THE EFFECT OF EXCESS CARBON IN THE ANOXIC BASIN OF A BIOLOGICAL

PRE-DENITRIFICATION SYSTEM FOR THE TREATMENT OF LANDFILL LEACHATE

by

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ABSTRACT

This study investigated the effect of excess carbon loading in the anoxic reactor on the nitrogen removal capacity of a biological pre-denitrification system for the treatment of a high ammonia leachate. The influent leachate was low in degradable organic carbon, thus an external carbon source was needed for denitrification requirements. Four different carbon sources were studied: methanol, glucose, acetate, and a waste brewer's yeast. The carbon loading was increased over the duration of the experimental period. The COD:NOx added to the anoxic reactor reached more than three times the carbon loading required to just achieve complete denitrification.

All four carbon sources were found to support denitrification, but the glucose system showed erratic behaviour and ultimately failed after reaching a COD:NOx loading of about 23:1. The system using acetate appeared to require the least amount of COD:NOx (5.9:1) for complete denitrification, followed closely by methanol (6.2:1), then the yeast waste (8.5:1), and finally by glucose (9:1). Carbon breakthrough, the bleeding of carbon from the anoxic reactor into the aerobic reactor, was observed to occur just after complete denitrification was reached. The excess carbon did not appear to have any effect on denitrification, except in the case of the glucose system.

The unit nitrification was found to decrease as the COD:NOx was increased, even though the ammonia removal remained at 100%. The decrease in nitrification, with respect to the COD:NOx, was most pronounced in the system that used methanol, and about equal in the other three systems. The cause of the decrease in nitrification is suspected to be due to increased ammonia assimilation by the heterotrophs rather than an inhibition of the nitrifiers. Nitrification ceased in the glucose system, but was restored within 12 days after the glucose addition was halted. The cause of the failure of the nitrogen removal process in the glucose system was not determined.

Nitrite accumulation was observed in all the systems except the methanol system. The yeast waste system had nitrite accumulation in the aerobic reactor at COD:NOx loadings over 25:1. Free ammonia inhibition of **Nitrobacter** is suspected to be the cause of aerobic nitrite buildup. The glucose and acetate systems had nitrite buildup in the anoxic reactor until complete denitrification was achieved. Facultative anaerobic bacteria are suspected of causing this nitrite accumulation. This theory was supported by observations in the glucose system, such as low anoxic pH; this may have been due to volatile fatty acids produced from fermentation.

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1. INTRODUCTION

This introduction will briefly outline the biological processes of nitrification, denitrification, and the concept of carbon breakthrough on which this study is based.

Nitrification is an aerobic biological process conducted by autotrophic bacteria. These bacteria are predominantly of the genera **Nitrosomonas** and **Nitrobacter**, and, unlike heterotrophic bacteria which derive energy through the oxidation of organic carbon compounds, these autotrophs derive energy from the oxidation of inorganic nitrogen compounds, such as ammonia and nitrite. **Nitrosomonas** can only oxidize ammonia to nitrite, and **Nitrobacter** can only oxidize nitrite to nitrate. Both these autotrophs utilize inorganic carbon compounds, such as carbon dioxide and carbonate, for cell synthesis. Nitrification reduces the alkalinity, and, if synthesis is neglected, alkalinity is theoretically reduced by 7.14 mg as $CaCO_3$ for every mg ammonia nitrogen oxidized. The equations for synthesis-oxidation for nitrification are listed. These equations assume that a bacterial cell is $C_5H_7NO_2$ (**U.S. EPA** 1975).

For **Nitrosomonas**:

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

(1)

For Nitrobacter:

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 1950_2 \longrightarrow$$

$$C_5H_7NO_2 + 3H_2O + 400NO_3^-$$
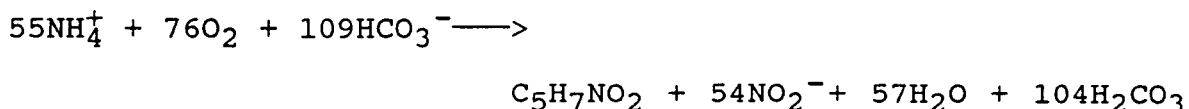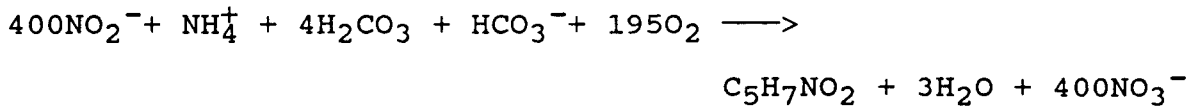
(2)

The growth rate for **Nitrosomonas** is reported to be considerably less than the rate for **Nitrobacter** (**U.S. EPA 1975**). This means that aerobic nitrite accumulation should not occur unless the **Nitrobacter** experience some form of inhibition. Nitrification is also very sensitive to pH outside the optimum range of pH 7-9 (**U.S. EPA 1975**). If the pH drops below 7, nitrification may be greatly reduced.

Denitrification is the biological process that ultimately converts nitrate and nitrite to gaseous nitrogen, generally nitrogen gas. Many bacteria, such as **Pseudomonas, Archromobacter, Micrococcus,** and **Bacillus,** are known to have the capability for denitrification (**U.S. EPA 1975**). Facultative anaerobic bacteria have been shown to reduce nitrate to nitrite only, using glucose as an electron donor, and are not considered true denitrifiers (**Wilderer et al. 1987**). Denitrifiers are heterotrophic bacteria that oxidize organic carbon compounds for energy. The true denitrifiers can use either oxygen or nitrate and nitrite as the terminal

electron acceptor for the same metabolic pathways, but oxygen is preferred if it is available. Oxygen represses the enzymes required for denitrification (**Simpkin and Boyle 1985**). An anoxic condition is when oxygen is absent and compounds that can donate oxygen, such as nitrate and nitrite, are present. Anaerobic conditions occur when there is an absence of oxygen, nitrate, and nitrite.

