.84
17	18	10:00 am	8634	7150	0.83
18	19	11:00 am	7826	6462	0.83
19	20	9:00 am	5962	4902	0.82
20	21	12:00 pm	6436	5286	0.82
21	22	11:00 am	7298	6028	0.83
22	23	10:00 am	6292	5212	0.83
23	24	10:00 am	7512	6176	0.82
24	25	10:00 am	6574	5436	0.83
25	26	9:30 am	6114	5016	0.82
26	27	10:00 am	5586	4540	0.81
27	28	1:00 pm	7400	6038	0.82
28	29	9:30 am	7242	5874	0.81
29	30	11:00 am	5632	4590	0.81
30	31	10:00 am	8450	6948	0.82
31	Nov/01/90	10:30 am	6836	5578	0.82
32	02	8:30 am	6182	5154	0.83
33	03	10:00 am	5522	4560	0.83
34	04	9:30 am	6160	5060	0.82
35	05	10:30 am	7442	6160	0.83
36	06	9:30 am	6982	5828	0.83
37	07	11:00 am	6798	5650	0.83
38	08	11:00 am	6868	5664	0.82
39	09	11:30 am	5170	4278	0.83
40	10	11:00 am	5974	4928	0.82
41	11	--------	----	----	----
42	12	--------	----	----	----
43	13	9:30 am	6870	5630	0.82
44	14	10:10 am	6630	5434	0.82
45	15	8:30 am	6016	4918	0.82
46	16	10:00 am	6256	5130	0.82
47	17	11:30 am	6086	4972	0.82
48	18	12:00 pm	5472	4446	0.81
49	19	10:30 am	6000	4880	0.81
50	20	10:00 am	5498	4500	0.82
51	21	10:30 am	5604	4570	0.82
52	22	10:00 am	5438	4438	0.82
53	23	10:30 am	6632	5434	0.82
54	24	11:30 am	6082	4920	0.81
55	25	1:00 pm	5524	4480	0.81
56	26	9:30 am	5436	4402	0.81
57	27	11:30 am	5560	4554	0.82
58	28	10:00 am	4714	3930	0.83
59	29	11:00 am	4300	3606	0.84
60	30	10:30 am	6118	5148	0.84
Maximum			10610	8466	
Mean			6547	5376	
Minimum			4040	3362	
Std. Dev.			1372	1109	

AASD#1 FIXED TIME REACTOR SUSPENDED SOLID CONCENTRATIONS

DAY	DATE	Sampling Time (Hr:Min)	MLSS (mg/L)	MLVSS (mg/L)	SOLIDS RATIO
1	Jun/19/90	12:00 pm	5716	4496	0.79
2	20	10:35 am	5598	4412	0.79
3	21	10:15 am	5790	4552	0.79
4	22	1:30 pm	5524	4358	0.79
5	23	6:00 pm	5436	4252	0.78
6	24	5:30 pm	5336	4154	0.78
7	25	1:20 pm	5376	4216	0.78
8	26	11:10 am	5924	4728	0.80
9	27	1:50 pm	5866	4632	0.79
10	28	2:00 pm	5712	4454	0.78
11	29	2:15 pm	5938	4606	0.78
12	30	3:00 pm	5826	4510	0.77
13	Jul/01/90	6:15 pm	6100	4704	0.77
14	02	3:50 pm	5854	4506	0.77
15	03	10:00 am	5826	4490	0.77
16	04	9:10 am	5852	4508	0.77
17	05	10:15 am	5878	4522	0.77
18	06	11:50 am	5970	4602	0.77
19	07	3:50 pm	6278	4864	0.77
20	08	3:40 pm	6724	5204	0.77
21	09	2:20 pm	6980	5416	0.76
22	10	10:40 am	6818	5298	0.78
23	11	3:10 pm	6774	5272	0.78
24	12	9:35 am	6752	5236	0.78
25	13	1:15 pm	6666	5192	0.78
26	14	2:40 pm	6702	5202	0.78
27	15	3:05 pm	6568	5088	0.77
28	16	10:15 am	6530	5046	0.77
29	17	12:35 pm	6604	5084	0.77
30	18	3:15 pm	6960	5400	0.78
31	Jul/19/90	1:15 pm	6980	5388	0.77
32	20	3:15 pm	6800	5240	0.77
33	21	12:45 pm	6856	5284	0.77
34	22	4:00 pm	6956	5370	0.77
35	23	12:15 pm	7416	5718	0.77
36	24	1:10 pm	7172	5428	0.76
37	25	5:15 pm	7006	5406	0.77
38	26	3:55 pm	6954	5380	0.77
39	27	10:30 am	7028	5424	0.77
40	28	1:15 pm	7370	5702	0.77
41	29	7:45 pm	7472	5812	0.78
42	30	11:25 pm	7322	5692	0.77
43	31	1:40 pm	7084	5468	0.77
44	Aug/01/90	12:35 pm	7140	5498	0.77
45	02	4:50 pm	6792	5228	0.77
46	03	4:00 pm	7052	5452	0.77
47	04	1:30 pm	7252	5566	0.77
48	05	10:50 pm	7088	5418	0.76
49	06	1:20 pm	7456	5732	0.77
50	07	1:30 pm	7216	5538	0.77
51	08	1:30 pm	6904	5274	0.76
52	09	1:45 pm	6826	5266	0.77
53	10	1:25 pm	7082	5456	0.77
54	11	1:55 pm	7278	5584	0.77
55	12	2:15 pm	6960	5330	0.77
56	13	8:15 am	6756	5152	0.76
57	14	1:30 pm	6628	5058	0.76
58	15	2:20 pm	6516	4994	0.77
59	16	9:30 am	6646	5090	0.77
60	17	8:30 am	6270	4818	0.77
Maximum			7472	5812	
Mean			6569	5080	
Minimum			5336	4154	
Std. Dev.			600	442	

AASD#2 FIXED TIME REACTOR SUSPENDED SOLID CONCENTRATIONS

DAY	DATE	Sampling Time Hr:Min	MLSS (mg/L)	MLVSS (mg/L)	SOLIDS RATIO
1	Oct/02/90	2:00 pm	6332	5032	0.79
2	03	10:20 am	6678	5316	0.80
3	04	2:05 pm	6772	5350	0.80
4	05	2:00 pm	6468	5148	0.80
5	06	2:40 pm	6554	5204	0.79
6	07	2:15 pm	6340	5032	0.79
7	08	12:55 pm	6324	4966	0.79
8	09	11:25 am	6242	4912	0.79
9	10	1:30 pm	6266	4930	0.79
10	11	2:40 pm	6374	5060	0.79
11	12	3:00 pm	6654	5268	0.79
12	13	4:25 pm	6382	5096	0.80
13	14	2:30 pm	6470	5162	0.80
14	15	11:45 am	6502	5176	0.80
15	16	3:05 pm	6366	5092	0.80
16	17	12:55 pm	6394	5132	0.80
17	18	1:05 pm	6148	4934	0.80
18	19	3:20 pm	6046	4830	0.80
19	20	11:05 am	6248	4978	0.80
20	21	3:20 pm	6196	4952	0.80
21	22	2:20 pm	6168	4956	0.80
22	23	1:30 pm	6194	4982	0.80
23	24	3:30 pm	6254	5018	0.80
24	25	1:35 pm	6154	4954	0.81
25	26	2:55 pm	6146	4906	0.80
26	27	1:20 pm	6212	4988	0.80
27	28	6:10 pm	5988	4784	0.80
28	29	1:10 pm	6066	4852	0.80
29	30	2:05 pm	6064	4850	0.80
30	31	1:10 pm	6034	4846	0.80
31	Nov/01/90	4:45 pm	6006	4802	0.80
32	02	7:40 pm	6104	4910	0.80
33	03	4:40 pm	5972	4772	0.80
34	04	5:50 pm	5916	4722	0.80
35	05	2:50 pm	5856	4676	0.80
36	06	1:05 pm	5970	4802	0.80
37	07	1:55 pm	5916	4760	0.80
38	08	2:10 pm	6078	4864	0.80
39	09	12:45 pm	6038	4850	0.80
40	10	1:10 pm	5890	4716	0.80
41	11	10:30 am	5932	4762	0.80
42	12	1:15 pm	5946	4764	0.80
43	13	4:50 pm	5830	4680	0.80
44	14	2:00 pm	6026	4834	0.80
45	15	1:20 pm	5984	4796	0.80
46	16	6:55 pm	5814	4664	0.80
47	17	1:15 pm	5842	4682	0.80
48	18	4:05 pm	5650	4562	0.81
49	19	1:20 pm	5738	4581	0.80
50	20	3:15 pm	5760	4624	0.80
51	21	1:30 pm	5760	4612	0.80
52	22	2:05 pm	5588	4492	0.80
53	23	9:30 pm	5288	4238	0.80
54	24	3:45 pm	5330	4266	0.80
55	25	3:30 pm	5368	4284	0.80
56	26	1:45 pm	5196	4122	0.79
57	27	12:25 pm	5208	4146	0.80
58	28	12:10 pm	5248	4208	0.80
59	29	12:15 pm	5036	4074	0.81
60	30	11:05 am	4904	4042	0.82
Maximum			6772	5350	
Mean			6039	4826	
Minimum			4904	4122	
Std. Dev.			362	281	

AASD#1 REAL TIME REACTOR SUSPENDED SOLID CONCENTRATIONS

DAY	DATE	Sampling Time (Hr:Min)	MLSS (mg/L)	MLVSS (mg/L)	SOLIDS RATIO
1	Jun/19/90	12:10 pm	5640	4430	0.79
2	20	10:50 am	5574	4386	0.79
3	21	10:25 am	5678	4460	0.79
4	22	2:00 pm	5470	4304	0.79
5	23	7:00 pm	5308	4148	0.78
6	24	5:45 pm	5288	4116	0.78
7	25	1:30 pm	5370	4390	0.82
8	26	10:45 am	5756	4526	0.79
9	27	2:30 pm	5736	4528	0.79
10	28	1:05 pm	5540	4328	0.78
11	29	4:05 pm	5700	4410	0.77
12	30	2:40 pm	6060	4694	0.77
13	Jul/01/90	6:40 pm	6054	4664	0.77
14	02	4:05 pm	5658	4346	0.77
15	03	10:10 am	6028	4645	0.77
16	04	8:55 am	5854	4498	0.77
17	05	10:25 am	5674	4370	0.77
18	06	11:45 am	5658	4356	0.77
19	07	3:25 pm	6122	4740	0.77
20	08	2:00 pm	6680	5168	0.77
21	09	2:25 pm	7054	5436	0.77
22	10	10:25 am	6900	5344	0.77
23	11	5:10 pm	6810	5256	0.77
24	12	9:50 am	6664	5152	0.77
25	13	12:50 pm	6740	5240	0.78
26	14	2:20 pm	6554	5020	0.77
27	15	2:35 pm	6448	4970	0.77
28	16	12:30 pm	6378	4848	0.76
29	17	12:15 pm	6528	5026	0.77
30	18	2:45 pm	6849	5288	0.77
31	Jul/19/90	2:00 pm	7040	5420	0.77
32	20	3:25 pm	6748	5178	0.77
33	21	1:00 pm	6930	5308	0.77
34	22	3:45 pm	6682	5124	0.77
35	23	11:45 am	7200	5500	0.76
36	24	12:50 pm	7138	5478	0.77
37	25	6:00 pm	6828	5232	0.77
38	26	3:45 pm	6776	5196	0.77
39	27	10:05 am	6974	5340	0.77
40	28	12:45 pm	7404	5712	0.77
41	29	7:50 pm	7328	5640	0.77
42	30	11:20 am	7274	5612	0.77
43	31	1:30 pm	6896	5290	0.77
44	Aug/01/90	12:05 pm	7186	5502	0.77
45	02	5:05 pm	6862	5254	0.77
46	03	4:15 pm	7182	5498	0.77
47	04	1:45 pm	7010	5320	0.76
48	05	11:05 pm	6992	5306	0.76
49	06	10:00 am	7218	5498	0.76
50	07	12:35 pm	6856	5200	0.76
51	08	1:10 pm	6984	5326	0.76
52	09	12:05 pm	6964	5282	0.76
53	10	1:55 pm	7106	5388	0.76
54	11	11:30 am	7274	5560	0.76
55	12	3:25 pm	6852	5170	0.75
56	13	8:30 am	6666	4984	0.75
57	14	2:30 pm	6774	5064	0.75
58	15	3:15 pm	6482	4870	0.75
59	16	9:20 am	6706	5008	0.75
60	17	8:20 am	6562	4956	0.76
Maximum			7404	5712	
Mean			6511	5005	
Minimum			5288	4116	
Std. Dev.			610	432	

AASD#2 REAL TIME REACTOR SUSPENDED SOLID CONCENTRATIONS

DAY	DATE	Sampling Time Hr:Min	MLSS (mg/L)	MLVSS (mg/L)	SOLIDS RATIO
1	Oct/02/90	2:10 pm	6658	5282	0.79
2	03	10:10 am	6820	5442	0.80
3	04	2:10 pm	6768	5392	0.80
4	05	2:05 pm	6580	5238	0.80
5	06	2:50 pm	6558	5224	0.79
6	07	2:25 pm	6374	5072	0.80
7	08	1:00 pm	6222	4920	0.80
8	09	11:30 am	6132	4824	0.79
9	10	1:35 pm	6208	4904	0.79
10	11	2:45 pm	6402	5092	0.80
11	12	3:05 pm	6612	5260	0.80
12	13	4:30 pm	6488	5178	0.80
13	14	2:35 pm	6392	5100	0.80
14	15	11:50 am	6660	5334	0.80
15	16	3:25 pm	6404	5122	0.80
16	17	1:00 pm	6414	5156	0.80
17	18	1:10 pm	6150	4950	0.80
18	19	3:25 pm	6338	5068	0.80
19	20	11:10 am	6290	5036	0.80
20	21	3:25 pm	6250	4990	0.80
21	22	2:25 pm	6204	4992	0.80
22	23	1:35 pm	6304	5086	0.81
23	24	3:25 pm	6222	5024	0.81
24	25	1:40 pm	6136	4932	0.80
25	26	3:10 pm	5856	4706	0.80
26	27	1:25 pm	5964	4792	0.80
27	28	6:00 pm	5832	4674	0.80
28	29	1:20 pm	5806	4645	0.80
29	30	3:05 pm	5962	4770	0.30
30	31	1:00 pm	5824	4680	0.80
31	Nov/01/90	4:40 pm	5938	4750	0.80
32	02	7:35 pm	5860	4708	0.80
33	03	3:55 pm	5934	4734	0.80
34	04	5:45 pm	5910	4714	0.80
35	05	2:25 pm	5794	4626	0.80
36	06	1:00 pm	5818	4678	0.80
37	07	1:45 pm	5812	4672	0.80
38	08	2:15 pm	5866	4708	0.80
39	09	1:00 pm	5768	4628	0.80
40	10	1:20 pm	5678	4552	0.80
41	11	10:35 am	5630	4518	0.80
42	12	1:25 pm	5592	4474	0.80
43	13	5:00 pm	5448	4384	0.80
44	14	2:05 pm	5574	4486	0.80
45	15	1:15 pm	5510	4538	0.82
46	16	7:00 pm	5651	4567	0.81
47	17	1:30 pm	5514	4430	0.80
48	18	3:55 pm	5442	4362	0.80
49	19	1:35 pm	5406	4332	0.80
50	20	3:20 pm	5530	4444	0.80
51	21	1:35 pm	5454	4390	0.80
52	22	2:20 pm	5464	4398	0.80
53	23	9:40 pm	5068	4068	0.80
54	24	3:40 pm	5152	4126	0.80
55	25	3:25 pm	5192	4154	0.80
56	26	1:55 pm	5068	4034	0.80
57	27	12:15 pm	5098	4060	0.80
58	28	12:05 pm	4942	3954	0.80
59	29	12:05 pm	4976	4028	0.81
60	30	10:50 am	4762	3920	0.82
Maximum			6820	5442	
Mean			5931	4748	
Minimum			4942	3954	
Std. Dev.			470	367	

AASD#1 FEED NITROGEN CONCENTRATIONS

DAY	DATE	Elapsed Time Since Raw Sludge Collection (Hr:Min)	TKN (mg/L)	NOx (mg/L)	NH3 (mg/L)
1	Jun/19/90	3:55	477	1.45	2.43
2	20	2:30	509	1.75	0.15
3	21	2:05	331	3.05	1.19
4	22	5:35	445	0.53	4.00
5	23	4:45	410	0.45	0.61
6	24	5:30	552	0.71	0.49
7	25	1:30	598	1.72	0.22
8	26	2:30	483	3.17	0.13
9	27	2:00	407	2.54	0.24
10	28	1:25	674	0.61	0.15
11	29	6:00	541	0.78	0.49
12	30	0:40	509	6.24	0.08
13	Jul/01/90	4:25	452	1.94	0.66
14	02	7:30	439	0.24	0.40
15	03	1:50	460	5.84	0.08
16	04	0:50	438	7.26	0.06
17	05	2:05	532	3.46	0.10
18	06	3:25	630	0.32	0.82
19	07	4:00	807	0.79	2.75
20	08	5:05	953	0.35	5.59
21	09	5:30	513	0.17	7.67
22	10	2:00	525	0.70	8.14
23	11	7:15	529	0.29	11.14
24	12	1:35	559	0.91	9.66
25	13	4:55	570	0.51	12.66
26	14	2:30	527	0.58	7.75
27	15	2:50	571	0.85	6.31
28	16	3:10	497	0.38	8.41
29	17	2:55	713	0.93	7.75
30	18	6:30	616	0.13	8.60
31	Jul/19/90	----	----	----	-----
32	20	----	----	----	-----
33	21	2:50	541	0.24	12.95
34	22	4:20	770	0.23	16.60
35	23	3:35	441	0.39	13.85
36	24	1:20	441	1.50	7.20
37	25	5:20	432	0.55	0.80
38	26	3:50	617	0.39	0.36
39	27	2:20	679	5.93	0.11
40	28	4:05	498	0.58	0.07
41	29	1:35	548	1.81	0.23
42	30	4:30	545	2.57	0.72
43	31	28:30	584	0.22	1.94
44	Aug/01/90	52:30	589	0.22	2.72
45	02	8:30	657	0.31	2.02
46	03	7:15	587	0.52	1.57
47	04	1:40	494	0.84	0.12
48	05	11:00	691	0.52	2.09
49	06	1:15	534	5.23	0.06
50	07	4:40	444	2.95	0.21
51	08	2:25	556	4.54	0.07
52	09	4:05	691	0.56	0.23
53	10	4:35	705	2.20	0.48
54	11	2:40	432	3.02	0.19
55	12	8:15	405	2.48	0.10
56	13	1:20	581	5.68	0.06
57	14	3:45	461	3.32	0.11
58	15	5:35	600	0.21	0.48
59	16	1:45	403	7.68	0.07
60	17	1:30	477	6.56	0.07
Maximum			953	7.68	16.60
Mean			546	1.89	3.00
Minimum			331	0.13	0.06
Std. Dev.			111	2.05	4.27

AASD#2 FEED NITROGEN CONCENTRATIONS

DAY	DATE	Elapsed Time Since Raw Sludge Collection (Hr:Min)	TKN (mg/L)	NOx (mg/L)	NH3 (mg/L)
1	Oct/02/90	5:20	652	0.90	0.28
2	03	1:50	734	1.48	0.10
3	04	6:35	536	0.08	10.57
4	05	5:30	435	2.18	0.25
5	06	6:25	401	0.10	0.22
6	07	3:25	392	3.92	0.09
7	08	4:40	436	2.49	0.46
8	09	3:45	294	0.20	0.47
9	10	3:40	646	1.48	0.26
10	11	3:45	713	0.72	0.19
11	12	6:10	464	0.09	0.29
12	13	7:30	562	1.69	0.43
13	14	2:40	687	1.07	0.12
14	15	6:20	397	0.14	11.20
15	16	5:20	473	2.21	0.36
16	17	2:35	351	4.23	0.16
17	18	4:25	614	2.35	0.36
18	19	5:00	552	0.07	0.55
19	20	3:00	405	3.69	0.05
20	21	3:35	446	0.18	0.40
21	22	3:40	511	0.16	0.32
22	23	3:35	426	0.18	0.32
23	24	5:35	553	1.24	0.93
24	25	6:20	506	2.10	0.67
25	26	8:00	453	0.41	1.41
26	27	5:00	408	6.25	0.31
27	28	5:10	559	0.24	1.10
28	29	4:20	520	0.34	0.52
29	30	3:15	422	1.16	0.12
30	31	3:10	631	0.57	0.16
31	Nov/01/90	6:15	533	0.57	0.07
32	02	11:15	472	0.31	0.38
33	03	6:45	423	0.23	0.07
34	04	8:25	450	0.30	0.67
35	05	5:45	556	0.24	10.42
36	06	3:45	513	0.26	0.05
37	07	3:00	510	0.30	0.05
38	08	3:30	486	0.30	0.28
39	09	1:30	394	6.74	0.05
40	10	2:30	456	1.39	0.15
41	11	----	---	----	----
42	12	----	---	----	----
43	13	7:45	517	0.22	0.76
44	14	4:15	510	0.36	0.17
45	15	5:05	453	0.57	0.06
46	16	9:05	465	0.25	0.60
47	17	2:10	467	3.04	0.09
48	18	6:00	422	0.56	0.09
49	19	3:05	452	4.62	0.09
50	20	5:30	402	0.42	0.33
51	21	3:15	433	3.65	0.17
52	22	4:50	407	1.88	0.24
53	23	12:00	509	0.15	1.46
54	24	4:45	475	0.21	0.32
55	25	2:30	433	3.35	0.04
56	26	4:30	421	1.65	0.05
57	27	1:00	429	0.37	0.81
58	28	2:15	333	0.27	5.38
59	29	1:25	316	0.31	5.77
60	30	1:25	429	0.21	4.79
Maximum			734	6.74	11.20
Mean			480	1.29	1.14
Minimum			294	0.07	0.04
Std. Dev.			92	1.55	2.52