Denitrification releases alkalinity at a theoretical rate of 3.57 mg alkalinity as $CaCO_3$ per mg of nitrate nitrogen reduced to nitrogen gas. The following equations illustrate denitrification using methanol for nitrate and nitrite reduction, and denitrifier cell synthesis (from **U.S. EPA 1975**). A cell is assumed to be $C_5H_7NO_2$.

Nitrate Reduction to Nitrite:

$$NO_3^- + 0.33CH_3OH \longrightarrow NO_2^- + 0.33H_2O + 0.33H_2CO_3$$
(3)
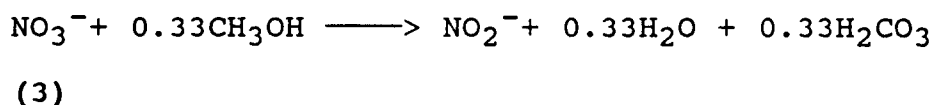
Nitrite Reduction to Nitrogen Gas:

$$NO_2^- + 0.5CH_3OH + 0.5H_2CO_3 \longrightarrow 0.5N_2 + HCO_3^- + H_2O$$
(4)

Denitrifier Synthesis:

$$3NO_3^- + 14CH_3OH + 4H_2CO_3 \longrightarrow 3C_5H_7NO_2 + 20H_2O + 3HCO_3^-$$
(5)
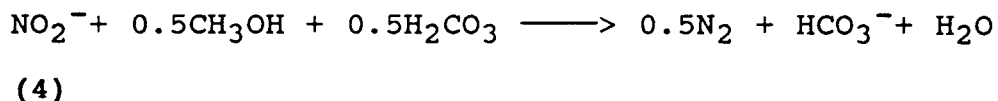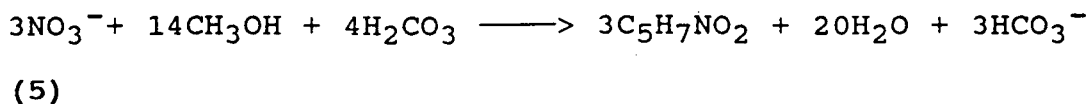
The reactions for the other carbon sources will be similar and will not be presented. Denitrification becomes sensitive to pH at values under pH 7 and over pH 8 (**U.S. EPA 1975**).

The nitrogen removal system used in this study was a single sludge pre-denitrification completely mixed activated sludge system. Pre-denitrification indicates that the anoxic reactor was placed before the aerobic reactor. The influent ammonia entered the anoxic reactor, where about 10% was removed by assimilation. The ammonia then entered the aerobic reactor where nitrification converted it to nitrate. Some ammonia may have been lost to assimilation and air stripping, but these losses were assumed to be negligible. The nitrified mixed liquor from the aerobic reactor then passed into the clarifier to separate the solids from the supernatant. The nitrified return sludge was recycled back to the front of the system into the anoxic reactor. Denitrification in the anoxic reactor ultimately converted the nitrate to nitrogen gas by using external carbon. This process train is illustrated in **Figure 1**. If the aerobic reactor was placed before the anoxic reactor, then denitrification may carry over into the clarifier and produce nitrogen gas that could result in a rising sludge and poor settling. Carbon oxidation ideally occurs only by denitrification in the anoxic reactor.

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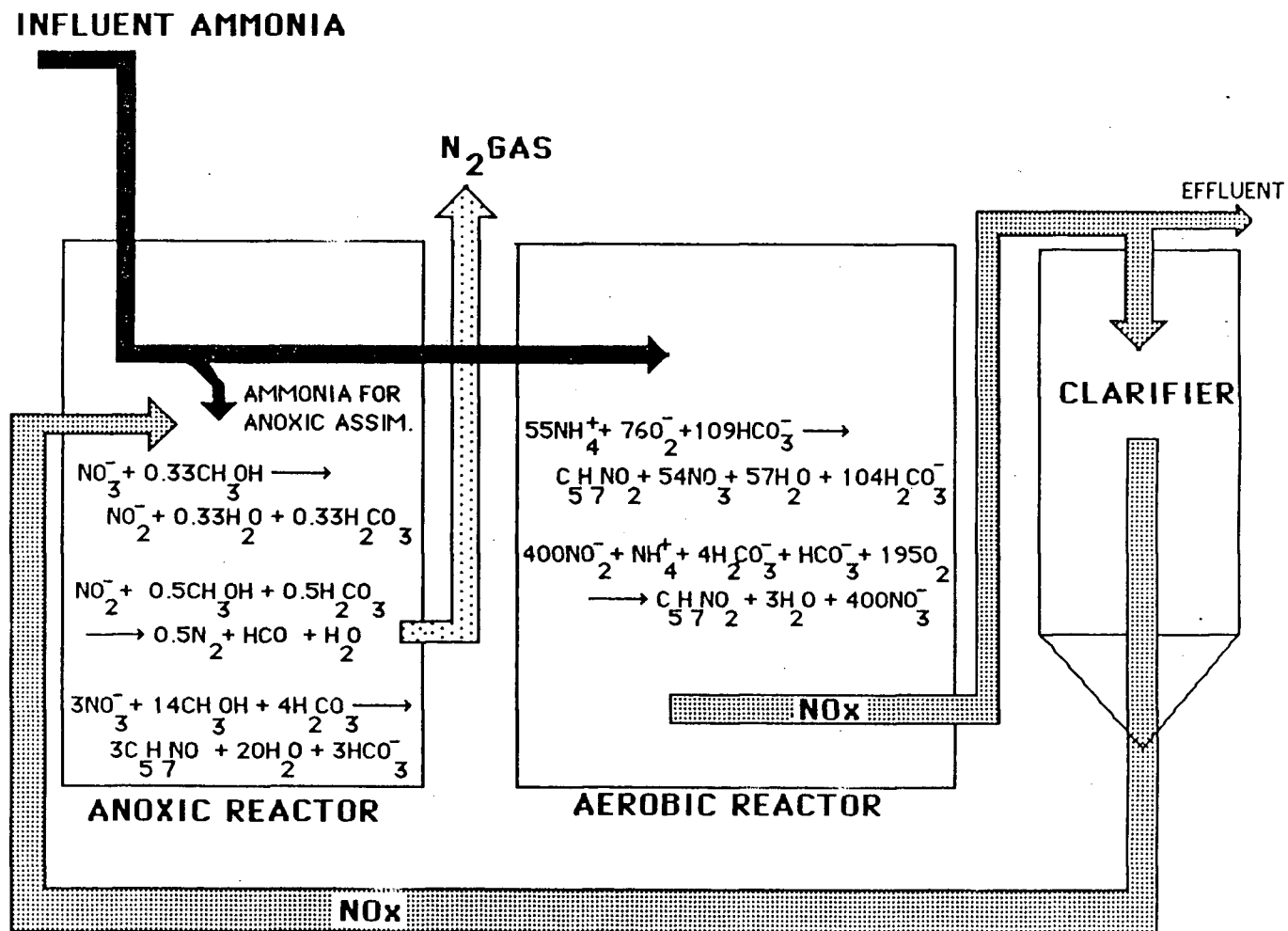
Figure 1. NITROGEN REMOVAL PROCESS SCHEMATIC

INFLUENT AMMONIA

N_2 GAS

EFFLUENT

AMMONIA FOR ANOXIC ASSIM.

CLARIFIER

$NO_3^- + 0.33CH_3OH \longrightarrow$
$NO_2^- + 0.33H_2O + 0.33H_2CO_3$

$NO_2^- + 0.5CH_3OH + 0.5H_2CO_3$
$\longrightarrow 0.5N_2 + HCO_2 + H_2O$

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

$55NH_4^+ + 76O_2^- + 109HCO_3^- \longrightarrow$
$C_5H_7NO_2 + 54NO_3^- + 57H_2O + 104H_2CO_3^-$

$400NO_2^- + NH_4^+ + 4H_2CO_3^- + HCO_3^- + 1950_2$
$\longrightarrow C_5H_7NO_2 + 3H_2O + 400NO_3^-$

ANOXIC REACTOR

AEROBIC REACTOR

NOx

NOx

Ideally, only nitrification occurs in the aerobic reactor.

If carbon is added to the anoxic reactor in excess of the minimum required to sustain complete denitrification, then carbon can bleed into the aerobic reactor. This is called "carbon breakthrough". The aerobic reactor may have both nitrification and denitrification, as well as heterotrophic carbon oxidation, occurring at the same time. Excess carbon in the anoxic basin may promote anaerobic conditions when the nitrate and nitrite has been used up. Fermentation under anaerobic conditions may lower the pH due to the production of volatile fatty acids; these in turn may disrupt either the denitrifiers or nitrifiers. The effect of excess carbon added to the anoxic reactor was the purpose of this study. The waste being treated was a high-ammonia municipal landfill leachate.

2. <u>LITERATURE SEARCH</u>

This brief literature review examines nitrogen removal, particularly nitrogen removal by nitrification and denitrification. This review examines only those references which are considered to be germane to this study. There are four sections in this review. The introduction gives some reasons on the need for leachate treatment by examining the formation of landfill leachate, leachate characteristics, and health aspects of nitrogen compounds. The next section is a brief discussion on leachate treatment for nitrogen removal other than by nitrification or denitrification. Nitrification is then discussed in some detail, especially inhibition of nitrifiers as nitrification inhibition was observed in the results of this study. The last section is on denitrification and deals mainly with various carbon sources as an alternative to methanol for denitrification purposes. The effect of carbon breakthrough in pre-denitrification systems is also examined because the purpose of this study was to induce carbon breakthrough, the bleeding of the anoxic carbon source into the aerobic reactor, and observe the effects on biological nitrogen removal.

2.1 INTRODUCTION

The primary concern connected with the disposal of refuse into landfills is the generation of leachate. Leachate is

produced when water, from precipitation, surface runoff, groundwater intrusion, or from within the refuse, percolates through the refuse. As the water seeps through the landfill, contaminants are leached out of the refuse and incorporated into the water, thus producing leachate. The contaminants are from the refuse directly or from products of bacterial degradation. The composition of leachate can vary widely between landfills and even between different cells within the same landfill. The leachate composition can vary with the age of the refuse, the amount of water entering the landfill, and with the amount and type of industrial wastes incorporated into the waste stream (Fuller, et al. 1979). **Jasper, et al. (1985, 1986)** hypothesized that the organic constituents of leachate varied with water flow and retention time within the landfill. Some typical characteristics of landfill leachate are low BOD, high refractory COD, high ammonia, low phosphorus, and the presence of a wide range of metals and toxic organic contaminants (**Henry 1985**). The common inorganic constituents of leachate are chlorides, sulphates, bicarbonates, ammonia, iron (II), manganese (II), sodium, potassium, calcium, chromium, copper, nickel, lead, and zinc (**Jasper, et al. 1986**).