AASD#1 FIXED TIME REACTOR NITROGEN CONCENTRATIONS

DAY	DATE	Elapsed Time Since Air ON or OFF (Hr:Min)	TKN (mg/L)	NOx (mg/L)	NH3 (mg/L)
1	Jun/19/90	On 1:15	345	1.72	0.13
2	20	Off 2:35	395	0.15	0.86
3	21	On 2:10	378	0.19	0.83
4	22	On 2:15	364	2.92	0.06
5	23	On 0:30	388	1.77	0.10
6	24	Off 2:50	265	0.08	0.99
7	25	On 1:30	357	1.94	0.12
8	26	Off 2:10	384	0.60	0.77
9	27	On 1:40	360	2.22	0.11
10	28	On 1:35	384	2.11	0.07
11	29	On 1:45	395	2.09	0.06
12	30	On 2:10	398	2.51	0.08
13	Jul/01/90	Off 2:15	413	0.52	0.75
14	02	On 2:35	376	2.39	0.06
15	03	On 2:40	373	2.20	0.06
16	04	On 1:45	409	1.81	0.08
17	05	On 2:30	406	1.72	0.06
18	06	Off 0:50	402	1.69	0.15
19	07	On 1:35	410	1.31	0.04
20	08	On 1:15	447	1.22	0.06
21	09	On 1:35	477	1.27	0.06
22	10	Off 0:45	486	1.54	0.29
23	11	On 2:05	465	2.02	0.06
24	12	On 2:20	453	2.09	0.06
25	13	Off 2:50	483	0.14	0.93
26	14	On 1:10	464	2.05	0.06
27	15	On 1:20	458	1.30	0.06
28	16	On 2:30	464	1.57	0.08
29	17	Off 1:40	430	0.92	0.45
30	18	On 1:05	458	1.05	0.06
31	Jul/19/90	Off 1:55	453	0.21	0.72
32	20	On 0:45	475	1.15	0.10
33	21	Off 1:05	447	1.93	0.39
34	22	On 1:20	453	1.15	0.05
35	23	Off 0:20	481	1.96	0.18
36	24	Off 1:05	471	1.40	0.32
37	25	On 1:10	464	1.65	0.05
38	26	Off 2:45	458	0.24	0.70
39	27	On 0:15	474	1.05	0.10
40	28	On 2:50	472	2.83	0.08
41	29	On 3:00	480	3.14	0.09
42	30	On 0:40	475	1.67	0.08
43	31	On 2:40	476	2.97	0.07
44	Aug/01/90	On 1:35	471	1.82	0.07
45	02	On 1:00	476	0.35	0.82
46	03	Off 1:45	473	1.15	0.56
47	04	On 2:05	463	2.26	0.08
48	05	Off 2:10	347	0.13	0.90
49	06	On 1:35	493	1.68	0.07
50	07	On 1:40	449	2.55	0.06
51	08	On 1:30	454	1.71	0.06
52	09	On 1:35	462	1.83	0.09
53	10	On 1:10	492	4.66	0.10
54	11	On 1:35	492	2.19	0.09
55	12	On 1:45	474	2.20	0.08
56	13	On 2:45	458	2.11	0.08
57	14	On 1:00	458	1.61	0.09
58	15	On 1:35	443	1.75	0.08
59	16	On 2:35	448	2.32	0.08
60	17	On 1:30	433	1.72	0.09
Maximum			493	4.66	0.99
Mean			436	1.64	0.23
Minimum			265	0.08	0.04
Std. Dev.			47	0.86	0.29

AASD#2 FIXED TIME REACTOR NITROGEN CONCENTRATIONS

DAY	DATE	Elapsed Time Since Air ON or OFF (Hr:Min)	TKN (mg/L)	NOx (mg/L)	NH3 (mg/L)
1	Oct/02/90	On 1:45	509	1.83	0.11
2	03	Off 1:00	503	0.15	0.64
3	04	On 1:35	522	1.23	0.11
4	05	On 1:10	528	1.10	0.11
5	06	On 2:40	512	1.20	0.16
6	07	On 1:00	487	0.96	0.10
7	08	Off 2:25	482	0.18	0.54
8	09	Off 0:55	486	1.66	0.12
9	10	Off 2:30	461	0.16	0.54
10	11	On 0:30	480	0.82	0.08
11	12	Off 0:50	454	1.41	0.17
12	13	Off 2:00	448	0.40	0.47
13	14	On 2:45	469	1.66	0.08
14	15	Off 3:00	451	0.10	0.62
15	16	Off 0:05	495	1.71	0.04
16	17	On 0:40	452	0.85	0.00
17	18	On 0:35	445	0.78	0.08
18	19	On 2:40	467	1.38	0.00
19	20	Off 1:05	465	1.24	0.14
20	21	On 2:05	453	1.36	0.00
21	22	On 0:50	438	0.93	0.02
22	23	Off 2:45	446	0.17	0.55
23	24	On 1:30	454	1.38	0.01
24	25	Off 2:25	462	0.14	0.58
25	26	On 0:40	460	1.04	0.10
26	27	Off 1:40	445	0.51	0.40
27	28	Off 1:15	443	1.69	0.16
28	29	Off 2:05	429	0.60	0.37
29	30	Off 2:45	448	0.20	0.63
30	31	Off 1:35	445	2.13	0.36
31	Nov/01/90	On 1:50	434	1.61	0.03
32	02	Off 1:35	457	0.62	0.42
33	03	On 1:20	451	1.27	0.04
34	04	On 2:15	421	1.66	0.05
35	05	Off 2:05	440	0.09	0.57
36	06	Off 0:05	446	4.05	0.37
37	07	Off 0:45	451	1.84	0.11
38	08	Off 0:45	436	1.70	0.19
39	09	On 2:05	424	1.89	0.05
40	10	On 2:15	436	2.17	0.08
41	11	Off 2:20	430	0.19	0.71
42	12	On 1:50	401	2.25	0.06
43	13	Off 2:45	406	1.05	0.57
44	14	On 2:10	431	2.15	0.06
45	15	On 1:15	401	1.70	0.06
46	16	On 0:35	407	1.36	0.06
47	17	On 0:45	398	1.45	0.06
48	18	On 0:15	408	2.46	0.05
49	19	On 0:15	410	0.70	0.37
50	20	On 1:55	410	1.99	0.06
51	21	Off 3:00	403	0.09	0.69
52	22	Off 0:55	399	2.48	0.17
53	23	Off 2:00	391	1.33	0.54
54	24	Off 2:00	366	1.24	0.45
55	25	Off 1:30	386	1.64	0.40
56	26	On 0:15	377	0.67	0.71
57	27	Off 1:45	352	1.75	0.36
58	28	Off 1:20	374	2.23	0.22
59	29	Off 1:10	361	0.19	4.75
60	30	On 2:50	372	0.28	10.23
Maximum			528	4.05	0.71
Mean			441	1.25	0.26
Minimum			352	0.09	0.00
Std. Dev.			38	0.77	0.23

AASD#1 REAL TIME REACTOR NITROGEN CONCENTRATIONS

DAY	DATE	Elapsed Time Since Air ON or OFF (Hr:Min)	TKN (mg/L)	NOx (mg/L)	NH3 (mg/L)
1	Jun/19/90	On 1:25	359	1.74	0.08
2	20	On 0:20	368	0.83	0.22
3	21	Off 0:45	401	1.55	0.49
4	22	On 2:45	323	0.14	0.92
5	23	On 1:05	351	1.74	0.10
6	24	Off 2:55	348	0.22	0.90
7	25	On 2:15	350	2.27	0.13
8	26	On 1:35	368	1.80	0.13
9	27	On 1:30	358	2.00	0.14
10	28	On 1:35	402	2.11	0.08
11	29	On 1:30	402	1.88	0.10
12	30	On 2:10	387	2.38	0.07
13	Jul/01/90	On 1:30	403	1.78	0.10
14	02	On 0:20	414	1.12	0.13
15	03	On 1:45	414	1.85	0.10
16	04	On 2:00	376	2.03	0.11
17	05	On 1:40	346	2.59	0.11
18	06	On 2:00	338	3.65	0.07
19	07	On 0:35	394	2.03	0.07
20	08	On 1:50	429	1.38	0.07
21	09	On 1:40	466	1.50	0.10
22	10	On 1:40	438	1.50	0.08
23	11	On 1:30	473	1.50	0.10
24	12	On 1:50	460	1.74	0.09
25	13	On 1:50	440	1.68	0.10
26	14	On 1:40	424	1.45	0.11
27	15	On 2:35	451	1.78	0.13
28	16	On 1:45	425	1.30	0.10
29	17	On 1:55	408	1.43	0.09
30	18	On 1:30	439	1.15	0.08
31	Jul/19/90	Off 0:40	450	1.59	0.20
32	20	Off 2:15	489	0.76	0.74
33	21	On 1:15	447	1.22	0.08
34	22	On 1:20	445	1.12	0.10
35	23	On 2:00	476	2.17	0.09
36	24	On 2:25	474	4.18	0.09
37	25	On 1:05	422	1.81	0.09
38	26	Off 3:00	457	0.17	0.61
39	27	On 2:05	471	1.77	0.10
40	28	On 1:50	500	2.18	0.10
41	29	On 1:35	491	2.03	0.10
42	30	On 1:30	462	2.01	0.10
43	31	On 1:30	434	2.00	0.09
44	Aug/01/90	On 1:40	450	2.12	0.10
45	02	On 1:15	464	1.59	0.11
46	03	On 1:40	473	0.04	0.10
47	04	On 1:20	483	1.60	0.11
48	05	On 1:20	475	1.98	0.11
49	06	On 1:30	464	2.34	0.11
50	07	On 1:40	472	2.22	0.12
51	08	On 2:00	430	2.39	0.11
52	09	On 1:50	449	2.31	0.11
53	10	On 1:35	440	3.20	0.11
54	11	On 1:40	495	2.54	0.12
55	12	On 2:55	448	2.36	0.12
56	13	On 1:40	449	2.32	0.16
57	14	On 1:05	432	1.75	0.11
58	15	On 1:35	448	1.91	0.10
59	16	On 2:30	432	2.55	0.11
60	17	On 1:35	391	1.90	0.10
Maximum			500	4.18	0.92
Mean			428	1.80	0.16
Minimum			323	0.04	0.07
Std. Dev.			44	0.73	0.18

AASD#2 REAL TIME REACTOR NITROGEN CONCENTRATIONS

DAY	DATE	Elapsed Time Since Air ON or OFF (Hr:Min)	TKN (mg/L)	NOx (mg/L)	NH3 (mg/L)
1	Oct/02/90	On 1:55	525	2.01	0.05
2	03	Off 1:35	473	0.19	0.35
3	04	Off 0:30	530	0.51	0.09
4	05	Off 0:45	498	0.19	0.29
5	06	On 1:25	472	0.91	0.05
6	07	Off 1:15	462	0.16	0.26
7	08	On 1:55	478	0.37	0.10
8	09	On 0:25	456	0.44	0.07
9	10	Off 1:15	455	0.19	0.24
10	11	Off 1:30	467	5.05	0.35
11	12	Off 0:55	479	1.04	0.19
12	13	On 0:35	461	0.61	0.03
13	14	On 0:35	470	0.44	0.03
14	15	On 1:20	475	0.96	0.03
15	16	On 0:45	463	0.56	0.02
16	17	On 3:55	470	0.60	0.04
17	18	On 0:25	432	0.37	0.02
18	19	On 1:30	441	1.06	0.02
19	20	On 0:10	435	0.47	0.09
20	21	On 0:35	455	0.57	0.04
21	22	On 2:15	437	1.32	0.04
22	23	On 0:05	444	0.28	0.12
23	24	On 1:05	446	0.37	0.04
24	25	Off 0:20	446	0.47	0.09
25	26	Off 1:00	437	0.35	0.27
26	27	On 0:30	439	0.57	0.06
27	28	On 1:00	452	0.94	0.08
28	29	Off 0:50	438	0.59	0.15
29	30	Off 0:45	427	0.30	0.17
30	31	On 1:35	407	1.08	0.06
31	Nov/01/90	On 0:30	446	0.50	0.05
32	02	On 0:05	442	0.28	0.19
33	03	On 0:55	429	0.75	0.05
34	04	On 0:05	429	0.31	0.10
35	05	Off 0:30	425	0.66	0.10
36	06	On 1:35	418	2.69	0.34
37	07	On 0:10	439	0.47	0.10
38	08	Off 0:35	404	0.42	0.17
39	09	On 0:05	430	0.14	0.21
40	10	On 0:05	408	0.26	0.30
41	11	On 0:15	414	0.67	0.09
42	12	On 0:15	401	0.61	0.27
43	13	On 0:05	395	0.99	0.89
44	14	On 1:40	409	1.74	0.07
45	15	Off 0:50	402	0.25	0.23
46	16	On 0:15	376	0.81	0.08
47	17	On 0:05	411	0.34	0.16
48	18	On 0:10	402	0.38	0.23
49	19	On 0:05	396	0.27	0.32
50	20	On 0:10	391	0.57	0.32
51	21	Off 3:00	385	0.15	0.57
52	22	Off 0:30	386	0.60	0.15
53	23	Off 0:30	354	0.68	0.16
54	24	Off 0:55	369	0.69	0.20
55	25	On 1:15	358	1.28	0.07
56	26	On 0:25	350	0.96	0.32
57	27	On 0:10	364	0.49	0.22
58	28	On 0:15	336	1.28	0.07
59	29	On 0:35	345	0.15	4.99
60	30	Off 4:00	354	0.30	10.58
Maximum			530	5.05	0.89
Mean			430	0.73	0.16
Minimum			336	0.14	0.02
Std. Dev.			41	0.74	0.15

AASD#1 PHOSPHORUS MEASUREMENTS

DAY	DATE	FEED		FIXED TIME REACTOR		REAL TIME REACTOR	
		TP	Ortho-P	TP	Ortho-P	TP	Ortho-P
1	Jun/19/90	220	8.47	186	23.82	199	25.00
2	20	241	0.20	218	28.43	205	28.80
3	21	164	0.53	211	39.46	225	33.02
4	22	214	5.60	210	35.90	199	46.18
5	23	205	8.76	226	43.88	216	45.40
6	24	271	18.78	164	46.38	215	46.32
7	25	307	6.26	216	47.38	219	48.30
8	26	250	0.20	234	47.38	231	49.68
9	27	216	6.94	230	50.73	230	54.08
10	28	352	1.76	261	52.18	256	54.68
11	29	294	12.46	265	53.38	251	56.23
12	30	279	0.45	259	54.33	247	51.08
13	Jul/01/90	259	19.23	277	55.18	264	55.10
14	02	246	11.64	260	54.33	254	53.30
15	03	259	0.28	258	50.73	258	51.58
16	04	246	0.28	263	50.00	275	51.93
17	05	308	0.45	269	48.53	255	48.78
18	06	354	5.07	270	47.23	252	49.38
19	07	410	27.18	259	48.90	254	48.65
20	08	472	30.85	277	48.53	265	46.40
21	09	252	18.94	297	46.40	289	45.08
22	10	262	0.45	292	45.55	279	44.00
23	11	261	25.13	292	49.13	298	48.90
24	12	276	0.36	286	48.05	293	46.28
25	13	292	17.96	309	46.27	280	44.06
26	14	263	7.45	287	44.59	274	44.27
27	15	301	1.77	289	44.90	288	41.96
28	16	246	2.11	292	43.33	271	39.75
29	17	413	2.03	311	43.22	326	37.23
30	18	366	18.76	341	40.70	341	36.28
31	Jul/19/90	---	-----	326	42.80	346	36.60
32	20	---	-----	354	45.74	370	43.01
33	21	325	15.48	346	53.84	373	42.17
34	22	445	31.70	342	46.69	359	46.48
35	23	261	10.45	385	41.58	369	36.64
36	24	271	0.00	344	40.53	361	35.07
37	25	279	4.14	344	40.11	331	36.96
38	26	385	4.06	334	38.75	351	51.68
39	27	429	0.00	343	35.07	350	40.11
40	28	330	0.00	353	35.38	376	38.85
41	29	345	0.00	358	36.01	385	38.54
42	30	320	4.48	321	33.49	320	37.38
43	31	340	16.26	325	34.22	309	37.48
44	Aug/01/90	344	23.40	329	32.96	320	37.48
45	02	399	23.04	329	44.53	334	37.77
46	03	361	12.19	333	43.65	338	37.66
47	04	301	0.64	323	41.91	338	36.14
48	05	332	27.88	328	47.36	351	39.52
49	06	332	0.38	347	44.53	341	35.48
50	07	276	0.00	328	44.31	350	33.96
51	08	347	0.64	329	47.47	328	36.90
52	09	415	3.78	332	49.21	343	35.16
53	10	323	18.37	348	50.21	333	35.53
54	11	265	0.00	359	53.93	364	36.18
55	12	250	11.50	355	55.04	349	39.25
56	13	364	0.00	339	53.93	349	39.34
57	14	294	6.59	344	60.43	363	40.83
58	15	375	11.94	332	59.50	361	42.68
59	16	253	0.00	346	57.55	348	42.68
60	17	295	0.00	338	61.54	333	44.08
Maximum		472	31.70	385	61.54	385	56.23
Mean		306	8.40	300	45.85	302	42.39
Minimum		164	0.00	164	23.82	199	25.00
Std. Dev.		64	9.27	49	7.59	53	6.79