Chian, et al. (1985) stated that landfills have 5 basic stages of biological degradation. The first is a relatively short aerobic decomposition phase, which can last from one to six months, depending on the amount of air space within the

refuse. The second stage is a transition from an aerobic to an anoxic/anaerobic microbial population. Nitrates, nitrites, and sulphates are used when the oxygen has been depleted. The third, or acid formation, stage involves facultative anaerobic bacteria, which degrade organic material into volatile fatty acids. The fourth stage involves the establishment of methanogenic bacteria which utilize the fatty acids to form methane and carbon dioxide. During these last two stages, a byproduct is ammonia, converted from organic nitrogen. This is the reason that "older" landfills have high ammonia leachate (**Henry** 1985). The fifth and final stage is final maturation, characterized by little biological activity as the readily available organic material and nutrients have been virtually exhausted.

The constituent of concern in this study is ammonia. Ammonia levels in landfill leachates have been reported at 70-150 mg/L (**Fuller**, et al. 1979), 76-790 mg/L (**Robinson** 1985), and 200-600 mg/L (**Knox** 1985). Ammonia concentrations in the Vancouver area are up to 372 mg/L for the Port Mann landfill leachate (**Jasper**, et al. 1986) and about 200-250 mg/L for the Burns Bog landfill leachate used in this study.

Ammonia has been shown to be toxic to fish, and can also affect receiving waters through eutrophication, nitrogenous oxygen depletion, and nitrate and nitrite contamination (**Water Pollution Control Fed.** 1983). There are health hazards

associated with nitrates and nitrites such as infant methemoglobinemia, and the suspected formation of potent carcinogenic compounds called nitrosamines (**Shuval and Gruener 1975**). **Mirvish (1975)** reported that nitrates may increase the risk of gastric cancer, and that N-Nitroso (NNO-) compounds, readily formed by nitrite and either amines or amides, may also be human carcinogens.

2.2 LEACHATE TREATMENT

High ammonia leachate can be treated by several different methods other than by biological nitrification and denitrification. Physical-chemical methods, recirculation, and biological removal by assimilation are viable alternatives. The choice for each method, or combination thereof, will depend on the leachate characteristics, the amount and form of nitrogen to be removed, and the economics involved.

2.2.1 Physical-Chemical

Physical-chemical treatment can include air stripping, ion-exchange, and breakpoint chlorination. The **Water Pollution Control Fed. (1983)** and the **U.S. EPA (1975)** have produced manuals for the design and theory of nitrogen removal, and include these physical-chemical removal techniques. **Atkins and Shcerger (1975)** summarized the advantages and disadvantages of nitrogen removal by physical-chemical methods. The advantages of most physical-chemical methods are

a uniformity of removal, insensitivity to toxins and temperature, and minimal sludge production in most cases. The disadvantages are the high cost of chemicals and power. The physical-chemical methods so far described cannot remove organic nitrogen, thus chemical coagulation, filtration, and possibly activated carbon adsorption may be necessary.

Keenan, et al. (1984) used air stripping to remove ammonia from landfill leachate. Chemical precipitation was used to remove metals and increase the pH for the air stripping process. Aerobic biological treatment was necessary to remove BOD, organic nitrogen, and residual ammonia from the air stripping process.

2.2.2 Recirculation

Recirculation of the leachate back into the landfill is not an ultimate nitrogen removal technique but rather a possible means for a slight nitrogen reduction. Recirculation is generally accomplished by spray irrigation onto the landfill surface. **Robinson and Maris (1985)** did a 3 year field study and concluded that recirculation promoted more rapid stabilization of BOD, decreased leachate volume through evaporation, and possibly produced a stronger but more consistent leachate. Ammonia may have been removed by air stripping and by aerobic bacteria. Air stripping by spray irrigation was probably fairly low due to a leachate pH of 7, whereas optimal pH for air stripping is above 10 (**Water**

pollution Control Fed. 1983; U.S. EPA 1975).

Maris, et al. (1985), commenting on the same 3 year study, stated that recirculation is only an intermediate step and not an end solution. Stegmann and Spendlin (1985) studied spray recirculation and determined that spray irrigation should be practiced to promote leachate volume reduction and for greater biological treatment within the landfill, before being sent to a treatment plant.

2.2.3 Biological Assimilation

Biological nitrogen assimilation is the removal of nitrogen as a nutrient for cell synthesis. This method requires a high BOD loading to stimulate biological growth. Robinson and Maris (1985) conducted a laboratory study to treat relatively low ammonia landfill leachate. An aerobic, completely-mixed fill and draw system was used. Influent ammonia concentration was 76 mg/L and effluent levels were below 1 mg/L. The study concluded that since the BOD:N was 100:5, the nitrogen was used for metabolic purposes rather than used for nitrification.

Robinson (1988) treated a high ammonia leachate in an aerated lagoon. The leachate had a low BOD:N (as low as 1:1), so an industrial jam waste was incorporated into the leachate stream to bring the BOD:N up to 100:9, which was lower than the optimum 100:5. At 100:9, 15% of the ammonia

was removed by assimilation, while 25% was observed to be nitrified. The remaining 60% was unaccounted for, but thought to be due air stripping and nitrification with denitrification.

Boyle and Ham (1974) studied the effect of leachate addition to sewage in the amounts of between 0 and 20%, using a lab-scale completely mixed aerobic fill and draw system. The leachate had a high COD (10,000 mg/L). They concluded that leachate could be added at a rate as high as 5%, without a serious increase in oxygen uptake rate or substantially increased solids production. They infer that the nitrogen was removed by biological assimilation.