AASD#2 PHOSPHORUS MEASUREMENTS

DAY	DATE	FEED		FIXED TIME REACTOR		REAL TIME REACTOR	
		TP	Ortho-P	TP	Ortho-P	TP	Ortho-P
1	Oct/02/90	287	7.40	297	48.41	306	47.71
2	03	322	0.22	301	51.02	286	52.51
3	04	237	18.14	306	49.89	317	56.26
4	05	191	2.58	306	52.24	304	58.18
5	06	177	0.31	297	52.51	293	59.74
6	07	175	0.07	287	51.72	292	60.97
7	08	199	2.41	290	53.38	298	58.61
8	09	134	0.81	289	54.25	280	58.96
9	10	330	2.19	279	53.81	283	60.79
10	11	425	0.16	292	53.38	288	59.48
11	12	201	1.13	278	60.21	291	60.45
12	13	245	9.64	281	57.40	283	61.36
13	14	301	0.17	289	59.55	286	60.62
14	15	165	8.88	278	58.23	287	61.44
15	16	203	4.82	296	60.78	283	61.35
16	17	151	0.92	273	59.63	285	61.85
17	18	264	5.45	273	59.13	271	62.76
18	19	243	7.79	287	61.03	273	62.93
19	20	184	0.07	279	59.79	268	61.44
20	21	206	0.48	274	60.21	274	63.83
21	22	225	0.18	267	59.88	269	63.59
22	23	193	0.19	270	61.61	267	63.09
23	24	242	8.91	275	62.10	273	63.83
24	25	222	4.29	281	59.96	272	63.50
25	26	202	3.82	267	60.95	267	62.16
26	27	185	0.07	271	61.21	273	62.16
27	28	256	8.25	271	63.20	274	64.84
28	29	242	0.25	263	60.26	270	63.20
29	30	198	0.14	274	61.47	267	64.93
30	31	297	0.07	272	61.13	267	64.06
31	Nov/01/90	241	2.83	216	60.87	230	64.93
32	02	210	8.07	230	60.61	229	64.24
33	03	186	1.84	227	61.47	222	64.50
34	04	202	8.04	220	60.87	222	63.98
35	05	238	8.04	226	62.34	226	65.71
36	06	223	0.09	228	59.92	218	63.20
37	07	221	0.08	231	57.50	226	63.37
38	08	210	2.75	223	59.97	215	60.96
39	09	169	0.09	218	59.35	223	62.47
40	10	193	0.09	223	59.44	212	62.92
41	11	---	----	248	58.10	242	62.38
42	12	---	----	244	63.99	241	68.81
43	13	224	9.53	245	73.09	245	75.94
44	14	222	0.35	254	65.86	244	70.87
45	15	200	0.12	242	61.22	237	68.63
46	16	208	8.18	244	63.10	228	65.77
47	17	204	0.08	240	60.87	238	65.06
48	18	185	0.07	240	62.56	237	64.97
49	19	201	0.06	245	61.58	237	67.91
50	20	180	0.99	245	61.22	235	65.95
51	21	198	0.10	248	64.97	249	67.65
52	22	187	0.10	246	64.17	245	67.74
53	23	237	22.26	248	68.40	235	67.08
54	24	223	1.03	241	64.62	239	66.70
55	25	205	0.08	245	66.41	237	69.81
56	26	196	0.12	243	65.28	232	70.28
57	27	185	0.09	235	66.70	240	70.76
58	28	134	2.49	243	65.75	231	67.17
59	29	116	0.31	231	78.30	227	79.34
60	30	152	0.57	231	88.68	222	90.76
Maximum		425	22.26	306	73.09	317	75.94
Mean		215	3.07	260	60.15	258	63.56
Minimum		116	0.06	216	48.41	212	47.71
Std. Dev.		50	4.54	25	4.63	27	4.38

DISSOLVED OXYGEN MEASUREMENTS
AASD#1 FIXED TIME REACTOR

DAY	DATE	Sampling Time (Hr:Min)	Length of Time of Aeration (Hr:Min)	Airflow Rate (mL/min)	Dissolved Oxygen Concentration (mg/L)
1	Jun/19/90	12:45 pm	2:00	154	2.50
2	20	1:00 pm	2:00	154	2.00
3	21	1:05 pm	2:00	154	2.00
4	22	1:45 pm	2:30	161	2.30
5	23	7:00 pm	1:30	154	2.60
6	24	2:35 pm	3:00	154	2.85
7	25	1:15 pm	1:30	151	2.70
8	26	1:30 pm	1:30	154	1.75
9	27	1:40 pm	1:30	154	2.60
10	28	1:55 pm	1:30	151	3.20
11	29	2:00 pm	1:30	161	3.85
12	30	2:50 pm	2:00	151	3.20
13	Jul/01/90	2:50 pm	1:50	161	4.00
14	02	10:05 am	2:50	154	4.20
15	03	9:55 am	2:30	151	4.00
16	04	8:55 am	1:30	151	4.45
17	05	10:10 am	2:00	151	4.90
18	06	9:55 am	2:00	146	5.20
19	07	3:45 pm	1:30	146	4.60
20	08	3:50 pm	1:30	143	2.80
21	09	2:15 pm	1:30	154	3.20
22	10	9:55 am	3:00	146	3.20
23	11	10:00 am	3:00	146	3.10
24	12	9:25 am	2:15	146	2.10
25	13	9:05 am	2:30	143	3.20
26	14	2:35 pm	1:00	146	2.80
27	15	2:35 pm	1:00	149	2.70
28	16	9:35 am	1:45	144	4.45
29	17	9:45 am	1:45	143	4.10
30	18	10:15 am	2:15	146	2.80
31	Jul/19/90	9:50 am	1:30	146	1.90
32	20	10:30 am	2:00	151	4.05
33	21	10:30 am	1:75	146	3.80
34	22	4:10 pm	1:30	149	2.20
35	23	10:55 am	2:00	144	1.40
36	24	10:30 am	1:30	146	2.80
37	25	5:05 pm	1:00	154	4.45
38	26	11:40 am	1:30	151	5.30
39	27	5:50 pm	1:30	165	4.05
40	28	11:55 am	1:30	151	3.75
41	29	6:15 pm	1:30	165	3.80
42	30	7:40 am	3:00	165	3.90
43	31	1:00 pm	2:00	151	4.40
44	Aug/01/90	12:30 pm	1:30	151	4.40
45	02	12:45 pm	1:30	146	4.30
46	03	12:45 pm	1:30	154	3.70
47	04	12:55 pm	1:30	154	3.05
48	05	7:45 pm	2:00	151	2.40
49	06	1:15 pm	1:30	158	2.85
50	07	1:25 pm	1:30	149	2.70
51	08	1:30 pm	1:30	151	2.90
52	09	1:40 pm	1:30	151	3.00
53	10	1:45 pm	1:30	154	2.90
54	11	1:50 pm	1:30	161	1.80
55	12	2:00 pm	1:30	154	1.60
56	13	8:00 am	1:30	154	2.15
57	14	9:00 am	2:30	151	2.40
58	15	2:15 pm	1:30	154	2.70
59	16	9:15 am	2:20	149	2.70
60	17	8:30 am	1:30	154	3.05
Maximum					5.30
Mean					3.20
Minimum					1.40
Std. Dev.					0.93

DISSOLVED OXYGEN MEASUREMENTS
AASD#1 REAL TIME REACTOR

DAY	DATE	Sampling Time (Hr:Min)	Length of Time of Aeration (Hr:Min)	Airflow Rate (mL/min)	Dissolved Oxygen Concentration (mg/L)
1	Jun/19/90	12:45 pm	2:00	128	1.90
2	20	12:30 pm	2:00	128	2.20
3	21	1:45 pm	2:00	128	1.80
4	22	11:00 am	2:30	128	2.00
5	23	7:25 pm	1:30	128	2.65
6	24	2:30 pm	3:00	127	3.10
7	25	1:15 pm	2:00	125	3.15
8	26	10:45 am	1:30	128	3.35
9	27	2:30 pm	1:30	125	3.00
10	28	1:00 pm	1:30	125	3.55
11	29	4:00 pm	1:30	125	3.15
12	30	2:45 pm	2:15	121	3.80
13	Jul/01/90	6:40 pm	1:50	125	3.70
14	02	12:35 pm	2:50	121	3.70
15	03	9:55 am	1:30	122	4.20
16	04	8:55 am	2:00	127	4.50
17	05	10:15 am	1:30	124	4.45
18	06	11:45 am	2:00	121	5.20
19	07	3:20 pm	1:30	117	4.45
20	08	1:40 pm	1:30	117	3.80
21	09	2:15 pm	1:30	121	2.30
22	10	10:15 am	1:30	132	3.30
23	11	1:15 pm	3:00	128	2.60
24	12	9:30 am	1:30	125	2.00
25	13	1:00 pm	2:00	125	3.15
26	14	2:15 pm	1:30	124	3.70
27	15	2:35 pm	2:30	128	3.90
28	16	12:20 pm	1:30	124	4.10
29	17	12:05 pm	1:75	121	3.95
30	18	9:30 am	2:15	121	3.85
31	Jul/19/90	11:45 am	1:30	132	3.45
32	20	12:10 pm	2:00	138	3.90
33	21	1:15 pm	1:30	128	3.50
34	22	3:55 pm	1:30	128	2.80
35	23	11:45 am	2:00	124	3.30
36	24	8:25 am	1:30	121	4.35
37	25	5:55 pm	1:00	127	3.35
38	26	11:20 am	1:30	125	4.50
39	27	9:30 am	1:30	121	4.75
40	28	7:50 am	3:00	121	4.05
41	29	7:45 pm	1:30	138	3.55
42	30	11:20 am	3:00	125	3.30
43	31	8:15 am	2:00	128	3.95
44	Aug/01/90	11:55 am	1:30	122	4.35
45	02	11:10 am	1:30	121	4.30
46	03	10:15 am	1:30	121	3.70
47	04	1:55 pm	1:30	122	2.50
48	05	11:15 pm	1:30	125	1.90
49	06	10:00 am	1:30	121	1.75
50	07	12:25 pm	1:30	121	2.40
51	08	12:40 pm	1:30	121	2.70
52	09	11:45 am	1:30	121	2.60
53	10	1:50 pm	1:30	124	2.00
54	11	11:20 am	1:30	125	1.70
55	12	3:10 pm	1:30	125	1.40
56	13	8:20 am	1:30	122	3.15
57	14	9:00 am	2:45	122	3.30
58	15	3:10 pm	1:30	124	3.75
59	16	9:15 am	2:15	117	3.85
60	17	8:15 am	1:30	119	4.05
Maximum					5.20
Mean					3.31
Minimum					1.40
Std. Dev.					0.88

DISSOLVED OXYGEN MEASUREMENTS
FIXED TIME REACTOR - AASD#2

DAY	DATE	Sampling Time (Hr:Min)	Length of Time of Aeration (Hr:Min)	Airflow Rate (mL/min)	Dissolved Oxygen Concentration (mg/L)
1	Oct/02/90	1:45 pm	1:30	37	1.90
2	03	8:15 am	2:15	38	5.30
3	04	2:45 pm	2:15	38	1.70
4	05	12:20 pm	1:00	45	4.70
5	06	2:30 pm	1:30	40	3.00
6	07	2:45 pm	1:30	38	3.35
7	08	9:30 am	2:10	35	3.60
8	09	10:00 am	2:30	37	3.80
9	10	9:15 am	1:15	36	3.40
10	11	10:00 am	1:50	35	3.30
11	12	12:35 pm	1:30	36	2.95
12	13	6:25 pm	1:00	33	3.00
13	14	2:00 pm	2:15	30	3.15
14	15	2:40 pm	3:00	33	2.75
15	16	9:00 am	3:00	30	3.10
16	17	9:10 am	3:00	28	3.00
17	18	1:30 pm	1:00	28	1.00
18	19	2:40 pm	2:00	26	1.25
19	20	9:55 am	3:00	30	4.40
20	21	3:30 pm	2:15	25	3.45
21	22	10:00 am	2:30	30	3.70
22	23	9:30 am	1:45	30	4.00
23	24	10:00 am	2:00	28	3.30
24	25	3:30 pm	1:30	28	2.30
25	26	4:15 pm	2:00	25	2.60
26	27	4:40 pm	2:00	30	3.15
27	28	4:40 pm	2:45	25	3.70
28	29	10:25 am	2:15	25	2.75
29	30	4:25 pm	2:00	30	2.55
30	31	10:50 am	2:20	25	2.40
31	Nov/01/90	11:35 am	2:45	20	2.00
32	02	10:55 am	1:50	30	2.50
33	03	4:45 pm	1:25	30	2.00
34	04	5:40 pm	2:00	33	3.50
35	05	11:15 am	1:30	33	2.50
36	06	12:00 pm	2:00	30	0.70
37	07	11:35 am	1:30	26	3.10
38	08	12:00 pm	1:30	25	2.50
39	09	12:10 pm	1:30	30	3.00
40	10	12:00 pm	1:00	30	2.15
41	11	1:10 pm	2:00	30	3.20
42	12	1:25 pm	2:00	27	3.25
43	13	1:35 pm	2:00	30	4.30
44	14	1:55 pm	2:00	28	3.40
45	15	1:35 pm	1:30	28	2.70
46	16	2:30 pm	2:10	30	2.20
47	17	8:55 am	2:30	33	3.10
48	18	2:40 pm	1:50	28	2.30
49	19	9:35 am	2:35	25	3.40
50	20	9:45 am	2:30	25	2.75
51	21	9:50 am	2:20	30	3.90
52	22	12:45 pm	2:30	30	4.25
53	23	1:15 pm	2:50	30	3.80
54	24	12:30 pm	1:45	30	4.50
55	25	1:50 pm	2:50	28	3.70
56	26	3:45 pm	2:15	34	4.20
57	27	9:45 am	2:05	33	4.50
58	28	10:20 am	2:30	30	5.10
59	29	11:00 am	2:45	33	7.20
60	30	10:05 am	1:30	30	7.35
Maximum					5.30
Mean					3.12
Minimum					0.70
Std. Dev.					0.93

DISSOLVED OXYGEN MEASUREMENTS
REAL TIME REACTOR - AASD#2

DAY	DATE	Sampling Time (Hr:Min)	Length of Time of Aeration (Hr:Min)	Airflow Rate (mL/min)	Dissolved Oxygen Concentration (mg/L)
1	Oct/02/90	1:50 pm	1:30	56	4.60
2	03	8:15 am	1:15	43	4.00
3	04	1:35 pm	0:50	38	2.75
4	05	1:50 pm	1:00	37	1.75
5	06	2:30 pm	1:00	40	4.20
6	07	3:25 pm	1:00	34	2.80
7	08	10:00 am	0:50	32	2.00
8	09	10:00 am	1:00	33	2.40
9	10	9:15 am	1:00	31	2.75
10	11	10:00 am	3:00	31	3.30
11	12	12:35 pm	1:30	32	1.40
12	13	4:55 pm	1:00	35	2.25
13	14	2:45 pm	0:45	30	1.60
14	15	1:30 pm	3:00	30	1.70
15	16	9:45 am	1:15	32	2.20
16	17	10:05 am	1:00	35	3.05
17	18	1:30 pm	0:45	31	1.90
18	19	3:55 pm	2:00	30	1.90
19	20	12:00 pm	1:00	30	2.05
20	21	3:35 pm	0:45	28	1.60
21	22	2:40 pm	2:30	28	1.50
22	23	12:40 pm	0:50	35	2.35
23	24	10:15 am	1:00	33	2.70
24	25	2:50 pm	0:50	33	2.30
25	26	4:15 pm	1:00	32	2.60
26	27	1:40 pm	0:45	36	3.00
27	28	5:45 pm	0:45	30	2.50
28	29	10:20 am	1:00	30	2.60
29	30	2:15 pm	0:45	30	2.10
30	31	1:00 pm	1:30	30	3.00
31	Nov/01/90	3:15 pm	0:50	30	2.30
32	02	12:15 pm	0:45	25	1.20
33	03	4:00 pm	1:00	34	3.40
34	04	4:30 pm	0:50	33	2.50
35	05	10:20 am	0:45	30	2.20
36	06	12:55 pm	1:30	33	1.00
37	07	12:30 pm	0:45	30	2.40
38	08	12:00 pm	0:45	30	2.00
39	09	10:25 am	0:45	28	1.60
40	10	12:00 pm	1:00	30	3.00
41	11	11:05 am	0:45	30	2.20
42	12	2:15 pm	1:05	30	2.30
43	13	11:30 am	2:30	30	3.80
44	14	1:55 pm	1:30	28	2.40
45	15	12:25 pm	0:40	30	1.20
46	16	2:30 pm	1:50	28	1.60
47	17	10:45 am	0:40	35	1.75
48	18	4:30 pm	0:45	36	2.55
49	19	11:30 am	0:50	35	3.30
50	20	12:15 pm	1:00	34	3.20
51	21	10:15 am	1:15	37	3.75
52	22	10:35 pm	0:45	30	2.00
53	23	9:05 pm	0:45	27	1.30
54	24	2:35 pm	1:00	32	3.10
55	25	2:55 pm	0:45	33	2.40
56	26	3:45 pm	2:15	37	3.90
57	27	9:35 am	0:50	33	2.60
58	28	12:15 pm	1:30	35	4.40
59	29	12:00 pm	1:30	35	6.50
60	30	10:00 am	3:10	35	7.10
Maximum					4.60
Mean					2.49
Minimum					1.00
Std. Dev.					0.82

AASD#1 TEMPERATURE AND pH MEASUREMENTS

DAY	DATE	FEED pH	FEED Temp °C	FIXED TIME REACTOR pH	FIXED TIME REACTOR Temp °C	REAL TIME REACTOR pH	REAL TIME REACTOR Temp °C
1	Jun/19/90	6.86	20	7.02	22	7.03	22
2	20	7.12	20	7.13	22	7.13	22
3	21	7.19	20	7.12	22	7.10	22
4	22	7.05	24	7.13	24	7.13	24
5	23	6.71	23	6.91	23	6.87	23
6	24	6.84	22	7.04	22	7.02	22
7	25	6.84	22	6.84	22	6.84	22
8	26	6.80	21	6.83	22	6.86	22
9	27	7.13	21	7.07	22	7.05	22
10	28	7.30	21	7.36	22	7.39	22
11	29	7.02	21	7.08	22	7.00	22
12	30	6.61	20	6.61	22	6.62	22
13	Jul/01/90	6.78	22	6.90	22	6.88	22
14	02	6.81	21	6.90	22	6.90	22
15	03	6.65	20	6.66	22	6.63	22
16	04	6.94	19	6.90	21	6.90	21
17	05	7.03	19	6.97	21	6.96	21
18	06	6.95	19	6.94	20	6.92	20
19	07	6.77	20	6.91	20	6.88	20
20	08	6.82	20	6.91	20	6.89	20
21	09	6.66	21	6.80	21	6.81	21
22	10	7.03	21	6.90	22	6.91	22
23	11	6.79	23	6.90	23	6.89	23
24	12	7.03	23	6.90	24	6.90	24
25	13	6.89	22	6.91	22	6.92	22
26	14	6.90	21	6.88	21	6.88	21
27	15	6.88	22	6.86	22	6.92	22
28	16	6.99	20	6.90	20	6.88	20
29	17	7.01	20	6.88	21	6.90	21
30	18	6.70	20	6.82	20	6.84	20
31	Jul/19/90	----	--	6.77	21	6.78	21
32	20	----	--	6.62	24	6.69	24
33	21	6.77	23	6.55	24	6.62	24
34	22	6.55	25	6.57	25	6.60	25
35	23	6.66	22	6.59	23	6.62	23
36	24	6.70	21	6.60	22	6.59	22
37	25	6.82	22	6.83	22	6.84	22
38	26	6.76	21	6.81	22	6.86	22
39	27	6.88	20	6.89	20	6.88	20
40	28	6.71	21	6.87	22	6.85	22
41	29	6.37	23	6.59	23	6.59	23
42	30	6.41	22	6.59	23	6.60	23
43	31	6.40	6	6.56	24	6.58	24
44	Aug/01/90	6.64	6	6.76	22	6.74	22
45	02	6.62	22	6.70	22	6.67	22
46	03	6.44	22	6.53	22	6.55	22
47	04	6.47	22	6.49	23	6.51	23
48	05	6.46	26	6.53	26	6.56	26
49	06	6.54	22	6.65	22	6.62	22
50	07	6.95	24	6.55	24	6.54	24
51	08	6.65	23	6.65	24	6.64	24
52	09	6.79	23	6.62	23	6.64	23
53	10	6.65	24	6.37	24	6.42	24
54	11	6.68	24	6.44	24	6.47	24
55	12	6.90	26	6.40	26	6.39	26
56	13	6.81	24	6.44	24	6.41	24
57	14	6.69	23	6.42	23	6.48	23
58	15	6.69	22	6.46	22	6.52	22
59	16	6.73	21	6.41	23	6.44	23
60	17	6.72	20	6.47	22	6.45	22
Maximum		7.30	26	7.36	26	7.39	26
Mean		6.79	21	6.76	22	6.77	22
Minimum		6.37	6	6.37	20	6.39	20
Std. Dev.		0.20	3.3	0.22	1.4	0.21	1.4