Kelly (1987) also studied leachate addition to sewage before treatment in a sewage treatment plant. Leachate was added at 2%, 4%, and 16% by volume to sewage into a pilot-scale aerobic activated sludge plant. The leachate COD was over 1100 mg/L and the ammonia was about 70 mg/L. Ammonia removals of up to 80% were observed for the 4% addition. Ammonia removal data was not available for the 16% leachate addition.

2.3 NITRIFICATION

Nitrification is a biological process through which ammonia becomes oxidized to nitrite and then further oxidized to nitrate. As described in the Chapter 1, the autotrophic

bacteria **Nitrosomonas** first converts the ammonia to nitrite, and then **Nitrobacter** converts nitrite to nitrate. Detailed reference to this process is widely documented (**U.S. EPA 1975; Benefield and Randall 1980; Water Pollution Control Fed. 1983; Barnes and Bliss 1983; Water Research Commission, S.A. 1984**). Nitrification can be inhibited by many substances, many of which are found in landfill leachate.

2.3.1 Nitrification Inhibition

Nitrification has been reported to be affected by a wide range of inhibitors, such as metals, pH, extreme temperatures, and even free ammonia and nitrous acid. Metals are important as many different metals can be present in leachate. **Beg and Hassan (1987)** studied the inhibitory effects of hexavalent chromium, trivalent arsenic, and fluoride on nitrification in a packed-bed biological flow reactor, and found that all three induced inhibitory effects. **Dedhar (1985), Dedhar and Mavinic (1985)** reported that elevated manganese concentrations did not inhibit nitrification of high ammonia leachate, but that zinc in concentrations of 17.6 mg/L did cause substantial inhibition. **Mavinic and Randall (unpublished)** studied the toxicity effects of zinc, chromium, and nickel on a biological pre-denitrification leachate treatment system. Preliminary analysis indicates that nitrification was inhibited by all three metals. They also observed the combined effect of zinc and cold temperature has also shown serious inhibitory

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effects on nitrification.

The effect of ammonia and nitrous acid, the acid form of nitrite, are of interest because these compounds are the substrates for the nitrifiers. Anthonsen, et al. (1976) conducted a study on the inhibitory effects of un-ionized ammonia and un-ionized nitrous acid on nitrification. They concluded that both caused some inhibition, and that un-ionized ammonia significantly affected the conversion of nitrite to nitrate by Nitrobacter.

Suthersan and Ganczarczyk (1986) studied the inhibitory effects on Nitrobacter by un-ionized ammonia. They found that pH played an important role in the inhibition by the ammonia. Higher pH (pH 8.0-8.8) caused greater inhibition.

Turk (1986), Turk and Mavinic (1986) attempted to use unionized ammonia for a shortened pathway for complete nitrogen removal. The process involved oxidation of ammonia to nitrite only due to the presence of un-ionized ammonia, and then denitrification of the nitrite to nitrogen gas. This system was able to operate until Nitrobacter apparently was able to acclimatize to the high levels of free ammonia.

Keenan, et al. (1979) reported that ammonia levels over 300 mg/L inhibited both the oxidation of ammonia and organic material. They also suspected that nitrification was

inhibited by relatively high BOD and COD concentrations of 9000 mg/L and 16,000 mg/L respectively.

Mueller, et al. (1985) reported that shock loading of ammonia in a refinery waste caused temporary inhibition of the nitrification process. This may have been caused by free ammonia inhibition or by a lag time by the microbial organisms to respond to the shock load.

Hooper and Terry (1973) studied inhibitors of **Nitrosomonas** and concluded that short-chain alcohols such as **methanol, ethanol, propanol,** and **butanol** were significant inhibitors of ammonia oxidation.

2.3.2 Nitrification of Leachate

Nitrification of landfill leachate has been used successfully to remove ammonia. **Dedhar** (1985) and **Mavinic and Randall** (unpublished) used pre-denitrification biological systems to remove ammonia. **Cook and Foree** (1974) used a lab-scale fill and draw aerobic reactor to remove organic material from leachate. At the same time, they noted nitrate increase with an ammonia decrease, which was attributed to nitrification.

Knox (1985) operated an outdoor aerobic activated sludge pilot plant and a trickling filter pilot plant over a two year period. The influent leachate had ammonia

concentrations in the range of 150-500 mg/L. Complete nitrification was established in both plants.

2.4 DENITRIFICATION

Denitrification is the biological reduction of nitrate to nitrite, and then a further reduction of nitrite to nitrogen gas. The bacteria, capable of nitrate and nitrite respiration, are heterotrophic bacteria which, unlike the autotrophic nitrifiers, require organic carbon as an electron donor. The denitrifiers produce an enzyme which enables them to use nitrate or nitrite. This enzyme is repressed in the presence of oxygen (**Simpkin and Boyle 1985**). Many bacterial species are capable of denitrification (**U.S. EPA 1975; Water Pollution Control Fed. 1983**).

Denitrification requires the absence of oxygen, the presence of nitrate or nitrite, and a readily degradable organic carbon source. The absence of oxygen can be easily managed and nitrate and nitrite can be supplied via nitrification. The organic carbon must either be present in the influent or added to the anoxic reactor from an external source. In the case of "older" leachate, which is characteristically low in easily degradable organic carbon, an external carbon source is necessary. The external source has traditionally been methanol, but the price of methanol has risen dramatically so alternative carbon sources have been evaluated.

2.4.1 Carbon Sources

The most famous paper on carbon sources for denitrification is by **McCarty, et al.** (1969). They tested acetic acid, acetone, ethanol, sugar, and methanol. Their data shows that acetic acid and ethanol were equally effective, if not more so, for denitrification purposes as methanol. Methanol was chosen to be the preferred carbon source on the basis of economics, as methanol was the less expensive than acetic acid and ethanol at the time.