AASD#2 TEMPERATURE, pH AND ALKALINITY MEASUREMENTS

DAY	DATE	FEED pH	FEED Temp °C	FEED Alk.	FIXED TIME REACTOR pH	FIXED TIME REACTOR Temp °C	FIXED TIME REACTOR Alk.	REAL TIME REACTOR pH	REAL TIME REACTOR Temp °C	REAL TIME REACTOR Alk.
1	Oct/02/90	6.83	20	204	6.54	20	136	6.55	20	140
2	03	6.94	18	194	6.62	20	144	6.44	20	140
3	04	6.75	20	188	6.60	20	166	6.53	20	174
4	05	6.65	18	150	6.69	20	176	6.61	20	166
5	06	6.89	18	180	6.61	21	145	6.50	21	142
6	07	6.84	16	178	6.65	20	155	6.52	20	138
7	08	6.72	15	165	6.62	20	140	6.48	20	140
8	09	6.64	18	136	6.44	20	124	6.45	20	124
9	10	6.72	18	172	6.43	20	124	6.40	20	124
10	11	6.81	18	164	6.42	20	124	6.28	20	110
11	12	6.85	20	180	6.36	20	120	6.38	20	126
12	13	6.77	20	190	6.41	20	134	6.41	20	128
13	14	6.93	15	208	6.43	20	128	6.40	20	130
14	15	6.86	18	220	6.44	20	132	6.46	20	128
15	16	7.01	19	178	6.40	20	142	6.41	20	130
16	17	6.89	18	162	6.42	20	138	6.41	20	136
17	18	6.83	18	220	6.44	20	130	6.45	20	134
18	19	6.67	18	190	6.46	20	128	6.37	20	132
19	20	6.83	14	166	6.45	19	142	6.47	19	138
20	21	6.69	18	152	6.46	20	138	6.46	20	142
21	22	6.64	18	152	6.46	20	140	6.48	20	142
22	23	6.57	15	128	6.46	20	134	6.44	20	134
23	24	6.75	18	160	6.45	20	136	6.46	20	134
24	25	6.74	18	154	6.45	20	128	6.43	20	130
25	26	6.68	20	150	6.40	20	126	6.39	20	128
26	27	6.75	16	138	6.43	20	134	6.73	20	128
27	28	6.59	19	168	6.42	20	124	6.38	20	128
28	29	6.79	17	164	6.41	20	124	6.42	20	128
29	30	6.78	17	148	6.44	20	134	6.40	20	132
30	31	6.76	17	182	6.45	20	138	6.41	20	140
31	Nov/01/90	6.76	16	186	6.48	20	152	6.42	20	142
32	02	6.64	16	192	6.68	20	176	6.88	20	176
33	03	6.74	18	152	6.55	20	154	6.56	20	156
34	04	6.80	18	170	6.53	20	148	6.51	20	148
35	05	7.17	14	256	6.72	20	170	6.65	20	180
36	06	7.01	16	204	6.54	20	144	6.54	20	148
37	07	7.05	18	248	6.58	20	148	6.54	20	148
38	08	7.06	16	220	6.59	20	154	6.56	20	150
39	09	7.07	16	176	6.65	20	154	6.63	20	160
40	10	7.12	15	200	6.66	20	164	6.59	20	158
41	11	----	--	---	6.70	20	166	6.64	20	150
42	12	----	--	---	6.65	21	166	6.62	21	168
43	13	6.93	18	180	6.59	20	158	6.56	20	144
44	14	7.01	16	190	6.62	20	152	6.61	20	150
45	15	7.02	16	196	6.65	20	158	6.60	20	156
46	16	6.98	17	208	6.61	20	152	6.61	20	164
47	17	7.02	18	188	6.66	20	156	6.63	20	156
48	18	7.15	14	192	6.63	20	156	6.60	20	160
49	19	7.04	12	184	6.62	19	150	6.62	19	152
50	20	7.07	15	196	6.66	19	164	6.61	19	160
51	21	7.05	15	186	6.63	18	152	6.63	18	154
52	22	7.18	14	190	6.78	20	154	6.75	20	158
53	23	6.81	16	232	6.67	20	152	6.62	20	162
54	24	7.21	14	218	6.68	18	160	6.67	18	162
55	25	7.37	12	220	6.69	18	158	6.72	18	158
56	26	7.12	15	220	6.72	19	164	6.69	19	162
57	27	7.27	13	238	6.71	19	164	6.72	19	170
58	28	6.95	14	166	6.73	18	164	6.73	18	166
59	29	6.99	13	160	6.98	20	206	6.94	20	218
60	30	6.96	12	218	6.98	18	226	6.98	18	222
Maximum		7.37	20	256	6.78	21	176	6.88	21	180
Mean		6.89	17	185	6.56	20	146	6.54	20	146
Minimum		6.57	12	128	6.36	18	120	6.28	18	110
Std. Dev.		0.18	2	28	0.11	1	15	0.12	1	15

AASD#1 TOTAL COD MEASUREMENTS

DAY	DATE	Total COD (mg/L) FEED	FT RCT	RT RCTR
1	Jun/19/90	6630	3148	3963
2	20	6704	4704	4280
3	21	3370	4417	4481
4	22	7444	3000	3074
5	23	7074	5222	3000
6	24	5963	4481	6333
7	25	10555	5888	5815
8	26	7132	7585	6113
9	27	7585	6642	7699
10	28	9585	7359	7397
11	29	9650	8321	12044
12	30	9172	8620	7628
13	Jul/01/90	8914	12500	5365
14	02	12597	8918	7518
15	03	13775	4776	9234
16	04	10019	7948	5037
17	05	18269	9888	8029
18	06	18343	9179	10949
19	07	19374	8097	10402
20	08	14917	9888	13029
21	09	N/A	N/A	N/A
22	10	N/A	N/A	N/A
23	11	N/A	N/A	N/A
24	12	N/A	N/A	N/A
25	13	N/A	N/A	N/A
26	14	N/A	N/A	N/A
27	15	N/A	N/A	N/A
28	16	N/A	N/A	N/A
29	17	N/A	N/A	N/A
30	18	N/A	N/A	N/A
Maximum		19374	12500	13029
Mean		10354	7029	7070
Minimum		3370	3000	3000
Std. Dev.		4373	2458	2826

AASD#2

Chemical Oxygen Demand Measurents
(mg/L)

DATE	FEED	FT#1	RT#2
Oct/12/90	8176	8257	8457
Nov/9/90	7425	7176	7984
Nov/23/90	8530	6882	6093

APPENDIX F

MASS BALANCES - AASD#1 and AASD#2

Chemical Parameter — Page

AASD#1 TOTAL SUSPENDED SOLIDS MASS BALANCE - FIXED-TIME REACTOR

Moving Average Mass Balance % Removed = 14.70

Overall Mass Balance % Removed = 15.79

Day 1-59	Day 2-60	FD-FT	Day 60-1	Solids Reduced
224582	186451	38131	2659	35472

DAY	FEED MLSS (mg/L)	RCTR#1 MLSS (mg/L)	SUMFEED Day 1-9 X 0.48	SUMRCT1 Day 2-10 X 0.48	(SUMFD- SUMFT)	DELTA RCT (Day10-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 -------- ColD
1	7108	5716						
2	7852	5598						
3	5188	5790						
4	6198	5524						
5	5936	5436						
6	8104	5336						
7	9244	5376						
8	7284	5924						
9	6370	5866						
10	9122	5712	30376	24270	6107	-19	6126	20.2
11	7638	5938	31343	24433	6910	1632	5278	16.8
12	7052	5826	31240	24450	6790	173	6617	21.2
13	6454	6100	32135	24727	7408	2765	4644	14.5
14	6698	5854	32258	24927	7331	2006	5324	16.5
15	6850	5826	32624	25163	7461	2352	5109	15.7
16	6106	5852	32022	25391	6631	2285	4346	13.6
17	8228	5878	30516	25369	5147	-221	5367	17.6
18	9568	5970	30969	25419	5550	499	5051	16.3
19	11866	6278	32504	25691	6813	2717	4096	12.6
20	13550	6724	33821	26068	7753	3773	3980	11.8
21	7216	6980	36659	26622	10037	5539	4498	12.3
22	7286	6818	36737	26966	9771	3446	6324	17.2
23	7656	6774	37137	27408	9729	4416	5313	14.3
24	7308	6752	37596	27852	9744	4445	5299	14.1
25	7624	6666	37816	28243	9573	3907	5666	15.0
26	6902	6702	38545	28639	9906	3955	5951	15.4
27	8034	6568	37908	28926	8983	2870	6112	16.1
28	6530	6530	37172	29047	8125	1210	6916	18.6
29	10540	6604	34611	28989	5622	-576	6198	17.9
30	9318	6960	33166	28980	4187	-96	4283	12.9
31	0	6980	34175	29057	5118	778	4340	12.7
32	0	6800	30678	29070	1608	125	1483	4.8
33	8070	6856	27003	29120	-2117	499	-2616	-9.7
34	11872	6956	31242	29259	1983	1392	591	1.9
35	6514	7416	38980	29602	9378	3427	5951	15.3
36	6858	7172	38794	29892	8902	2899	6003	15.5
37	6618	7006	38229	30120	8109	2285	5824	15.2
38	9594	6954	38271	30288	7983	1680	6303	16.5
39	10068	7028	37817	30321	7497	326	7170	19.0
40	7818	7370	38177	30508	7669	1872	5797	15.2
41	7818	7472	41930	30830	11100	3226	7874	18.8
42	8014	7322	45683	31054	14628	2237	12392	27.1
43	8042	7084	41782	31116	10667	614	10052	24.1
44	8072	7140	34245	30983	3262	-1325	4587	13.4
45	9430	6792	34993	30801	4192	-1824	6016	17.2
46	7964	7052	36228	30823	5405	221	5184	14.3
47	6940	7252	36874	30966	5908	1430	4477	12.1
48	9736	7088	35600	30995	4605	288	4317	12.1
49	7642	7456	35440	31036	4404	413	3992	11.3
50	6114	7216	35356	30913	4443	-1229	5672	16.0
51	7814	6904	34538	30712	3826	-2006	5832	16.9
52	9264	6826	34442	30588	3853	-1238	5092	14.8
53	9592	7082	35028	30561	4468	-278	4746	13.5
54	5950	7278	35758	30794	4964	2333	2631	7.4
55	5464	6960	34088	30750	3338	-442	3780	11.1
56	7696	6756	32888	30512	2376	-2381	4757	14.5
57	6482	6628	33251	30291	2960	-2208	5168	15.5
58	7936	6516	31689	29840	1849	-4512	6361	20.1
59	5726	6646	31830	29566	2264	-2736	5000	15.7
60	6848	6270	31644	29262	2382	-3043	5425	17.1

AASD#1 VOLATILE SUSPENDED SOLIDS MASS BALANCE - FIXED-TIME REACTOR

DAY	FEED MLVSS (mg/L)	RCTR#1 MLVSS (mg/L)	SUMFEED Day 1-9 X 0.48	SUMRCT1 Day 2-10 X 0.48	(SUMFD-SUMFT)	DELTA RCT (Day10-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 / ColD
1	5716	4496						
2	6308	4412	Moving Average Mass Balance % Removed =					16.79
3	4158	4552	Overall Mass Balance % Removed =					17.70
4	4982	4358					Solids	
5	4740	4252	Day 1-59	Day 2-60	FD-FT	Day 60-1	Reduced	
6	6438	4154	177010	144132	32878	1546	31332	
7	7318	4216						
8	5772	4728						
9	5104	4632						
10	7214	4454	24257	19084	5173	-202	5375	22.2
11	6056	4606	24976	19177	5799	931	4868	19.5
12	5550	4510	24855	19157	5699	-202	5900	23.7
13	5084	4704	25524	19323	6201	1661	4540	17.8
14	5186	4506	25572	19445	6128	1219	4908	19.2
15	5366	4490	25787	19606	6180	1613	4568	17.7
16	4798	4508	25272	19746	5526	1402	4124	16.3
17	6442	4522	24062	19647	4415	-989	5404	22.5
18	7516	4602	24384	19633	4751	-144	4895	20.1
19	9486	4864	25542	19830	5712	1968	3744	14.7
20	10794	5204	26632	20117	6516	2870	3645	13.7
21	5736	5416	28907	20552	8355	4349	4006	13.9
22	5772	5298	28996	20837	8159	2851	5308	18.3
23	6144	5272	29326	21204	8122	3677	4445	15.2
24	5756	5236	29786	21563	8223	3581	4643	15.6
25	6078	5192	29973	21891	8082	3283	4799	16.0
26	5472	5202	30588	22217	8370	3264	5106	16.7
27	6342	5088	30122	22451	7671	2333	5339	17.7
28	5170	5046	29558	22538	7020	874	6147	20.8
29	8308	5084	27487	22480	5006	-576	5582	20.3
30	7396	5400	26293	22473	3821	-77	3898	14.8
31	0	5388	27090	22516	4574	432	4142	15.3
32	0	5240	24320	22500	1819	-154	1973	8.1
33	6386	5284	21371	22524	-1153	230	-1383	-6.5
34	9568	5370	24738	22609	2129	854	1275	5.2
35	5228	5718	31006	22857	8149	2477	5673	18.3
36	5462	5428	30889	23020	7869	1632	6237	20.2
37	5230	5406	30467	23193	7274	1728	5546	18.2
38	7602	5380	30495	23335	7161	1421	5740	18.8
39	7864	5424	30156	23346	6810	115	6695	22.2
40	6114	5702	30381	23497	6884	1507	5377	17.7
41	6168	5812	33316	23772	9544	2746	6799	20.4
42	6288	5692	36276	23967	12309	1958	10351	28.5
43	6328	5468	33164	24014	9150	470	8679	26.2
44	6372	5498	27016	23909	3108	-1056	4164	15.4
45	7344	5228	27565	23813	3753	-960	4713	17.1
46	6214	5452	28469	23835	4634	221	4413	15.5
47	5384	5566	28941	23924	5017	893	4124	14.3
48	7608	5418	27876	23921	3955	-29	3984	14.3
49	5912	5732	27754	23936	3818	144	3674	13.2
50	4728	5538	27657	23804	3852	-1315	5168	18.7
51	6008	5274	26965	23604	3362	-2006	5368	19.9
52	7168	5266	26831	23507	3324	-970	4294	16.0
53	7512	5456	27234	23486	3748	-202	3949	14.5
54	4556	5584	27781	23657	4124	1709	2415	8.7
55	4202	5330	26443	23599	2844	-586	3430	13.0
56	5910	5152	25477	23400	2077	-1987	4065	16.0
57	4944	5058	25730	23227	2503	-1728	4231	16.4
58	6114	4994	24451	22873	1578	-3542	5121	20.9
59	4400	5090	24548	22658	1890	-2150	4041	16.5
60	5256	4818	24391	22439	1952	-2189	4140	17.0

AASD#1 NITROGEN MASS BALANCE - FIXED-TIME REACTOR

Moving Average Mass Balance % Removed = 17.47

Overall Mass Balance % Removed = 17.86

Day 1-59	Day 2-60	FD-FT	Day 60-1	Nitrogen Removed
15652	12434	3218	422	2796

DAY	FEED (TKN + NOx) (mg/L)	RCTR#1 (TKN + NOx) (mg/L)	SUMFEED Day 1-9 N In X 0.48	SUMRCT1 Day 2-10 N Out X 0.48	(SUMFD-SUMFT)	DELTA-N RCTR#1 (Day10-1) X 4.8	Nitrogen Lost ColF-G	% N Lost ColH*100 / ColD
1	478.45	346.72						
2	510.75	395.15						
3	334.05	378.19						
4	445.53	366.92						
5	410.45	389.77						
6	552.71	265.08						
7	599.72	358.94						
8	486.17	384.60						
9	409.54	362.22						
10	674.61	386.11	2029	1578	451	189	262	12.9
11	541.78	397.09	2123	1579	545	9	535	25.2
12	515.24	400.51	2138	1589	549	107	442	20.7
13	453.94	413.52	2225	1612	613	224	390	17.5
14	439.24	378.39	2229	1606	623	-55	678	30.4
15	465.84	375.20	2243	1659	584	529	55	2.5
16	445.26	410.81	2201	1684	517	249	268	12.2
17	535.46	407.72	2127	1695	432	111	321	15.1
18	630.32	403.69	2151	1715	436	199	237	11.0
19	807.79	411.31	2257	1727	530	121	409	18.1
20	953.35	448.22	2321	1752	569	245	324	13.9
21	513.17	478.27	2518	1789	729	373	356	14.1
22	525.70	487.54	2517	1825	693	355	337	13.4
23	529.29	467.02	2552	1867	685	425	259	10.2
24	559.91	455.09	2595	1905	690	383	306	11.8
25	570.51	483.14	2640	1940	700	347	353	13.4
26	527.58	466.05	2700	1968	732	280	452	16.7
27	571.85	459.30	2696	1995	702	267	435	16.1
28	497.38	465.57	2668	2021	647	260	387	14.5
29	713.93	430.92	2519	2013	507	-83	590	23.4
30	616.13	459.05	2404	2003	401	-92	493	20.5
31	0.00	453.21	2454	1987	467	-165	632	25.7
32	0.00	476.15	2202	1991	210	44	166	7.6
33	541.24	448.93	1947	1988	-41	-30	-11	-0.6
34	770.23	454.15	2198	1974	224	-139	363	16.5
35	441.39	482.96	2664	1983	681	81	600	22.5
36	442.50	472.40	2623	1989	634	63	571	21.8
37	432.55	465.65	2560	1989	572	0	571	22.3
38	617.39	458.24	2529	2002	527	131	396	15.7
39	684.93	475.05	2483	2010	473	77	397	16.0
40	498.58	474.83	2516	2020	496	104	392	15.6
41	549.81	483.14	2755	2023	732	34	698	25.3
42	547.57	476.67	3019	2037	983	133	849	28.1
43	584.22	478.97	2762	2049	714	119	595	21.5
44	589.22	472.82	2303	2044	260	-49	308	13.4
45	657.31	476.35	2374	2046	329	19	310	13.0
46	587.52	474.15	2478	2050	428	41	387	15.6
47	494.84	465.26	2552	2053	499	34	465	18.2
48	691.52	347.13	2493	1992	501	-614	1115	44.7
49	539.23	494.68	2496	2001	495	95	400	16.0
50	446.95	451.55	2516	1986	530	-152	681	27.1
51	560.54	455.71	2466	1976	490	-101	591	24.0
52	691.56	463.83	2473	1969	504	-73	577	23.3
53	707.20	496.66	2524	1980	544	114	430	17.0
54	435.02	494.19	2581	1989	592	86	506	19.6
55	407.48	476.20	2474	1990	484	10	475	19.2
56	586.68	460.11	2388	1987	400	-25	425	17.8
57	464.32	459.61	2432	2041	391	540	-149	-6.1
58	600.21	444.75	2323	2017	305	-240	545	23.5
59	410.68	450.32	2352	2017	335	-6	341	14.5
60	483.56	434.72	2335	2007	328	-101	429	18.4

AASD#1 PHOSPHORUS MASS BALANCE - FIXED-TIME REACTOR

DAY	FEED TP (mg/L)	RCTR#1 TP (mg/L)	SUMFEED Day 1-9 X 0.48	SUMRCT1 Day 2-10 X 0.48	(SUMFD- SUMFT)	DELTA RCT (Day10-1) *4.8	TOTAL P Lost ColF-G	% P Lost ColH*100 / ColD
1	220	186						
2	241	218	Moving Average Mass Balance % Removed =					-6.48
3	164	211	Overall Mass Balance % Removed =					-6.18
4	214	210					Phosphorus	
5	205	226	Day 1-59	Day 2-60	FD-FT	Day 60-1	Reduced	
6	271	164	8750	8562	189	730	-541	
7	307	216						
8	250	234						
9	216	230						
10	352	261	1002	946	57	360	-303	-30.3
11	294	265	1066	968	97	226	-128	-12.0
12	279	259	1091	991	100	230	-131	-12.0
13	259	277	1146	1023	123	322	-199	-17.3
14	246	260	1168	1040	128	163	-35	-3.0
15	259	258	1188	1085	103	451	-348	-29.3
16	246	263	1182	1107	74	226	-151	-12.8
17	308	269	1152	1124	28	168	-140	-12.1
18	354	270	1180	1143	37	192	-155	-13.1
19	410	259	1247	1142	104	-10	114	9.1
20	472	277	1274	1148	126	58	69	5.4
21	252	297	1360	1166	193	182	11	0.8
22	262	292	1347	1174	173	72	101	7.5
23	261	292	1348	1189	159	154	6	0.4
24	276	286	1356	1202	153	134	19	1.4
25	292	309	1364	1224	139	221	-82	-6.0
26	263	287	1386	1233	153	86	66	4.8
27	301	289	1364	1242	122	91	31	2.3
28	246	292	1339	1258	81	158	-78	-5.8
29	413	311	1260	1274	-14	163	-178	-14.1
30	366	341	1232	1296	-64	211	-275	-22.3
31	0	326	1286	1312	-25	163	-189	-14.7
32	0	354	1161	1342	-181	298	-479	-41.2
33	325	346	1035	1370	-335	288	-623	-60.2
34	445	342	1215	1386	-171	158	-330	-27.1
35	261	385	1502	1433	69	470	-402	-26.7
36	271	344	1501	1460	41	264	-223	-14.8
37	279	344	1487	1485	2	250	-248	-16.7
38	385	334	1502	1496	7	110	-104	-6.9
39	429	343	1489	1497	-8	10	-17	-1.2
40	330	353	1519	1510	10	130	-120	-7.9
41	345	358	1678	1512	166	19	147	8.8
42	320	321	1843	1500	344	-120	464	25.2
43	340	325	1685	1491	193	-82	275	16.3
44	344	329	1421	1464	-44	-269	225	15.8
45	399	329	1461	1457	3	-72	75	5.2
46	361	333	1522	1452	70	-53	123	8.1
47	301	323	1561	1447	115	-53	168	10.7
48	332	328	1521	1440	82	-72	154	10.1
49	332	347	1475	1437	38	-29	67	4.5
50	276	328	1476	1422	53	-144	197	13.4
51	347	329	1442	1426	16	38	-22	-1.5
52	415	332	1455	1429	26	34	-8	-0.5
53	323	348	1491	1439	53	91	-38	-2.6
54	265	359	1481	1453	28	144	-116	-7.8
55	250	355	1417	1464	-47	106	-152	-10.7
56	364	339	1364	1471	-108	77	-184	-13.5
57	294	344	1394	1479	-85	77	-162	-11.6
58	375	332	1376	1472	-96	-72	-24	-1.7
59	253	346	1396	1480	-84	86	-170	-12.2
60	295	338	1385	1485	-99	43	-143	-10.3