The **U.S. EPA Process Design Manual for Nitrogen Control** (1975) suggests the use of methanol based partially on the McCarty paper. The manual even has an entire section devoted to the handling, storage, feed control, and removal of methanol.

Barnes and Bliss (1983) mention alternative carbon sources such as acetic acid, acetone, raw waste water, methane, and endogenous respiration products, but all the details for denitrification calculations are based on methanol as the electron donor.

Methanol has been used successfully for denitrification in many denitrification studies (Smith 1971 Vol.1&2; Climenhage 1972; Sutton, et al. 1975; Lewandoswki 1982; Kaplan, et al. 1984; Melcer, et al. 1984; Manoharan, et al. 1988; Mavinic and Randall (unpublished)). The price of methanol has risen

with the price of petroleum and is now an expensive carbon source for denitrification (Water Pollution Control Fed. 1983). Alternatively, less expensive carbon sources have become desirable and have been studied. Denitrification has been achieved using nitro-celluose (Mudrack 1961), fish meal and gelatin (Ludzack and Ettinger 1962), lactate (du Toit and Davies 1973), peptone (Paskins, et al. 1978), and acetone (Lewandoswki 1982). Glucose (Schroeder and Busch 1967; Paskins, et al. 1978; Dedhar 1985) and a glucose and sodium acetate mixture (Argaman and Brenner 1986) have also been found to be satisfactory for denitrification. Lewandowski (1982) found acetic acid more effective than methanol for increasing the denitrification rate, and Narkis, et al. (1979) found sodium acetate to be just as effective as methanol.

Wilderer, et al. (1987) used lab-scale sequencing batch reactors to denitrify nitrate. Two SBR systems were studied, one with glucose as the carbon source, and the other with acetate. While the acetate system performed perfectly, the glucose system started to accumulate nitrite. The authors concluded that glucose promoted fermentative conditions under which facultative anaerobes predominated. Facultative anaerobes are thought to be capable of nitrate to nitrite conversion, hence the nitrite buildup. These findings are in accordance with a study by Blaszczyk (1983) in which different carbon sources, ethanol, methanol, glucose, and

acetate were each found to produce a different dominating species of denitrifiers under denitrification conditions. Only glucose showed problems by accumulating nitrite, and lowered pH due possibly to facultative anaerobes under fermentative conditions.

Manoharan, et al. (1988), and Mavinic and Randall (unpublished) used a pilot-scale single sludge pre-denitrification system to treat high ammonia leachate. Glucose and methanol were compared as carbon sources. Denitrification with methanol proved to be consistent and reliable. In contrast, glucose provided unreliable denitrification, which fluctuated from 0-100%. Both the pH and ORP in the anoxic basin dropped, which indicating the presence of facultative anaerobes. Nitrite buildup also occurred at this time.

Wastes that are high in degradable carbon are also being investigated for suitability in the denitrification process. Primary sludge (Abufayed and Schroeder 1986) and raw sewage (Nicholls 1975; Tholander 1975) are reported to work very reliably. Beer and Wang (1978) used endogenous respiration to provide carbon for nitrate respiration.

Industrial wastes such as brewery waste (Wilson and Newton 1973), industrial organic wastes (Haltrich 1967), and phenolic waste with methanol addition (Nutt and Marvan 1984)

have been investigated with favorable results. **Monteith, et al.** (1979, 1980) reviewed 30 wastes and compared the denitrification rates with that of methanol. Twenty-seven of the wastes exhibited denitrification rates greater than or equal to that of methanol. The majority of these wastes were from the food and beverage industry, especially the brewery and distillery industries.

Skrinde and Bhagat (1982) compared yeast, corn silage, whey, and spent sulphite liquor wastes with methanol for denitrification purposes. The denitrification efficiencies of all the wastes were found to be comparable to those observed with methanol.

Kaplan, et al. (1984) considered 11 industrial waste carbon sources for denitrification of nitrate-contaminated munitions process wastewater. Methanol was tested and found to be more efficient than the tested wastes, which included sweet and acid whey, corn steep liquor, soluble potato solids, brewery spent grain, sugar beet molasses, and raw sewage sludge. Ninety-five percent denitrification was recorded for all the wastes except the sewage sludge.

2.4.2 Carbon Breakthrough

Carbon breakthrough in a nitrification-denitrification system occurs when excess degradable carbon from the anoxic

reactor bleeds into the aerobic reactor. The effect of carbon breakthrough on a biological nitrogen removal system has not been well studied. Although there are very few references on this subject, there are studies in which this may have occurred.

Bridle, et al. (1979) studied a full-scale activated single sludge pre-denitrification plant that was used to treat nylon wastes. These wastes contained high concentrations of ammonia, organic nitrogen, nitric and nitrous acids, and organic carbon in the form of one to five chain mono-basic acids. The organic removal in the anoxic basin was recorded as 20-30%, which implies that carbon breakthrough was occurring. Denitrification efficiencies of greater than 98% were constant but consistent nitrification was a problem. The authors blamed temperature variations and high organic nitrogen levels for this inconsistency, but the another contributing factor may have been carbon breakthrough.

Narkis, et al. (1979) used a bench-scale two sludge pre-denitrification system for nitrogen removal for sewage. Lime treated sewage was the carbon source for denitrification. The study mentions that the nitrification reactor was very sensitive to organic loading, but no data was given to indicate how sensitive the reactor was. This illustrates that carbon breakthrough may be a problem.

Melcer, et al. (1984) used a bench-scale single sludge pre-denitrification system to treat coke plant and blast furnace blowdown water. The carbon sources for denitrification were phenolic compounds with methanol added. The system experienced carbon breakthrough, and the excess carbon, mainly in the form of methanol, resulted in a reduction in the specific nitrification rate. This reduction was surmised to be due to heterotrophic growth in the aerobic basin. The study states, "Comparison of total system operation with and without methanol addition demonstrated that the nitrification process was unstable when methanol was added unnecessarily to the system".

Carbon breakthrough was noted in the paper by Manoharan, et al. (1988). Carbon breakthrough by both glucose and by methanol was observed. Nitrification was not apparently affected by methanol, but glucose caused an inconsistent performance in nitrification, which was thought to be due to heterotrophic competition.

This literature review is by no means exhaustive for these selected topics. The topics and references were chosen to provide a foundation for this study to build upon. The literature selected is representative of the current state of knowledge and understanding of leachate treatment, inhibition of nitrification, carbon sources for denitrification, and carbon breakthrough.

3. EXPERIMENTAL SET-UP AND OPERATION

Two identical bench-scale biological single-sludge pre-denitrification systems, with recycle, were used in this study. The basic configuration of each system was an anoxic reactor, then an aerobic reactor, and a final clarifier with a recycle line back to the anoxic reactor. The system is shown schematically in **Figure** 2. Two experimental runs were conducted, each with two different carbon sources for denitrification requirements. The first run used glucose in one system and methanol in the other. The second run used acetate in one and waste brewer's yeast, from a Carling O'Keefe Brewery, in the other. The four systems studied were fed a municipal landfill leachate.

3.1 TREATMENT SYSTEM

3.1.1 Leachate Feed

The leachate feed was an "older" leachate, collected from the City of Vancouver's Burns Bog Landfill in Delta, British Columbia. The leachate was collected from the southwest corner of the landfill as shown in **Figure** 3. The leachate had a consistently high ammonia concentration of about 200 mg/L and a very low soluble BOD_5 of about 20 mg/L. The basic characteristics of the leachate have been compiled in Table 1. The leachate was collected once a week and stored at a temperature of 4 degrees Celsius until required. The leachate
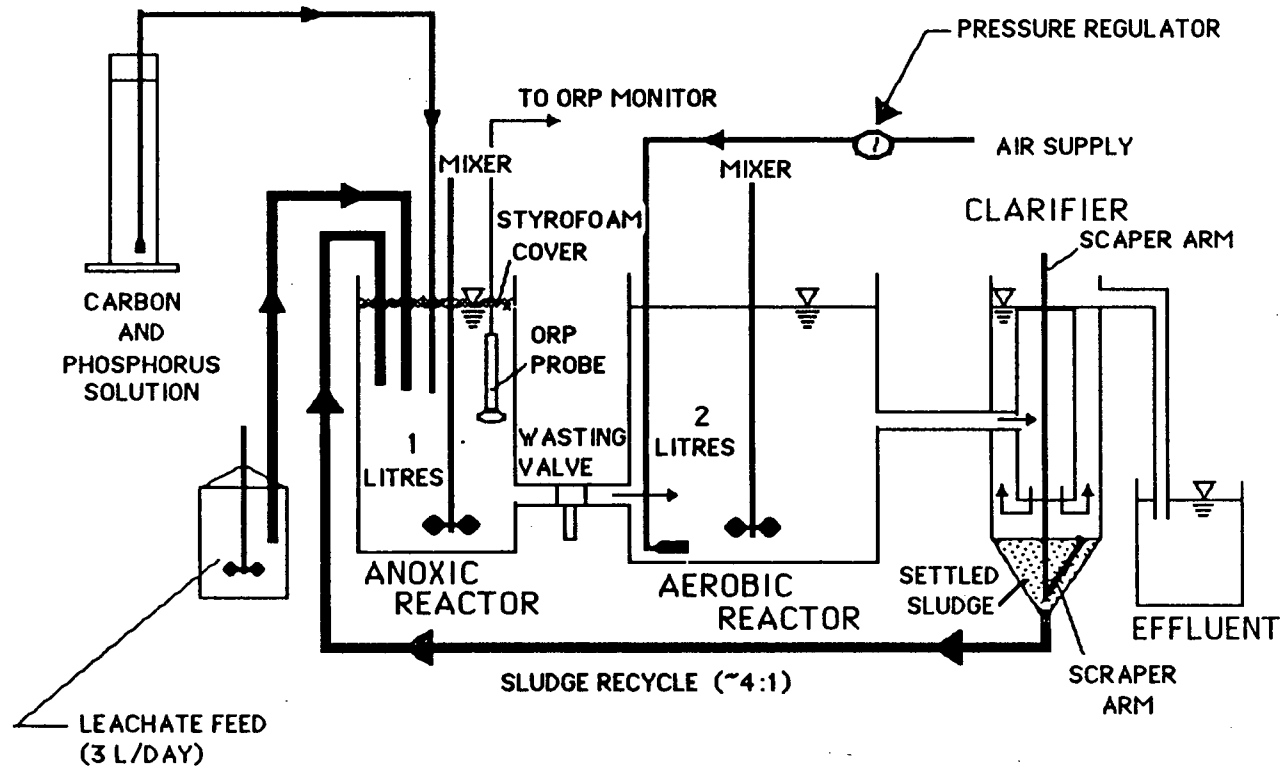
Figure 2. EXPERIMENTAL SYSTEM SCHEMATIC

Crescent Slough

Wet Well and
Pump

Surface Water Interception
Ditch to be converted to
Leachate Collector as
Fill advanced

Highway No. 499

Discharge Initially to
adjacent ditch during
Trial Period to determine
Flow Volumes - Flow will be
connected to Annacis Island
Interceptor when complete
(1979 - 1980)