AASD#1 TOTAL SUSPENDED SOLIDS MASS BALANCE - REAL-TIME REACTOR

Moving Average Mass Balance % Removed = 15.18

Overall Mass Balance % Removed = 15.74

Day 1-59	Day 2-60	FD-FT	Day 60-1	Solids Reduced
224582	184813	39769	4426	35344

DAY	FEED MLSS (mg/L)	RCTR#2 MLSS (mg/L)	SUMFEED Day 1-9 X 0.48	SUMRCT2 Day 2-10 X 0.48	(SUMFD-SUMRT)	DELTA RCT (Day10-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 / ColD
1	7108	5640						
2	7852	5574						
3	5188	5678						
4	6198	5470						
5	5936	5308						
6	8104	5288						
7	9244	5370						
8	7284	5756						
9	6370	5736						
10	9122	5540	30376	23866	6511	-480	6991	23.0
11	7638	5700	31343	23926	7417	605	6812	21.7
12	7052	6060	31240	24109	7131	1834	5297	17.0
13	6454	6054	32135	24390	7745	2803	4942	15.4
14	6698	5658	32258	24558	7700	1680	6020	18.7
15	6850	6028	32624	24913	7711	3552	4159	12.7
16	6106	5854	32022	25145	6876	2323	4553	14.2
17	8228	5674	30516	25106	5410	-394	5803	19.0
18	9568	5658	30969	25068	5900	-374	6275	20.3
19	11866	6122	32504	25348	7156	2794	4362	13.4
20	13550	6680	33821	25818	8003	4704	3299	9.8
21	7216	7054	36659	26295	10363	4771	5592	15.3
22	7286	6900	36737	26701	10036	4061	5975	16.3
23	7656	6810	37137	27254	9882	5530	4353	11.7
24	7308	6664	37596	27560	10037	3053	6984	18.6
25	7624	6740	37816	27985	9831	4253	5579	14.8
26	6902	6554	38545	28407	10138	4224	5914	15.3
27	8034	6448	37908	28787	9122	3792	5330	14.1
28	6530	6378	37172	28909	8263	1229	7034	18.9
29	10540	6528	34611	28836	5774	-730	6504	18.8
30	9318	6849	33166	28738	4428	-984	5412	16.3
31	0	7040	34175	28805	5370	672	4698	13.7
32	0	6748	30678	28776	1902	-298	2200	7.2
33	8070	6930	27003	28903	-1900	1277	-3177	-11.8
34	11872	6682	31242	28875	2367	-278	2645	8.5
35	6514	7200	38980	29185	9794	3101	6694	17.2
36	6858	7138	38794	29517	9277	3312	5965	15.4
37	6618	6828	38229	29733	8496	2160	6336	16.6
38	9594	6776	38271	29852	8420	1190	7229	18.9
39	10068	6974	37817	29912	7906	600	7306	19.3
40	7818	7404	38177	30086	8091	1747	6344	16.6
41	7818	7328	41930	30365	11565	2784	8781	20.9
42	8014	7274	45683	30530	15153	1651	13501	29.6
43	8042	6896	41782	30633	11149	1027	10122	24.2
44	8072	7186	34245	30626	3619	-67	3686	10.8
45	9430	6862	34993	30493	4500	-1325	5824	16.6
46	7964	7182	36228	30663	5564	1699	3865	10.7
47	6940	7010	36874	30776	6098	1123	4975	13.5
48	9736	6992	35600	30784	4815	86	4729	13.3
49	7642	7218	35440	30695	4745	-893	5638	15.9
50	6114	6856	35356	30468	4887	-2266	7153	20.2
51	7814	6984	34538	30329	4209	-1392	5601	16.2
52	9264	6964	34442	30362	4080	326	3754	10.9
53	9592	7106	35028	30324	4705	-384	5089	14.5
54	5950	7274	35758	30521	5237	1978	3259	9.1
55	5464	6852	34088	30363	3725	-1584	5309	15.6
56	7696	6666	32888	30198	2690	-1651	4341	13.2
57	6482	6774	33251	30093	3157	-1046	4204	12.6
58	7936	6482	31689	29740	1949	-3533	5482	17.3
59	5726	6706	31830	29668	2162	-720	2882	9.1
60	6848	6562	31644	29465	2178	-2026	4204	13.3

AASD#1 VOLATILE SUSPENDED SOLIDS MASS BALANCE - REAL-TIME REACTOR

Moving Average Mass Balance % Removed = 17.99
Overall Mass Balance % Removed = 18.34

Day 1-59	Day 2-60	FD-RT	Day 60-1	Solids Reduced
177010	142019	34991	2525	32466

DAY	FEED MLVSS (mg/L)	RCTR#2 MLVSS (mg/L)	SUMFEED Day 1-9 X 0.48	SUMRCT2 Day 2-10 X 0.48	(SUMFD-SUMRT)	DELTA RCT (Day10-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 / ColD
1	5716	4430						
2	6308	4386						
3	4158	4460						
4	4982	4304						
5	4740	4148						
6	6438	4116						
7	7318	4390						
8	5772	4526						
9	5104	4528						
10	7214	4328	24257	18809	5448	-490	5938	24.5
11	6056	4410	24976	18821	6156	115	6040	24.2
12	5550	4694	24855	18933	5922	1123	4799	19.3
13	5084	4664	25524	19106	6418	1728	4690	18.4
14	5186	4346	25572	19201	6372	950	5421	21.2
15	5366	4645	25787	19455	6332	2539	3792	14.7
16	4798	4498	25272	19507	5765	518	5247	20.8
17	6442	4370	24062	19432	4631	-749	5379	22.4
18	7516	4356	24384	19349	5035	-826	5860	24.0
19	9486	4740	25542	19547	5995	1978	4017	15.7
20	10794	5168	26632	19911	6721	3638	3083	11.6
21	5736	5436	28907	20267	8640	3562	5078	17.6
22	5772	5344	28996	20593	8402	3264	5138	17.7
23	6144	5256	29326	21030	8296	4368	3928	13.4
24	5756	5152	29786	21274	8512	2434	6079	20.4
25	6078	5240	29973	21630	8343	3562	4782	16.0
26	5472	5020	30588	21942	8646	3120	5526	18.1
27	6342	4970	30122	22236	7885	2947	4938	16.4
28	5170	4848	29558	22288	7270	518	6752	22.8
29	8308	5026	27487	22220	5267	-682	5948	21.6
30	7396	5288	26293	22149	4144	-710	4855	18.5
31	0	5420	27090	22186	4905	365	4540	16.8
32	0	5178	24320	22148	2172	-374	2546	10.5
33	6386	5308	21371	22223	-852	749	-1601	-7.5
34	9568	5124	24738	22167	2571	-557	3128	12.6
35	5228	5500	31006	22398	8608	2304	6304	20.3
36	5462	5478	30889	22642	8247	2438	5809	18.8
37	5230	5232	30467	22826	7641	1843	5797	19.0
38	7602	5196	30495	22908	7588	816	6772	22.2
39	7864	5340	30156	22932	7224	250	6974	23.1
40	6114	5712	30381	23073	7308	1402	5907	19.4
41	6168	5640	33316	23294	10021	2218	7804	23.4
42	6288	5612	36276	23440	12836	1459	11377	31.4
43	6328	5290	33164	23520	9644	797	8847	26.7
44	6372	5502	27016	23521	3495	10	3486	12.9
45	7344	5254	27565	23413	4152	-1075	5227	19.0
46	6214	5498	28469	23541	4928	1277	3651	12.8
47	5384	5320	28941	23601	5340	595	4745	16.4
48	7608	5306	27876	23584	4292	-163	4455	16.0
49	5912	5498	27754	23482	4272	-1027	5299	19.1
50	4728	5200	27657	23270	4386	-2112	6498	23.5
51	6008	5326	26965	23133	3832	-1373	5205	19.3
52	7168	5282	26831	23129	3702	-38	3740	13.9
53	7512	5388	27234	23075	4160	-547	4707	17.3
54	4556	5560	27781	23221	4560	1469	3091	11.1
55	4202	5170	26443	23064	3379	-1574	4954	18.7
56	5910	4984	25477	22903	2575	-1613	4188	16.4
57	4944	5064	25730	22787	2943	-1162	4105	16.0
58	6114	4870	24451	22485	1966	-3014	4980	20.4
59	4400	5008	24548	22393	2155	-922	3077	12.5
60	5256	4956	24391	22215	2175	-1776	3951	16.2

AASD#1 NITROGEN MASS BALANCE - REAL-TIME REACTOR

Moving Average Mass Balance % Removed = 19.51

Overall Mass Balance % Removed = 21.07

Day 1-59	Day 2-60	FD-RT	Day 60-1	Nitrogen Removed
15652	12199	3452	154	3298

DAY	FEED (TKN + NOx) (mg/L)	RCTR#2 (TKN + NOx) (mg/L)	SUMFEED Day 1-9 N In X 0.48	SUMRCT2 Day 2-10 N Out X 0.48	(SUMFD-SUMRT)	DELTA-N RCTR#2 (Day10-1) X 4.8	Nitrogen Lost ColF-G	% N Lost ColH*100 -------- ColD
1	478.45	360.74						
2	510.75	368.83						
3	334.05	402.55						
4	445.53	323.14						
5	410.45	352.74						
6	552.71	348.22						
7	599.72	352.27						
8	486.17	369.80						
9	409.54	360.00						
10	674.61	404.11	2029	1575	454	208	246	12.1
11	541.78	403.88	2123	1592	531	168	363	17.1
12	515.24	389.38	2138	1586	552	-63	616	28.8
13	453.94	404.78	2225	1625	600	392	208	9.4
14	439.24	415.12	2229	1655	574	299	275	12.3
15	465.84	415.85	2243	1687	556	325	231	10.3
16	445.26	378.03	2201	1700	502	124	378	17.2
17	535.46	348.59	2127	1689	438	-102	540	25.4
18	630.32	341.65	2151	1681	470	-88	558	26.0
19	807.79	396.03	2257	1677	580	-39	619	27.4
20	953.35	430.38	2321	1690	631	127	504	21.7
21	513.17	467.50	2518	1727	791	375	416	16.5
22	525.70	439.50	2517	1744	774	167	607	24.1
23	529.29	474.50	2552	1772	780	285	495	19.4
24	559.91	461.74	2595	1794	801	220	580	22.4
25	570.51	441.68	2640	1825	815	306	510	19.3
26	527.58	425.45	2700	1862	839	369	470	17.4
27	571.85	452.78	2696	1915	781	533	248	9.2
28	497.38	426.30	2668	1930	739	145	594	22.2
29	713.93	409.43	2519	1919	600	-101	700	27.8
30	616.13	440.15	2404	1906	498	-131	629	26.2
31	0.00	451.59	2454	1912	542	58	484	19.7
32	0.00	489.76	2202	1919	282	73	209	9.5
33	541.24	448.22	1947	1913	35	-65	99	5.1
34	770.23	446.12	2198	1915	283	21	262	11.9
35	441.39	478.17	2664	1940	723	253	470	17.7
36	442.50	478.18	2623	1953	670	122	548	20.9
37	432.55	423.81	2560	1951	609	-12	621	24.3
38	617.39	457.17	2529	1974	555	229	326	12.9
39	684.93	472.77	2483	1990	493	157	336	13.5
40	498.58	502.18	2516	2014	502	243	259	10.3
41	549.81	493.03	2755	2016	740	16	724	26.3
42	547.57	464.01	3019	2023	996	76	920	30.5
43	584.22	436.00	2762	2019	744	-49	793	28.7
44	589.22	452.12	2303	2006	297	-125	422	18.3
45	657.31	465.59	2374	2000	374	-60	435	18.3
46	587.52	473.04	2478	2024	454	236	218	8.8
47	494.84	484.60	2552	2037	515	132	383	15.0
48	691.52	476.98	2493	2039	454	20	434	17.4
49	539.23	466.34	2496	2022	475	-172	647	25.9
50	446.95	474.22	2516	2013	503	-90	593	23.6
51	560.54	432.39	2466	1997	469	-152	621	25.2
52	691.56	451.31	2473	2005	468	73	394	16.0
53	707.20	443.20	2524	2000	524	-43	567	22.4
54	435.02	497.54	2581	2016	565	153	412	15.9
55	407.48	450.36	2474	2005	469	-109	578	23.4
56	586.68	451.32	2388	1989	399	-160	558	23.4
57	464.32	433.75	2432	1968	464	-208	671	27.6
58	600.21	449.91	2323	1960	362	-79	441	19.0
59	410.68	434.55	2352	1941	411	-190	601	25.6
60	483.56	392.90	2335	1922	412	-190	602	25.8

AASD#1 PHOSPHORUS MASS BALANCE - REAL-TIME REACTOR

DAY	FEED TP (mg/L)	RCTR#2 TP (mg/L)	SUMFEED Day 1-9 X 0.48	SUMRCT2 Day 2-10 X 0.48	(SUMFD-SUMRT)	DELTA RCT (Day10-1) *4.8	TOTAL P Lost ColF-G	% P Lost ColH*100 / ColD
1	220	199						
2	241	205	Moving Average Mass Balance % Removed =					-6.90
3	164	225	Overall Mass Balance % Removed =					-5.83
4	214	199					Phosphorus	
5	205	216	Day 1-59	Day 2-60	FD-RT	Day 60-1	Reduced	
6	271	215	8750	8617	133	643	-510	
7	307	219						
8	250	231						
9	216	230						
10	352	256	1002	958	44	274	-229	-22.9
11	294	251	1066	980	85	221	-135	-12.7
12	279	247	1091	991	100	106	-5	-0.5
13	259	264	1146	1022	124	312	-188	-16.4
14	246	254	1168	1040	128	182	-55	-4.7
15	259	258	1188	1061	127	206	-80	-6.7
16	246	275	1182	1088	94	269	-175	-14.8
17	308	255	1152	1099	53	115	-62	-5.4
18	354	252	1180	1110	71	106	-35	-3.0
19	410	254	1247	1109	138	-10	147	11.8
20	472	265	1274	1116	159	67	92	7.2
21	252	289	1360	1136	224	202	23	1.7
22	262	279	1347	1143	204	72	132	9.8
23	261	298	1348	1164	184	211	-27	-2.0
24	276	293	1356	1181	175	168	7	0.5
25	292	280	1364	1183	180	24	156	11.5
26	263	274	1386	1192	193	91	102	7.4
27	301	288	1364	1210	155	173	-18	-1.3
28	246	271	1339	1218	121	82	39	2.9
29	413	326	1260	1247	13	293	-280	-22.2
30	366	341	1232	1272	-40	250	-290	-23.5
31	0	346	1286	1304	-18	322	-339	-26.4
32	0	370	1161	1339	-178	346	-524	-45.1
33	325	373	1035	1377	-342	384	-726	-70.1
34	445	359	1215	1415	-200	379	-579	-47.7
35	261	369	1502	1461	41	456	-415	-27.6
36	271	361	1501	1496	5	350	-345	-23.0
37	279	331	1487	1524	-38	288	-326	-21.9
38	385	351	1502	1536	-34	120	-154	-10.3
39	429	350	1489	1541	-52	43	-95	-6.4
40	330	376	1519	1555	-36	144	-180	-11.8
41	345	385	1678	1562	115	72	43	2.6
42	320	320	1843	1537	306	-254	561	30.4
43	340	309	1685	1513	172	-240	412	24.4
44	344	320	1421	1489	-69	-235	167	11.7
45	399	334	1461	1476	-16	-130	114	7.8
46	361	338	1522	1480	42	34	9	0.6
47	301	338	1561	1474	88	-62	150	9.6
48	332	351	1521	1474	47	5	42	2.8
49	332	341	1475	1457	17	-168	185	12.6
50	276	350	1476	1440	35	-168	203	13.8
51	347	328	1442	1444	-2	38	-40	-2.8
52	415	343	1455	1461	-5	163	-168	-11.6
53	323	333	1491	1467	24	62	-38	-2.5
54	265	364	1481	1481	0	144	-144	-9.7
55	250	349	1417	1487	-70	53	-122	-8.6
56	364	349	1364	1492	-128	53	-181	-13.3
57	294	363	1394	1498	-104	58	-161	-11.6
58	375	361	1376	1507	-132	96	-228	-16.5
59	253	348	1396	1506	-110	-10	-100	-7.2
60	295	333	1385	1509	-123	24	-147	-10.6

AASD#2 TOTAL SUSPENDED SOLIDS MASS BALANCE - FIXED-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = 14.14

Overall Mass Balance % Removed = 14.77

Day 1-57	Day 2-58	(FD-FT)	Day 58-1	Solids Reduced
90746	82550	8196	-5203	13399

DAY	FEED MLSS (mg/L)	RCTR#1 MLSS (mg/L)	SUMFEED Day1-19 X 0.24	SUMRCT1 Day 2-20 X 0.24	(SUMFD- SUMFT)	DELTA RCT (Day20-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 / ColD
1	10610	6332						
2	9596	6678						
3	4040	6772						
4	5986	6468						
5	5384	6554						
6	5914	6340						
7	6078	6324						
8	7454	6242						
9	10356	6266						
10	9210	6374						
11	6074	6654						
12	7854	6382						
13	9562	6470						
14	5190	6502						
15	6380	6366						
16	4924	6394						
17	8634	6148						
18	7826	6046						
19	5962	6248						
20	6436	6196	32888	29142	3746	-653	4399	13.4
21	7298	6168	31886	29019	2867	-2448	5315	16.7
22	6292	6194	31335	28881	2454	-2774	5229	16.7
23	7512	6254	31875	28829	3046	-1027	4073	12.8
24	6574	6154	32242	28733	3508	-1920	5428	16.8
25	6114	6146	32527	28687	3840	-931	4772	14.7
26	5586	6212	32575	28660	3915	-538	4453	13.7
27	7400	5988	32457	28599	3858	-1219	5077	15.6
28	7242	6066	32444	28551	3893	-960	4853	15.0
29	5632	6064	31697	28476	3220	-1488	4708	14.9
30	8450	6034	30838	28328	2510	-2976	5486	17.8
31	6836	6006	31408	28237	3171	-1805	4976	15.8
32	6182	6104	31164	28150	3014	-1757	4771	15.3
33	5522	5972	30353	28022	2330	-2544	4874	16.1
34	6160	5916	30432	27914	2518	-2160	4678	15.4
35	7442	5856	30380	27785	2594	-2582	5177	17.0
36	6982	5970	30984	27743	3241	-854	4096	13.2
37	6798	5916	30588	27711	2876	-624	3500	11.4
38	6868	6078	30341	27671	2670	-816	3486	11.5
39	5170	6038	30558	27633	2926	-758	3684	12.1
40	5974	5890	30254	27566	2688	-1334	4023	13.3
41	0	5932	29937	27503	2434	-1258	3691	12.3
42	0	5946	28427	27429	997	-1478	2476	8.7
43	6870	5830	26624	27351	-728	-1555	828	3.1
44	6630	6026	28344	27323	1021	-576	1597	5.6
45	6016	5984	30059	27268	2791	-1094	3885	12.9
46	6256	5814	30162	27226	2936	-835	3771	12.5
47	6086	5842	29887	27172	2715	-1075	3790	12.7
48	5472	5650	29610	27073	2537	-1987	4524	15.3
49	6000	5738	29571	27002	2569	-1421	3990	13.5
50	5498	5760	28983	26943	2040	-1181	3221	11.1
51	5604	5760	28662	26860	1802	-1651	3453	12.0
52	5438	5588	28524	26768	1755	-1843	3599	12.6
53	6632	5288	28503	26617	1886	-3014	4900	17.2
54	6082	5330	28617	26491	2125	-2525	4650	16.3
55	5524	5368	28290	26347	1944	-2890	4833	17.1
56	5436	5196	27940	26174	1766	-3456	5222	18.7
57	5560	5208	27613	25965	1648	-4176	5824	21.1
58	4714	5248	27300	25776	1524	-3792	5316	19.5
59	4300	5036	27190	25571	1620	-4099	5719	21.0
60	6118	4904	26788	25324	1464	-4934	6399	23.9

AASD#2 VOLATILE SUSPENDED SOLIDS MASS BALANCE - FIXED-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = 16.08
Overall Mass Balance % Removed = 16.71

Day 1-57	Day 2-58	(FD-FT)	Day 58-1	Solids Reduced
74452	65968	8484	-3955	12439

DAY	FEED MLVSS (mg/L)	RCTR#1 MLVSS (mg/L)	SUMFEED Day1-19 X 0.24	SUMRCT1 Day 2-20 X 0.24	(SUMFD-SUMFT)	DELTA RCT (Day20-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 / ColD
1	8466	5032						
2	7818	5316						
3	3362	5350						
4	4922	5148						
5	4438	5204						
6	4832	5032						
7	4958	4966						
8	6092	4912						
9	8442	4930						
10	7510	5060						
11	4984	5268						
12	6476	5096						
13	7898	5162						
14	4326	5176						
15	5282	5092						
16	4120	5132						
17	7150	4934						
18	6462	4830						
19	4902	4978						
20	5286	4952	26986	23169	3816	-384	4200	15.6
21	6028	4956	26222	23083	3140	-1728	4868	18.6
22	5212	4982	25793	22994	2798	-1766	4565	17.7
23	6176	5018	26237	22963	3274	-624	3898	14.9
24	5436	4954	26538	22903	3635	-1200	4835	18.2
25	5016	4906	26777	22873	3904	-605	4509	16.8
26	4540	4988	26821	22878	3943	106	3838	14.3
27	6038	4784	26721	22848	3874	-614	4488	16.8
28	5874	4852	26708	22829	3879	-374	4254	15.9
29	4590	4850	26092	22778	3313	-1008	4321	16.6
30	6948	4846	25391	22677	2714	-2026	4740	18.7
31	5578	4802	25862	22607	3256	-1411	4667	18.0
32	5154	4910	25647	22546	3101	-1210	4310	16.8
33	4560	4772	24988	22449	2539	-1939	4478	17.9
34	5060	4722	25044	22360	2684	-1776	4460	17.8
35	6160	4676	24991	22251	2740	-2189	4929	19.7
36	5828	4802	25481	22219	3262	-634	3895	15.3
37	5650	4760	25164	22202	2961	-336	3297	13.1
38	5664	4864	24969	22175	2794	-547	3341	13.4
39	4278	4850	25152	22151	3001	-490	3491	13.9
40	4928	4716	24910	22093	2817	-1152	3969	15.9
41	0	4762	24646	22040	2605	-1056	3661	14.9
42	0	4764	23395	21979	1416	-1219	2635	11.3
43	5630	4680	21912	21913	-1	-1315	1314	6.0
44	5434	4834	23310	21896	1414	-346	1760	7.5
45	4918	4796	24715	21850	2865	-922	3786	15.3
46	5130	4664	24805	21821	2984	-576	3560	14.4
47	4972	4682	24588	21780	2807	-816	3623	14.7
48	4446	4562	24371	21711	2660	-1382	4042	16.6
49	4880	4581	24336	21648	2689	-1272	3961	16.3
50	4500	4624	23840	21605	2235	-854	3090	13.0
51	4570	4612	23581	21534	2048	-1430	3478	14.8
52	4438	4492	23441	21466	1975	-1344	3319	14.2
53	5434	4238	23412	21350	2062	-2323	4385	18.7
54	4920	4266	23502	21252	2250	-1968	4218	17.9
55	4480	4284	23204	21127	2077	-2486	4563	19.7
56	4402	4122	22881	20974	1906	-3062	4969	21.7
57	4554	4146	22581	20802	1779	-3446	5226	23.1
58	3930	4208	22315	20648	1667	-3082	4748	21.3
59	3606	4074	22231	20494	1737	-3082	4819	21.7
60	5148	4042	21914	20321	1593	-3456	5049	23.0

AASD#2 NITROGEN MASS BALANCE - FIXED-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = 17.67

Overall Mass Balance % Removed = 19.43

Day 1-57	Day 2-58	(FD-FT)	Day 58-1	Nitrogen Removed
6688	6035	653	-646	1299

DAY	FEED (NOx + NOx) (mg/L)	RCTR#1 (TKN + NOx) (mg/L)	SUMFEED Day1-19 N In X 0.24	SUMRCT1 Day 2-20 N Out X 0.24	(SUMFD-SUMFT)	DELTA-N RCTR#1 (Day20-1) X 4.8	Nitrogen Lost ColF-G	% N Lost ColH*100 / ColD
1	652.90	510.83						
2	735.48	503.15						
3	536.08	523.23						
4	437.18	529.10						
5	401.10	513.20						
6	395.92	487.96						
7	438.49	482.18						
8	294.20	487.66						
9	647.48	461.16						
10	713.72	480.82						
11	464.09	455.41						
12	563.69	448.40						
13	688.07	470.66						
14	397.14	451.10						
15	475.21	496.71						
16	355.23	452.85						
17	616.35	445.78						
18	552.07	468.38						
19	408.69	466.24						
20	446.18	454.36	2346	2179	167	-271	438	18.7
21	511.16	438.93	2296	2163	133	-308	441	19.2
22	426.18	446.17	2242	2145	97	-370	467	20.8
23	554.24	455.38	2216	2127	89	-354	442	20.0
24	508.10	462.14	2244	2115	129	-245	374	16.7
25	453.41	461.04	2269	2108	161	-129	290	12.8
26	414.25	445.51	2283	2100	184	-176	360	15.7
27	559.24	444.69	2277	2089	188	-206	394	17.3
28	520.34	429.60	2341	2082	259	-151	411	17.5
29	423.16	448.20	2311	2074	237	-157	393	17.0
30	631.57	447.13	2241	2072	169	-40	209	9.3
31	533.57	435.61	2281	2069	212	-61	274	12.0
32	472.31	457.62	2274	2066	208	-63	271	11.9
33	423.23	452.27	2222	2066	156	6	150	6.8
34	450.30	422.66	2228	2048	180	-355	535	24.0
35	556.24	440.09	2222	2045	177	-61	238	10.7
36	513.26	450.05	2271	2046	224	20	204	9.0
37	510.30	452.84	2246	2043	203	-75	278	12.4
38	486.30	437.70	2236	2036	200	-137	337	15.1
39	400.74	425.89	2254	2029	226	-137	362	16.1
40	457.39	438.17	2243	2029	215	-4	218	9.7
41	0.00	430.19	2231	2025	206	-77	282	12.7
42	0.00	403.25	2128	2012	116	-250	366	17.2
43	517.22	407.05	1995	1999	-4	-264	261	13.1
44	510.36	433.15	2122	1992	129	-134	263	12.4
45	453.57	402.70	2258	1982	276	-205	481	21.3
46	465.25	408.36	2267	1973	294	-174	468	20.7
47	470.04	399.45	2245	1966	278	-145	423	18.9
48	422.56	410.46	2233	1957	275	-181	457	20.5
49	456.62	410.70	2232	1948	284	-175	459	20.6
50	402.42	411.99	2190	1943	248	-113	361	16.5
51	436.65	403.09	2159	1930	229	-262	491	22.7
52	408.88	401.48	2150	1917	233	-244	477	22.2
53	509.15	392.33	2147	1910	237	-146	382	17.8
54	475.21	367.24	2161	1893	268	-350	618	28.6
55	436.35	387.64	2142	1878	264	-300	564	26.3
56	422.65	377.67	2123	1860	264	-361	624	29.4
57	429.37	353.75	2102	1839	263	-403	666	31.7
58	333.27	376.23	2088	1828	261	-238	499	23.9
59	316.31	361.19	2072	1809	263	-370	633	30.5
60	429.21	372.28	2038	1795	243	-278	521	25.6

AASD#2 PHOSPHORUS MASS BALANCE - FIXED-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = -7.50
Overall Mass Balance % Removed = -9.83

Day 1-57	Day 2-58	(FD-FT)	Day 58-1	Phosphorus Removed
2999	3553	-554	-259	-295

DAY	FEED TP (mg/L)	RCTR#1 TP (mg/L)	SUMFEED Day1-19 P In X 0.24	SUMRCT1 Day 2-20 P Out X 0.24	(SUMFD-SUMFT)	DELTA-P RCTR#1 (Day20-1) X 4.8	Total P Lost ColF-G	% P Lost ColH*100 / ColD
1	287	297						
2	322	301						
3	237	306						
4	191	306						
5	177	297						
6	175	287						
7	199	290						
8	134	289						
9	330	279						
10	425	292						
11	201	278						
12	245	281						
13	301	289						
14	165	278						
15	203	296						
16	151	273						
17	264	273						
18	243	287						
19	184	279						
20	206	274	1064	1309	-245	-110	-135	-12.7
21	225	267	1045	1301	-256	-163	-93	-8.9
22	193	270	1021	1292	-271	-173	-98	-9.6
23	242	275	1011	1285	-274	-149	-125	-12.4
24	222	281	1023	1281	-258	-77	-181	-17.7
25	202	267	1034	1276	-242	-96	-146	-14.2
26	185	271	1040	1272	-231	-91	-140	-13.5
27	256	271	1037	1267	-230	-86	-144	-13.9
28	242	263	1066	1264	-197	-77	-120	-11.3
29	198	274	1045	1259	-214	-86	-128	-12.2
30	297	272	991	1258	-267	-29	-238	-24.1
31	241	216	1014	1242	-228	-312	84	8.2
32	210	230	1013	1228	-215	-283	68	6.7
33	186	227	991	1216	-225	-245	20	2.0
34	202	220	996	1198	-202	-365	163	16.4
35	238	226	996	1186	-191	-226	35	3.5
36	223	228	1017	1176	-159	-216	57	5.6
37	221	231	1007	1162	-155	-269	114	11.3
38	210	223	1002	1149	-147	-269	122	12.1
39	169	218	1008	1135	-127	-269	141	14.0
40	193	223	999	1125	-126	-211	85	8.6
41	0	248	991	1119	-128	-106	-23	-2.3
42	0	244	945	1112	-167	-149	-18	-1.9
43	224	245	887	1103	-216	-173	-44	-4.9
44	222	254	941	1100	-159	-62	-97	-10.3
45	200	242	999	1093	-94	-139	45	4.5
46	208	244	1003	1087	-84	-130	46	4.5
47	204	240	991	1081	-90	-110	20	2.1
48	185	240	982	1073	-91	-163	72	7.4
49	201	245	979	1067	-88	-130	42	4.3
50	180	245	956	1074	-118	139	-257	-26.9
51	198	248	941	1078	-137	86	-223	-23.7
52	187	246	938	1082	-144	91	-235	-25.1
53	237	248	939	1089	-150	134	-285	-30.4
54	223	241	947	1093	-146	72	-218	-23.0
55	205	245	943	1097	-153	82	-235	-24.9
56	196	243	939	1100	-161	58	-218	-23.2
57	185	235	933	1103	-169	58	-227	-24.3
58	134	243	927	1109	-181	120	-301	-32.5
59	116	231	919	1110	-192	38	-230	-25.1
60	152	231	900	1106	-206	-82	-125	-13.8

AASD#2 ALKALINITY MASS BALANCE - FIXED-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = 13.82
Overall Mass Balance % Removed = 15.49

Day 1-57	Day 2-58	(FD-FT)	Day 58-1	Alkalinity Removed
2533	2006	527	134	392

DAY	FEED ALK (mg/L)	RCTR#1 ALK (mg/L)	SUMFEED Day1-19 ALK In X 0.24	SUMRCT1 Day 2-20 ALK Out X 0.24	(SUMFD-SUMFT)	DELTA-A RCTR#1 (Day20-1) X 4.8	ALK Lost ColF-G	% ALK Lost ColH*100 / ColD
1	204	136						
2	194	144						
3	188	166						
4	150	176						
5	180	145						
6	178	155						
7	165	140						
8	136	124						
9	172	124						
10	164	124						
11	180	120						
12	190	134						
13	208	128						
14	220	132						
15	178	142						
16	162	138						
17	220	130						
18	190	128						
19	166	142						
20	152	138	827	631	196	10	186	22.5
21	152	140	814	630	184	-19	203	25.0
22	128	134	804	623	182	-154	335	41.7
23	160	136	790	613	177	-192	369	46.7
24	154	128	792	609	183	-82	265	33.4
25	150	126	786	602	184	-139	323	41.1
26	138	134	779	600	179	-29	208	26.6
27	168	124	773	600	172	0	172	22.3
28	164	124	780	600	180	0	180	23.1
29	148	134	779	603	176	48	128	16.4
30	182	138	775	607	168	86	81	10.5
31	186	152	775	612	164	86	77	10.0
32	192	176	774	623	151	230	-79	-10.2
33	152	154	770	628	142	106	36	4.7
34	170	148	754	630	124	29	96	12.7
35	256	170	752	637	115	154	-39	-5.2
36	204	144	775	641	134	67	67	8.6
37	248	148	771	646	125	96	29	3.8
38	220	154	785	648	136	58	79	10.0
39	176	154	798	652	145	77	69	8.6
40	200	164	804	658	145	115	30	3.8
41	0	166	815	666	149	154	-4	-0.5
42	0	166	784	673	111	144	-33	-4.2
43	180	158	746	680	66	144	-78	-10.5
44	190	152	795	686	109	125	-16	-2.0
45	196	158	851	692	158	115	43	5.1
46	208	152	864	699	166	134	31	3.6
47	188	156	874	707	168	154	14	1.6
48	192	156	880	712	168	106	62	7.1
49	184	150	890	715	176	58	118	13.3
50	196	164	891	718	173	58	116	13.0
51	186	152	893	712	181	-115	297	33.2
52	190	154	892	712	180	0	180	20.2
53	232	152	901	713	188	19	169	18.8
54	218	160	916	710	205	-48	253	27.7
55	220	158	907	714	193	67	126	13.9
56	220	164	911	718	193	77	116	12.8
57	238	164	904	720	184	48	136	15.0
58	166	164	908	722	186	48	138	15.2
59	160	206	906	732	173	202	-28	-3.1
60	218	226	896	747	149	288	-139	-15.5

AASD#2 TOTAL SUSPENDED SOLIDS MASS BALANCE - REAL-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = 18.49

Overall Mass Balance % Removed = 19.87

	Day 1-57	Day 2-58	(FD-RT)	Day 58-1	Solids Reduced
	90746	80948	9798	-8237	18034

DAY	FEED MLSS (mg/L)	RCTR#2 MLSS (mg/L)	SUMFEED Day1-19 X 0.24	SUMRCT2 Day 2-20 X 0.24	(SUMFD-SUMRT)	DELTA RCT (Day20-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 / ColD
1	10610	6658						
2	9596	6820						
3	4040	6768						
4	5986	6580						
5	5384	6558						
6	5914	6374						
7	6078	6222						
8	7454	6132						
9	10356	6208						
10	9210	6402						
11	6074	6612						
12	7854	6488						
13	9562	6392						
14	5190	6660						
15	6380	6404						
16	4924	6414						
17	8634	6150						
18	7826	6338						
19	5962	6290						
20	6436	6250	32888	29295	3593	-1958	5552	16.9
21	7298	6204	31886	29147	2739	-2957	5696	17.9
22	6292	6304	31335	29036	2299	-2227	4526	14.4
23	7512	6222	31875	28950	2926	-1718	4644	14.6
24	6574	6136	32242	28848	3393	-2026	5419	16.8
25	6114	5856	32527	28724	3803	-2486	6289	19.3
26	5586	5964	32575	28662	3913	-1238	5151	15.8
27	7400	5832	32457	28590	3867	-1440	5307	16.4
28	7242	5806	32444	28494	3950	-1930	5880	18.1
29	5632	5962	31697	28388	3309	-2112	5421	17.1
30	8450	5824	30838	28199	2639	-3782	6421	20.8
31	6836	5938	31408	28067	3341	-2640	5981	19.0
32	6182	5860	31164	27939	3225	-2554	5778	18.5
33	5522	5934	30353	27765	2588	-3485	6072	20.0
34	6160	5910	30432	27647	2786	-2371	5157	16.9
35	7442	5794	30380	27498	2882	-2976	5858	19.3
36	6982	5818	30984	27418	3566	-1594	5160	16.7
37	6798	5812	30588	27292	3296	-2525	5820	19.0
38	6868	5866	30341	27190	3151	-2035	5186	17.1
39	5170	5768	30558	27074	3484	-2314	5797	19.0
40	5974	5678	30254	26948	3306	-2525	5831	19.3
41	0	5630	29937	26786	3150	-3235	6385	21.3
42	0	5592	28427	26635	1791	-3024	4815	16.9
43	6870	5448	26624	26470	154	-3302	3456	13.0
44	6630	5574	28344	26402	1941	-1354	3295	11.6
45	6016	5510	30059	26293	3765	-2179	5944	19.8
46	6256	5651	30162	26250	3912	-869	4781	15.8
47	6086	5514	29887	26180	3707	-1402	5109	17.1
48	5472	5442	29610	26055	3555	-2496	6051	20.4
49	6000	5406	29571	25955	3617	-2006	5623	19.0
50	5498	5530	28983	25857	3126	-1958	5085	17.5
51	5604	5454	28662	25759	2903	-1949	4852	16.9
52	5438	5464	28524	25647	2877	-2256	5133	18.0
53	6632	5068	28503	25445	3059	-4042	7100	24.9
54	6082	5152	28617	25290	3326	-3082	6408	22.4
55	5524	5192	28290	25140	3150	-3005	6155	21.8
56	5436	5068	27940	24962	2979	-3571	6550	23.4
57	5560	5098	27613	24777	2836	-3686	6522	23.6
58	4714	4942	27300	24579	2720	-3965	6685	24.5
59	4300	4976	27190	24411	2779	-3370	6149	22.6
60	6118	4762	26788	24202	2586	-4166	6752	25.2

AASD#2 VOLATILE SUSPENDED SOLIDS MASS BALANCE - REAL-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = 20.16

Overall Mass Balance % Removed = 21.50

Day 1-57	Day 2-58	(FD-RT)	Day 58-1	Solids Reduced
74452	64822	9630	-6374	16004

DAY	FEED MLVSS (mg/L)	RCTR#2 MLVSS (mg/L)	SUMFEED Day1-19 X 0.24	SUMRCT2 Day 2-20 X 0.24	(SUMFD-SUMRT)	DELTA RCT (Day20-1) *4.8	SOLIDS RED ColF-G	% SOLIDS REDUCED ColH*100 / ColD
1	8466	5282						
2	7818	5442						
3	3362	5392						
4	4922	5238						
5	4438	5224						
6	4832	5072						
7	4958	4920						
8	6092	4824						
9	8442	4904						
10	7510	5092						
11	4984	5260						
12	6476	5178						
13	7898	5100						
14	4326	5334						
15	5282	5122						
16	4120	5156						
17	7150	4950						
18	6462	5068						
19	4902	5036						
20	5286	4990	26986	23352	3633	-1402	5035	18.7
21	6028	4992	26222	23244	2978	-2160	5138	19.6
22	5212	5086	25793	23171	2622	-1469	4091	15.9
23	6176	5024	26237	23120	3117	-1027	4144	15.8
24	5436	4932	26538	23050	3488	-1402	4890	18.4
25	5016	4706	26777	22962	3816	-1757	5572	20.8
26	4540	4792	26821	22931	3890	-614	4505	16.8
27	6038	4674	26721	22895	3826	-720	4546	17.0
28	5874	4645	26708	22833	3875	-1243	5118	19.2
29	4590	4770	26092	22756	3336	-1546	4882	18.7
30	6948	4680	25391	22616	2775	-2784	5559	21.9
31	5578	4750	25862	22514	3349	-2054	5403	20.9
32	5154	4708	25647	22420	3227	-1882	5109	19.9
33	4560	4734	24988	22276	2713	-2880	5593	22.4
34	5060	4714	25044	22178	2867	-1958	4825	19.3
35	6160	4626	24991	22050	2941	-2544	5485	21.9
36	5828	4678	25481	21985	3496	-1306	4801	18.8
37	5650	4672	25164	21890	3273	-1901	5174	20.6
38	5664	4708	24969	21811	3157	-1574	4732	19.0
39	4278	4628	25152	21725	3427	-1738	5165	20.5
40	4928	4552	24910	21619	3291	-2112	5403	21.7
41	0	4518	24646	21483	3163	-2726	5889	23.9
42	0	4474	23395	21351	2044	-2640	4684	20.0
43	5630	4384	21912	21219	693	-2630	3324	15.2
44	5434	4486	23310	21166	2144	-1056	3200	13.7
45	4918	4538	24715	21105	3609	-1219	4829	19.5
46	5130	4567	24805	21080	3726	-514	4239	17.1
47	4972	4430	24588	21028	3559	-1032	4591	18.7
48	4446	4362	24371	20930	3441	-1958	5399	22.2
49	4880	4332	24336	20847	3490	-1670	5160	21.2
50	4500	4444	23840	20773	3067	-1469	4536	19.0
51	4570	4390	23581	20697	2885	-1526	4411	18.7
52	4438	4398	23441	20616	2825	-1613	4438	18.9
53	5434	4068	23412	20461	2951	-3101	6052	25.8
54	4920	4126	23502	20341	3161	-2400	5561	23.7
55	4480	4154	23204	20215	2989	-2515	5504	23.7
56	4402	4034	22881	20062	2818	-3062	5881	25.7
57	4554	4060	22581	19907	2674	-3110	5785	25.6
58	3930	3954	22315	19745	2570	-3235	5805	26.0
59	3606	4028	22231	19619	2612	-2515	5127	23.1
60	5148	3920	21914	19476	2438	-2870	5309	24.2

AASD#2 NITROGEN MASS BALANCE - REAL-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = 20.59

Overall Mass Balance % Removed = 25.87

Day 1-57	Day 2-58	(FD-RT)	Day 58-1	Nitrogen Removed
6688	5869	819	-911	1730

DAY	FEED (NOx + NOx) (mg/L)	RCTR#2 (TKN + NOx) (mg/L)	SUMFEED Day1-19 N In X 0.24	SUMRCT2 Day 2-20 N Out X 0.24	(SUMFD-SUMRT)	DELTA-N RCTR#2 (Day20-1) X 4.8	Nitrogen Lost ColF-G	% N Lost ColH*100 / ColD
1	652.90	527.01						
2	735.48	473.19						
3	536.08	530.51						
4	437.18	498.19						
5	401.10	472.91						
6	395.92	462.16						
7	438.49	478.37						
8	294.20	456.44						
9	647.48	455.19						
10	713.72	472.05						
11	464.09	480.04						
12	563.69	461.61						
13	688.07	470.44						
14	397.14	475.96						
15	475.21	463.56						
16	355.23	470.6						
17	616.35	432.37						
18	552.07	442.06						
19	408.69	435.47						
20	446.18	455.57	2346	2133	213	-343	556	23.7
21	511.16	438.32	2296	2124	171	-167	339	14.8
22	426.18	444.28	2242	2104	138	-414	552	24.6
23	554.24	446.37	2216	2091	124	-249	373	16.8
24	508.10	446.47	2244	2085	159	-127	286	12.7
25	453.41	437.35	2269	2079	190	-119	310	13.6
26	414.25	439.57	2283	2070	214	-186	400	17.5
27	559.24	452.94	2277	2069	209	-17	225	9.9
28	520.34	438.59	2341	2065	276	-80	356	15.2
29	423.16	427.3	2311	2054	256	-215	471	20.4
30	631.57	408.08	2241	2037	204	-345	549	24.5
31	533.57	446.5	2281	2033	248	-73	320	14.0
32	472.31	442.28	2274	2026	247	-135	382	16.8
33	423.23	429.75	2222	2015	207	-222	428	19.3
34	450.30	429.31	2228	2007	221	-164	386	17.3
35	556.24	425.66	2222	1996	226	-216	442	19.9
36	513.26	420.69	2271	1994	277	-56	333	14.7
37	510.30	439.47	2246	1993	253	-12	265	11.8
38	486.30	404.42	2236	1986	250	-149	399	17.9
39	400.74	430.14	2254	1979	275	-122	397	17.6
40	457.39	408.26	2243	1972	271	-144	416	18.5
41	0.00	414.67	2231	1965	266	-142	408	18.3
42	0.00	401.61	2128	1954	174	-215	389	18.3
43	517.22	395.99	1995	1942	53	-242	295	14.8
44	510.36	410.74	2122	1936	186	-128	314	14.8
45	453.57	402.25	2258	1927	331	-179	510	22.6
46	465.25	376.81	2267	1909	359	-365	724	31.9
47	470.04	411.34	2245	1902	343	-131	473	21.1
48	422.56	402.38	2233	1896	336	-120	456	20.4
49	456.62	396.27	2232	1893	339	-57	396	17.7
50	402.42	391.57	2190	1880	310	-264	574	26.2
51	436.65	385.15	2159	1866	293	-274	567	26.3
52	408.88	386.6	2150	1856	294	-207	502	23.3
53	509.15	354.68	2147	1838	309	-358	667	31.1
54	475.21	369.69	2161	1825	336	-269	605	28.0
55	436.35	359.28	2142	1810	332	-295	626	29.3
56	422.65	350.96	2123	1789	335	-425	759	35.8
57	429.37	364.49	2102	1779	323	-192	515	24.5
58	333.27	337.28	2088	1757	332	-446	777	37.2
59	316.31	345.15	2072	1742	331	-303	634	30.6
60	429.21	354.3	2038	1727	311	-290	601	29.5

AASD#2 PHOSPHORUS MASS BALANCE - REAL-TIME REACTOR

Note: Mass Balance has used 58 days of data.

Moving Average Mass Balance % Removed = -4.95
Overall Mass Balance % Removed = -5.28

Day 1-57	Day 2-58	(FD-RT)	Day 58-1	Phosphorus Removed
2999	3517	-518	-360	-158

DAY	FEED TP (mg/L)	RCTR#2 TP (mg/L)	SUMFEED Day1-19 P In X 0.24	SUMRCT2 Day 2-20 P Out X 0.24	(SUMFD-SUMRT)	DELTA-P RCTR#2 (Day20-1) X 4.8	Total P Lost ColF-G	% P Lost ColH*100 / ColD
1	287	306						
2	322	286						
3	237	317						
4	191	304						
5	177	293						
6	175	292						
7	199	298						
8	134	280						
9	330	283						
10	425	288						
11	201	291						
12	245	283						
13	301	286						
14	165	287						
15	203	283						
16	151	285						
17	264	271						
18	243	273						
19	184	268						
20	206	274	1064	1306	-242	-154	-88	-8.3
21	225	269	1045	1302	-257	-82	-176	-16.8
22	193	267	1021	1290	-269	-240	-29	-2.8
23	242	273	1011	1283	-272	-149	-123	-12.2
24	222	272	1023	1278	-254	-101	-154	-15.0
25	202	267	1034	1272	-238	-120	-118	-11.4
26	185	273	1040	1266	-225	-120	-105	-10.1
27	256	274	1037	1264	-227	-29	-198	-19.1
28	242	270	1066	1261	-195	-62	-132	-12.4
29	198	267	1045	1256	-211	-101	-110	-10.5
30	297	267	991	1250	-259	-115	-144	-14.6
31	241	230	1014	1237	-224	-254	31	3.0
32	210	229	1013	1224	-211	-274	63	6.2
33	186	222	991	1208	-217	-312	95	9.6
34	202	222	996	1194	-198	-293	95	9.6
35	238	226	996	1179	-184	-283	100	10.0
36	223	218	1017	1167	-150	-254	104	10.3
37	221	226	1007	1155	-149	-226	77	7.7
38	210	215	1002	1143	-141	-254	113	11.3
39	169	223	1008	1130	-123	-245	122	12.1
40	193	212	999	1117	-118	-274	156	15.6
41	0	242	991	1111	-120	-120	0	0.0
42	0	241	945	1103	-158	-154	-5	-0.5
43	224	245	887	1097	-210	-130	-80	-9.0
44	222	244	941	1091	-150	-110	-40	-4.2
45	200	237	999	1082	-83	-173	90	9.0
46	208	228	1003	1071	-69	-221	152	15.2
47	204	238	991	1064	-72	-154	81	8.2
48	185	237	982	1056	-74	-144	70	7.1
49	201	237	979	1049	-70	-144	74	7.5
50	180	235	956	1050	-95	24	-119	-12.4
51	198	249	941	1055	-114	96	-210	-22.3
52	187	245	938	1061	-122	110	-233	-24.8
53	237	235	939	1064	-125	62	-188	-20.0
54	223	239	947	1067	-120	62	-182	-19.3
55	205	237	943	1072	-128	91	-219	-23.3
56	196	232	939	1073	-134	29	-163	-17.3
57	185	240	933	1079	-146	120	-266	-28.5
58	134	231	927	1081	-154	38	-192	-20.7
59	116	227	919	1085	-166	72	-238	-25.9
60	152	222	900	1080	-180	-96	-84	-9.3

AASD#2 ALKALINITY MASS BALANCE - REAL-TIME REACTOR

Note: Mass Balance has used 58 days of data.

DAY	FEED ALK (mg/L)	RCTR#2 ALK (mg/L)	SUMFEED Day1-19 ALK In X 0.24	SUMRCT2 Day 2-20 ALK Out X 0.24	(SUMFD-SUMRT)	DELTA-A RCTR#2 (Day20-1) X 4.8	ALK Lost ColF-G	% ALK Lost ColH*100 -------- ColD
1	204	140						
2	194	140						
3	188	174						
4	150	166						
5	180	142						
6	178	138						
7	165	140						
8	136	124						
9	172	124						
10	164	110						
11	180	126						
12	190	128						
13	208	130						
14	220	128						
15	178	130						
16	162	136						
17	220	134						
18	190	132						
19	166	138						
20	152	142	827	620	207	10	198	23.9
21	152	142	814	620	194	10	185	22.7
22	128	134	804	611	194	-192	386	48.0
23	160	134	790	603	187	-154	341	43.1
24	154	130	792	600	192	-58	250	31.5
25	150	128	786	598	188	-48	236	30.1
26	138	128	779	595	185	-58	242	31.1
27	168	128	773	596	177	19	158	20.4
28	164	128	780	597	184	19	165	21.1
29	148	132	779	602	177	106	71	9.1
30	182	140	775	605	169	67	102	13.2
31	186	142	775	609	167	67	99	12.8
32	192	176	774	620	155	221	-66	-8.6
33	152	156	770	626	144	134	10	1.2
34	170	148	754	631	123	86	37	4.9
35	256	180	752	641	111	211	-100	-13.3
36	204	148	775	645	130	67	63	8.1
37	248	148	771	648	122	77	46	5.9
38	220	150	785	651	133	58	76	9.7
39	176	160	798	656	142	86	56	7.0
40	200	158	804	660	144	77	67	8.4
41	0	150	815	663	152	77	75	9.2
42	0	168	784	672	113	163	-50	-6.4
43	180	144	746	675	71	67	4	0.5
44	190	150	795	680	115	106	10	1.2
45	196	156	851	687	164	134	29	3.4
46	208	164	864	696	169	173	-4	-0.4
47	188	156	874	702	172	134	37	4.3
48	192	160	880	709	171	134	36	4.1
49	184	152	890	712	179	58	121	13.6
50	196	160	891	716	175	86	88	9.9
51	186	154	893	711	182	-106	288	32.2
52	190	158	892	711	180	10	171	19.2
53	232	162	901	715	186	67	119	13.2
54	218	162	916	710	205	-86	292	31.9
55	220	158	907	713	194	48	146	16.1
56	220	162	911	716	194	67	127	14.0
57	238	170	904	721	183	96	87	9.6
58	166	166	908	722	186	29	157	17.3
59	160	218	906	737	169	288	-119	-13.1
60	218	222	896	754	142	346	-204	-22.7

Moving Average Mass Balance % Removed = 13.41

Overall Mass Balance % Removed = 16.19

Day 1-57	Day 2-58	(FD-RT)	Day 58-1	Alkalinity Removed
2533	1998	535	125	410

APPENDIX G

SOME BIO-P CALCULATIONS

APPENDIX G

SOME BIO-P CALCULATIONS

A Inorganic P Additions

Adding Na_2HPO_4 M.W. = 142 gms/mole contains 31 gms/mole of P.

Since target is around 7 mg/L P in the Feed Bucket...

Thus, need $\frac{142}{31} \times 7 = 32$ mg Na_2HPO_4/Litre of Influent.

Feed Bucket contains approximately 3 Carboys (approx. 48 L)...

Add $32 \frac{mg}{L} \times 48 \text{ L} \times \frac{1 \text{ gm}}{1000 \text{ mg}} = 1.5$ gms Na_2HPO_4/Feed Bucket Fill

B Sodium Acetate Additions

Calculate COD equivalent of Acetate... (Assume complete oxidation)

$$NaCH_3COO + 2\ O_2 \Leftrightarrow NaHCO_3 + CO_2 + H_2O$$

82 gms 64 gms 84 gms 44 gms 18 gms

If assumed to add 30 mg/L RBD COD (must be >= 25 mg/L)

$\frac{82}{64} \times 30 =$ 38 mg of $NaAc^-$ / L of influent must be added

Each Influent Feed is 2.4 L; Acetate Pump delivers 30 mL/6 min.

Thus.. $38 \text{ mg} \times 2.4 \text{ L} \times \frac{1}{30 \text{ mL}} \times \frac{1000 \text{ mL}}{\text{L}} \times \frac{1 \text{ gm}}{1000 \text{ mg}}$

= 3.04 gms/L Acetate Solution must be made up in volumetric flask

APPENDIX H

CHEMICAL DATA - BIO-P

Parameter Page

BIO-P #1 Feb/19/91-Mar/30/91

Solids Concentrations

Day of Run	Date	FEED TSS mg/L	FEED VSS mg/L	FEED Ratio mg/L	FT RCTR SOLIDS TSS mg/L	FT RCTR SOLIDS VSS mg/L	FT RCTR SOLIDS Ratio mg/L	FT EFFLUENT SOLIDS TSS mg/L	FT EFFLUENT SOLIDS VSS mg/L	FT EFFLUENT SOLIDS Ratio mg/L	RT RCTR SOLIDS TSS mg/L	RT RCTR SOLIDS VSS mg/L	RT RCTR SOLIDS Ratio mg/L	RT EFFLUENT SOLIDS TSS mg/L	RT EFFLUENT SOLIDS VSS mg/L	RT EFFLUENT SOLIDS Ratio mg/L
1	Feb/19/91	99	89	0.90	2212	1722	0.78	2	2	1.00	2366	1880	0.79	3	3	1.00
2	/20/															
3	/21/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
4	/22/															
5	/23/	80	69	0.86	2352	1804	0.77	2	2	1.00	2612	2012	0.77	2	2	1.00
6	/24/															
7	/25/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
8	/26/															
9	/27/	77	68	0.88	2128	1632	0.77	11	11	1.00	2384	1822	0.76	3	3	1.00
10	/28/															
11	Mar/01/91	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
12	/02/															
13	/03/	116	105	0.91	2376	1834	0.77	2	2	1.00	2466	1892	0.77	1	1	1.00
14	/04/															
15	/05/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
16	/06/															
17	/07/	97	87	0.90	2342	1826	0.78	4	4	1.00	2404	1870	0.78	2	2	1.00
18	/08/															
19	/09/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
20	/10/															
21	/11/	105	93	0.89	2014	1542	0.77	5	5	1.00	2156	1636	0.76	5	5	1.00
22	/12/															
23	/13/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
24	/14/															
25	/15/	113	94	0.83	1620	1208	0.75	5	5	1.00	1890	1392	0.74	4	4	1.00
26	/16/															
27	/17/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
28	/18/															
29	/19/	107	96	0.90	1860	1344	0.73	5	5	1.00	2012	1428	0.71	5	5	1.00
30	/20/															
31	/21/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
32	/22/															
33	/23/	121	107	0.89	2170	1618	0.75	5	5	1.00	2252	1646	0.73	4	4	1.00
34	/24/															
35	/25/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
36	/26/															
37	/27/	85	75	0.88	2166	1625	0.75	1	1	1.00	2272	1696	0.75	2	2	1.00
38	/28/															
39	/29/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
40	/30/															
Maximum		121	107	0.91	2376	1834	0.78	11	11	1.00	2612	2012	0.79	5	5	1.00
Mean		100	88	0.88	2124	1616	0.76	4	4	1.00	2281	1727	0.76	3	3	1.00
Minimum		77	68	0.83	1620	1280	0.73	1	1	1.00	1890	1392	0.71	1	1	1.00
Std. Dev.		15	13	0.02	226	196	0.02	3	3	0.00	205	195	0.02	1	1	0.00

BIO-P #2 Apr/22/91-May/31/91

Solids Concentrations

Day of Run	Date	FEED TSS mg/L	FEED VSS mg/L	FEED Ratio mg/L	FT RCTR SOLIDS TSS mg/L	FT RCTR SOLIDS VSS mg/L	FT RCTR SOLIDS Ratio mg/L	FT EFFLUENT SOLIDS TSS mg/L	FT EFFLUENT SOLIDS VSS mg/L	FT EFFLUENT SOLIDS Ratio mg/L	RT RCTR SOLIDS TSS mg/L	RT RCTR SOLIDS VSS mg/L	RT RCTR SOLIDS Ratio mg/L	RT EFFLUENT SOLIDS TSS mg/L	RT EFFLUENT SOLIDS VSS mg/L	RT EFFLUENT SOLIDS Ratio mg/L
1	Apr/22/91	174	158	0.91	3018	2648	0.88	10	10	1.00	3026	2650	0.88	10	10	1.00
2	/23/															
3	/24/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
4	/25/															
5	/26/	181	162	0.90	2578	2222	0.86	2	2	1.00	2582	2216	0.86	2	2	1.00
6	/27/															
7	/28/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
8	/29/															
9	/30/	146	129	0.88	2440	2082	0.85	4	4	1.00	2460	2106	0.86	4	4	1.00
10	May/01/91															
11	/02/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
12	/03/															
13	/04/	79	71	0.90	2486	2074	0.83	10	10	1.00	2494	2066	0.83	8	8	1.00
14	/05/															
15	/06/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
16	/07/															
17	/08/	86	79	0.92	2084	1722	0.83	6	6	1.00	2108	1732	0.82	6	6	1.00
18	/09/															
19	/10/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
20	/11/															
21	/12/	78	73	0.94	2128	1756	0.83	6	6	1.00	2010	1664	0.83	7	7	1.00
22	/13/															
23	/14/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
24	/15/															
25	/16/	65	59	0.91	1998	1616	0.81	6	6	1.00	1824	1484	0.81	8	8	1.00
26	/17/															
27	/18/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
28	/19/															
29	/20/	78	70	0.90	1986	1568	0.79	4	4	1.00	1806	1428	0.79	4	4	1.00
30	/21/															
31	/22/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
32	/23/															
33	/24/	86	78	0.91	1598	1266	0.79	8	8	1.00	1630	1276	0.78	7	7	1.00
34	/25/															
35	/26/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
36	/27/															
37	/28/	99	88	0.89	1628	1297	0.80	5	5	1.00	1656	1290	0.78	2	2	1.00
38	/29/															
39	/30/	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
40	/31/															
Maximum		181	162	0.94	3018	2648	0.88	10	10	1.00	3026	2650	0.88	10	10	1.00
Mean		107	97	0.90	1825	1825	0.83	6	6	1.00	2159	1791	0.82	6	6	1.00
Minimum		65	59	0.88	1266	1266	0.79	2	2	1.00	1630	1276	0.79	2	2	1.00
Std. Dev.		41	36	0.01	410	410	0.03	2	2	0.00	439	431	0.03	3	3	0.00

BIO-P #1 Feb/19/91-Mar/30/91 FEED

Nitrogen and Phosphorus

Day of Run	Date	Ortho -P mg/L	TP mg/L	NOx mg/L	NH3 mg/L	TKN mg/L
1	Feb/19/91	7.42	9.9	0.09	17.0	28.2
2	/20/					
3	/21/	----	----	----	----	----
4	/22/					
5	/23/	7.64	----	0.14	17.0	----
6	/24/					
7	/25/	----	----	----	----	----
8	/26/					
9	/27/	4.91	----	0.18	----	----
10	/28/					
11	Mar/01/91	----	----	----	----	----
12	/02/					
13	/03/	7.43	9.1	0.00	12.5	26.8
14	/04/					
15	/05/	----	----	----	----	----
16	/06/					
17	/07/	6.21	----	0.11	11.3	----
18	/08/					
19	/09/	----	----	----	----	----
20	/10/					
21	/11/	6.21	----	0.06	13.0	----
22	/12/					
23	/13/	----	----	----	----	----
24	/14/					
25	/15/	5.55	----	0.35	13.8	----
26	/16/					
27	/17/	----	----	----	----	----
28	/18/					
29	/19/	6.72	9.7	0.06	9.8	30.3
30	/20/					
31	/21/	----	----	----	----	----
32	/22/					
33	/23/	6.80	----	0.21	10.7	----
34	/24/					
35	/25/	----	----	----	----	----
36	/26/					
37	/27/	5.53	----	0.17	12.0	----
38	/28/					
39	/29/	----	----	----	----	----
40	/30/					
Maximum		7.64	9.7	0.35	17.0	30.3
Mean		6.44	9.5	0.14	13.0	28.4
Minimum		4.91	9.1	0.00	9.8	26.8
Std. Dev.		0.87	0.4	0.09	2.4	1.4

BIO-P #2 Apr/22/91-May/31/91 FEED

Nitrogen and Phosphorus

Day of Run	Date	Ortho -P mg/L	TP mg/L	NOx mg/L	NH3 mg/L	TKN mg/L
1	Apr/22/91	2.41	6.3	0.16	11.95	41.2
2	/23/					
3	/24/	2.61	----	0.30	----	----
4	/25/					
5	/26/	2.45	----	0.04	12.59	----
6	/27/					
7	/28/	2.53	----	0.08	----	----
8	/29/					
9	/30/	2.56	----	0.17	11.97	----
10	May/01/91					
11	/02/	3.18	----	0.10	----	----
12	/03/					
13	/04/	1.60	3.7	0.14	11.64	24.0
14	/05/					
15	/06/	1.69	----	0.09	----	----
16	/07/					
17	/08/	1.72	----	0.20	12.04	----
18	/09/					
19	/10/	1.95	----	0.22	----	----
20	/11/					
21	/12/	2.04	----	0.10	12.54	----
22	/13/					
23	/14/	2.04	----	0.22	----	----
24	/15/					
25	/16/	2.13	----	0.19	13.78	----
26	/17/					
27	/18/	2.15	4.1	0.14	----	27.7
28	/19/					
29	/20/	1.99	----	0.19	12.00	----
30	/21/					
31	/22/	2.03	----	0.11	----	----
32	/23/					
33	/24/	2.14	----	0.19	12.33	----
34	/25/					
35	/26/	2.17	----	0.19	----	----
36	/27/					
37	/28/	2.14	----	0.27	12.98	----
38	/29/					
39	/30/	2.29	----	0.18	----	----
40	/31/					
Maximum		3.18	6.3	0.30	13.78	41.2
Mean		2.19	4.7	0.16	12.38	31.0
Minimum		1.60	3.7	0.04	11.64	24.0
Std. Dev.		0.36	1.1	0.06	0.60	7.4

BIO-P #1 Feb/19/91-Mar/30/91 FT RCTR

Nitrogen and Phosphorus

Day of Run	Date	Ortho -P mg/L	Percent P (%)	NOx mg/L	NH3 mg/L	Percent N (%)
1	Feb/19/91	3.39	2.95	7.79	0.1	4.81
2	/20/					
3	/21/	----	----	----	----	----
4	/22/					
5	/23/	7.46	2.92	8.22	----	5.04
6	/24/					
7	/25/	4.93	----	8.21	----	----
8	/26/					
9	/27/	8.27	3.23	9.22	----	5.32
10	/28/					
11	Mar/01/91	----	----	----	----	----
12	/02/					
13	/03/	4.60	3.10	7.48	N/D	5.31
14	/04/					
15	/05/	5.87	----	7.61	----	----
16	/06/					
17	/07/	8.10	2.92	8.05	N/D	5.42
18	/08/					
19	/09/	4.76	----	8.44	----	----
20	/10/					
21	/11/	9.30	3.35	9.26	N/D	5.50
22	/12/					
23	/13/	5.29	----	8.09	----	----
24	/14/					
25	/15/	9.60	3.50	8.24	N/D	5.35
26	/16/					
27	/17/	3.26	----	8.35	----	----
28	/18/					
29	/19/	10.70	3.56	8.97	N/D	5.16
30	/20/					
31	/21/	5.88	----	6.44	----	----
32	/22/					
33	/23/	7.71	3.45	6.64	N/D	5.53
34	/24/					
35	/25/	3.89	----	6.31	----	----
36	/26/					
37	/27/	7.12	3.52	6.68	N/D	5.72
38	/28/					
39	/29/	4.78	----	9.43	----	----
40	/30/					
Maximum		10.70	3.56	9.43	0.1	5.72
Mean		6.38	3.25	7.97	N/D	5.32
Minimum		3.26	2.92	6.31	N/D	4.81
Std. Dev.		2.17	0.25	0.94	N/D	0.25

Note: N/D - Not Detectable
Less than lowest standard 0.05 mg/L

BIO-P #2 Apr/22/91-May/31/91 FT RCTR

Nitrogen and Phosphorus

Day of Run	Date	Ortho -P mg/L	Percent P (%)	NOx mg/L	NH3 mg/L	Percent N (%)
1	Apr/22/91	0.03	1.12	7.68	N/D	5.45
2	/23/					
3	/24/	0.02	----	9.18	----	----
4	/25/					
5	/26/	0.02	1.48	9.71	N/D	6.27
6	/27/					
7	/28/	0.02	----	8.33	----	----
8	/29/					
9	/30/	0.03	2.06	8.96	N/D	6.41
10	May/01/91					
11	/02/	0.03	----	9.22	----	----
12	/03/					
13	/04/	0.00	2.29	9.16	N/D	6.75
14	/05/					
15	/06/	0.02	----	7.47	----	----
16	/07/					
17	/08/	0.33	2.75	7.19	N/D	6.82
18	/09/					
19	/10/	0.12	----	7.38	----	----
20	/11/					
21	/12/	2.07	2.57	8.41	N/D	6.50
22	/13/					
23	/14/	0.16	----	8.24	----	----
24	/15/					
25	/16/	2.07	3.05	8.66	N/D	6.37
26	/17/					
27	/18/	0.12	----	8.62	----	----
28	/19/					
29	/20/	1.73	3.13	8.21	N/D	6.15
30	/21/					
31	/22/	0.11	----	8.52	----	----
32	/23/					
33	/24/	1.90	3.15	8.73	N/D	6.11
34	/25/					
35	/26/	0.11	----	8.71	----	----
36	/27/					
37	/28/	1.51	3.36	8.95	N/D	6.35
38	/29/					
39	/30/	0.09	----	8.53	----	----
40	/31/					
Maximum		2.07	3.36	9.71	N/D	6.82
Mean		0.52	2.50	8.49	N/D	6.32
Minimum		0.00	1.12	7.19	N/D	5.45
Std. Dev.		0.78	0.71	0.65	N/D	0.36

BIO-P #1 Feb/19/91-Mar/30/91 RT RCTR

Nitrogen and Phosphorus

Day of Run	Date	Ortho -P mg/L	Percent P (%)	NOx mg/L	NH3 mg/L	Percent N (%)
1	Feb/19/91	5.10	2.53	7.83	0.2	4.53
2	/20/					
3	/21/	----	----	----	----	----
4	/22/					
5	/23/	5.30	2.63	8.07	----	4.78
6	/24/					
7	/25/	4.20	----	8.08	----	----
8	/26/					
9	/27/	6.90	3.06	8.75	----	4.93
10	/28/					
11	Mar/01/91	----	----	----	----	----
12	/02/					
13	/03/	4.37	3.27	5.91	N/D	5.19
14	/04/					
15	/05/	5.21	----	6.57	----	----
16	/06/					
17	/07/	7.00	2.73	7.13	N/D	4.87
18	/08/					
19	/09/	5.13	----	3.89	----	----
20	/10/					
21	/11/	8.01	3.28	8.30	N/D	5.02
22	/12/					
23	/13/	4.05	----	5.51	----	----
24	/14/					
25	/15/	8.49	3.36	12.39	0.1	4.94
26	/16/					
27	/17/	2.51	----	7.61	----	----
28	/18/					
29	/19/	8.80	4.07	12.89	N/D	5.07
30	/20/					
31	/21/	4.49	----	8.65	----	----
32	/22/					
33	/23/	7.32	3.69	9.19	N/D	5.00
34	/24/					
35	/25/	5.72	----	2.69	----	----
36	/26/					
37	/27/	5.51	3.68	8.85	2.5	5.18
38	/28/					
39	/29/	3.01	----	6.69	----	----
40	/30/					
Maximum		8.80	4.07	12.89	2.5	5.19
Mean		5.60	3.20	7.70	0.4	4.90
Minimum		2.51	2.53	2.69	N/D	4.53
Std. Dev.		1.70	0.40	2.40	0.8	0.10

Note: N/D - Not Detectable
Less than lowest standard 0.05 mg/L

BIO-P #2 Apr/22/91-May/31/91 RT RCTR

Nitrogen and Phosphorus

Day of Run	Date	Ortho -P mg/L	Percent P (%)	NOx mg/L	NH3 mg/L	Percent N (%)
1	Apr/22/91	0.03	1.22	7.46	N/D	5.53
2	/23/					
3	/24/	0.03	----	9.14	----	----
4	/25/					
5	/26/	0.03	1.55	8.99	N/D	6.02
6	/27/					
7	/28/	0.02	----	10.58	----	----
8	/29/					
9	/30/	0.02	2.09	8.96	N/D	5.81
10	May/01/91					
11	/02/	0.03	----	9.02	----	----
12	/03/					
13	/04/	0.01	2.38	9.23	N/D	6.26
14	/05/					
15	/06/	0.02	----	7.69	----	----
16	/07/					
17	/08/	1.59	2.58	9.28	N/D	6.09
18	/09/					
19	/10/	0.50	----	7.40	----	----
20	/11/					
21	/12/	1.92	2.76	9.44	N/D	6.05
22	/13/					
23	/14/	0.72	----	8.30	----	----
24	/15/					
25	/16/	1.36	2.86	9.21	N/D	5.68
26	/17/					
27	/18/	0.20	----	8.46	----	----
28	/19/					
29	/20/	0.95	3.12	9.97	N/D	5.58
30	/21/					
31	/22/	0.15	----	8.53	----	----
32	/23/					
33	/24/	0.86	3.30	9.87	N/D	5.68
34	/25/					
35	/26/	0.76	----	10.68	----	----
36	/27/					
37	/28/	1.13	3.52	9.38	N/D	5.63
38	/29/					
39	/30/	0.12	----	8.48	----	----
40	/31/					
Maximum		1.92	3.52	10.68	N/D	6.26
Mean		0.52	2.54	9.00	N/D	5.83
Minimum		0.01	1.22	7.40	N/D	5.53
Std. Dev.		0.59	0.71	0.88	N/D	0.24

BIO-P #1 Feb/19/91-Mar/30/91

Day of Run	Date	FEED pH	FEED Alk. mg/L as $CaCO_3$	FEED Diss. Oxygen mg/L @3:30pm	FEED TC mg/L	FEED IC mg/L	FEED TOC mg/L	FEED COD mg/L	FT RCTR pH	FT RCTR Alk. mg/L as $CaCO_3$	FT RCTR Diss. Oxygen mg/L @3:30pm	RCTR EFFL TC mg/L	RCTR EFFL IC mg/L	RCTR EFFL TOC mg/L	RCTR EFFL COD mg/L
1	Feb/19/91	7.49	320	----	108	66	42	131	7.16	270	0.70	55	46	9	29
2	/20/										0.80				
3	/21/										----				
4	/22/										----				
5	/23/	7.34	298	----	103	61	42	--	7.02	284	6.40	63	52	11	--
6	/24/										----				
7	/25/										5.50				
8	/26/										6.90				
9	/27/	7.37	222	----	82	44	38	118	7.37	288	7.00	58	48	10	27
10	/28/										----				
11	Mar/01/91										----				
12	/02/										----				
13	/03/	7.56	228	----	90	42	48	141	7.12	192	7.00	32	25	7	29
14	/04/										7.00				
15	/05/										4.70				
16	/06/										4.10				
17	/07/	7.18	206	----	92	44	48	--	6.90	212	5.30	31	25	6	--
18	/08/										1.10				
19	/09/										----				
20	/10/										----				
21	/11/	7.13	164	----	97	49	48	--	7.37	260	6.50	34	27	7	--
22	/12/										3.30				
23	/13/										5.60				
24	/14/										5.50				
25	/15/	7.27	278	----	114	54	60	155	7.03	266	6.80	46	39	7	28
26	/16/										----				
27	/17/										----				
28	/18/										5.20				
29	/19/	7.50	248	----	98	48	50	155	7.28	310	6.50	54	46	8	28
30	/20/										----				
31	/21/										4.00				
32	/22/										----				
33	/23/	6.81	186	----	89	43	46	147	6.84	222	6.00	44	36	8	20
34	/24/										----				
35	/25/										1.45				
36	/26/										2.60				
37	/27/	7.15	224	----	79	31	48	151	7.13	250	5.50	42	35	8	28
38	/28/										1.80				
39	/29/										3.30				
40	/30/										----				
Maximum		7.56	320	----	114	66	60	155	7.37	310	7.00	63	52	11	29
Mean		7.28	237	----	95	48	47	143	7.12	254	4.60	45	37	8	27
Minimum		6.81	164	----	79	31	38	118	6.84	192	0.70	31	25	6	20
Std. Dev.		0.21	47	----	11	10	6	13	0.18	37	2.07	11	10	1	3

BIO-P #1 Feb/19/91-Mar/30/91 RT RCTR pH/Alkalinity/Carbon

Day of Run	Date	pH	Alk. mg/L as $CaCO_3$	Diss. Oxygen mg/L @3:30pm	RCTR EFFL TC mg/L	RCTR EFFL IC mg/L	RCTR EFFL TOC mg/L	RCTR EFFL COD mg/L
1	Feb/19/91	7.10	252	0.70	53	44	9	27
2	/20/			0.80				
3	/21/			----				
4	/22/			----				
5	/23/	7.08	282	5.40	63	53	10	--
6	/24/			----				
7	/25/			0.70				
8	/26/			1.00				
9	/27/	7.32	290	6.50	56	47	9	15
10	/28/			----				
11	Mar/01/91			----				
12	/02/			----				
13	/03/	7.05	178	6.40	34	28	6	27
14	/04/			6.00				
15	/05/			0.80				
16	/06/			4.70				
17	/07/	6.97	220	2.70	31	25	6	--
18	/08/			1.00				
19	/09/			----				
20	/10/			----				
21	/11/	7.38	258	6.90	36	30	6	--
22	/12/			0.70				
23	/13/			0.80				
24	/14/			4.20				
25	/15/	7.06	268	6.90	47	39	8	28
26	/16/			----				
27	/17/			----				
28	/18/			0.80				
29	/19/	7.34	312	5.10	52	45	7	28
30	/20/			----				
31	/21/			0.90				
32	/22/			----				
33	/23/	7.02	232	5.80	44	38	6	28
34	/24/			----				
35	/25/			1.00				
36	/26/			1.10				
37	/27/	7.21	242	1.50	37	30	7	24
38	/28/			1.50				
39	/29/			1.60				
40	/30/			----				
Maximum		7.38	312	6.90	63	53	10	28
Mean		7.15	253	2.90	45	38	7	25
Minimum		6.97	178	0.70	31	25	6	15
Std. Dev.		0.14	36	2.37	10	9	1	4

BIO-P #2 Apr/22/91-May/31/91

				FEED pH/Alkalinity/Carbon						FT RCTR pH/Alkalinity/Carbon					
Day of Run	Date	pH	Alk. mg/L as $CaCO_3$	Diss. Oxygen mg/L @3:30pm	FEED TC mg/L	FEED IC mg/L	FEED TOC mg/L	FEED COD mg/L	pH	Alk. mg/L as $CaCO_3$	Diss. Oxygen mg/L @3:30pm	RCTR EFFL TC mg/L	RCTR EFFL IC mg/L	RCTR EFFL TOC mg/L	RCTR EFFL COD mg/L
1	Apr/22/91	7.54	360	----	129	79	50	72	7.80	392	6.90	78	64	14	20
2	/23/										----				
3	/24/										7.30				
4	/25/										----				
5	/26/	7.29	276	----	101	54	47	66	7.86	352	8.00	70	61	9	12
6	/27/										----				
7	/28/										----				
8	/29/										5.90				
9	/30/	7.11	220	----	93	43	50	71	7.58	310	6.30	49	40	9	14
10	May/01/91										----				
11	/02/										1.20				
12	/03/										6.00				
13	/04/	7.43	210	----	74	42	32	44	7.56	196	7.30	41	33	8	10
14	/05/										----				
15	/06/										7.20				
16	/07/										----				
17	/08/	7.39	212	----	75	43	32	47	7.49	220	7.80	38	31	7	12
18	/09/										----				
19	/10/										6.80				
20	/11/										----				
21	/12/	7.59	268	----	92	59	33	42	7.51	172	7.10	40	31	9	14
22	/13/										----				
23	/14/										6.70				
24	/15/										----				
25	/16/	7.43	264	----	82	54	28	44	7.51	296	7.10	59	53	6	12
26	/17/										----				
27	/18/										----				
28	/19/										----				
29	/20/	7.47	292	----	97	63	34	50	7.11	240	7.40	53	47	6	11
30	/21/										----				
31	/22/										7.00				
32	/23/										----				
33	/24/	7.43	312	----	102	68	34	46	7.48	290	6.60	59	52	7	11
34	/25/										----				
35	/26/										7.20				
36	/27/										----				
37	/28/	7.09	232	----	85	51	34	49	7.46	306	6.30	63	55	8	12
38	/29/										----				
39	/30/										6.80				
40	/31/										----				
Maximum		7.59	360	----	129	79	50	72	7.86	392	8.00	78	64	14	20
Mean		7.38	265	----	93	56	37	53	7.54	277	6.65	55	47	8	13
Minimum		7.09	210	----	74	42	28	42	7.11	172	1.20	38	31	6	10
Std. Dev.		0.16	46	----	15	11	8	11	0.19	66	1.36	13	12	2	3

BIO-P #2 Apr/22/91-May/31/91 RT RCTR pH/Alkalinity/Carbon

Day of Run	Date	pH	Alk. mg/L as $CaCO_3$	Diss. Oxygen mg/L @3:30pm	RCTR EFFL TC mg/L	RCTR EFFL IC mg/L	RCTR EFFL TOC mg/L	RCTR EFFL COD mg/L
1	Apr/22/91	7.86	390	8.00	78	65	13	18
2	/23/			----				
3	/24/			7.80				
4	/25/			----				
5	/26/	7.97	343	8.00	75	66	9	4
6	/27/			----				
7	/28/			----				
8	/29/			7.60				
9	/30/	7.69	330	7.90	56	45	11	14
10	May/01/91			----				
11	/02/			4.20				
12	/03/			7.60				
13	/04/	7.92	200	7.90	41	33	8	10
14	/05/			----				
15	/06/			7.50				
16	/07/			----				
17	/08/	7.61	218	7.80	35	28	7	10
18	/09/			----				
19	/10/			6.60				
20	/11/			----				
21	/12/	7.57	170	7.20	40	32	8	12
22	/13/			----				
23	/14/			6.80				
24	/15/			----				
25	/16/	7.61	290	7.30	60	53	7	14
26	/17/			----				
27	/18/			----				
28	/19/			----				
29	/20/	7.34	230	7.60	51	45	6	9
30	/21/			----				
31	/22/			7.20				
32	/23/			----				
33	/24/	7.50	306	7.00	58	51	7	11
34	/25/			----				
35	/26/			6.30				
36	/27/			----				
37	/28/	7.49	340	7.30	61	53	8	11
38	/29/			----				
39	/30/			7.50				
40	/31/			----				
Maximum		7.97	390	8.00	78	66	13	18
Mean		7.66	282	7.26	56	47	8	11
Minimum		7.34	170	4.20	35	28	6	4
Std. Dev.		0.19	69	0.84	14	13	2	3

Carbon Decay in Cold Room
Raw Influent Sewage

Day	COD	TC	TIC	TOC
1	128	62.4	21.2	41.2
2	137	60.4	21.4	39.0
3	120	56.8	22.0	34.8
4	110	55.1	20.8	34.3
5	110	56.1	22.9	33.2
6	110	52.8	22.2	30.6
7	101	52.3	22.4	29.9
8	82	45.0	19.4	25.6
10	73	49.9	23.0	26.9
11	92	46.9	21.3	25.7
12	64	49.7	26.0	23.7
13	64	46.7	24.7	22.0
14	73	43.2	23.3	19.9
15	55	44.6	25.2	19.4
16	46	44.7	25.0	19.7

Carbon Decay in Feed Bucket
Raw Influent Sewage

Day	COD	TC	TIC	TOC
1	110	62.5	21.5	41.0
2	70	54.1	21.8	32.3
3	64	48.1	21.3	26.8
4	64	46.6	21.2	25.4