LEGEND

— — — — — Surface Drainage Ditches

— — — — Leachate Ditches
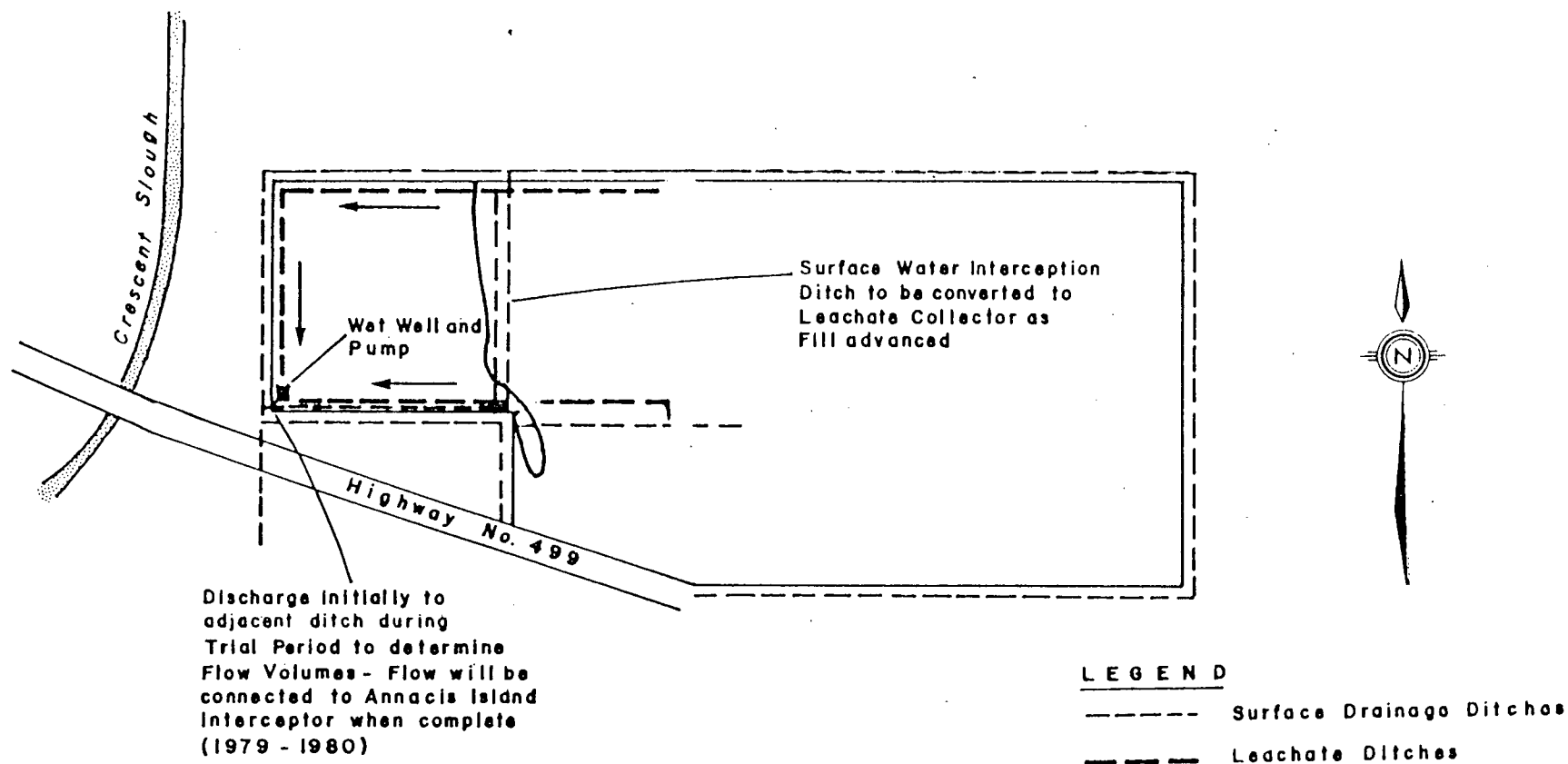
Figure 3. Burns Bog Landfill Site

ref: Atwater, 1980

TABLE 1.

BASIC CHARACTERISTICS OF BURNS BOG LEACHATE

PARAMETER		CONCENTRATION (mg/L) MEAN	RANGE
COD		325	175-425
BOD		25	10-60
AMMONIA		200	170-240
NOx		8	0-25
NITRITE		3	0-10
ORTHOPHOSPHATE		0.2	0.1-0.6
TKN		230	180-300
SOLIDS	VSS	44	20-100
	TSS	90	20-300
IRON	TOTAL	15	8-30
	DISS.	5	1-7
MANGANESE	TOTAL	1.5	0.7-2.0
	DISS.	1.0	0.2-1.3
ZINC	TOTAL	0.3	0.1-0.5
	DISS.	0.15	0.1-0.5
pH		7.6	7.3-8.0

was fed continuously into the anoxic reactors at an approximate rate of 3 litres per day for each system. The leachate supply was contained in a covered plastic bucket at room temperature, between 17 and 22 degrees Celsius, and was mixed continuously by a mechanical mixer. The stored leachate was added every three or four days as necessary. The leachate exhibited a small ammonia loss in the supply bucket. Nitrate and nitrite also appeared as ammonia disappeared, indicating that a small amount of biological nitrification was occurring in the supply bucket.

3.1.2 Anoxic Reactor

The anoxic reactor was a cylindrical plexiglass container. The liquid volume of the reactor was 1 litre and was completely mixed by a mechanical mixer. A floating styrofoam cover prevented aeration by reducing contact between the air and the liquid. An Oxidation-Reduction Potential (ORP) probe continuously monitored the ORP in the reactor.

The reactor received three incoming liquid streams: influent leachate, nitrified return sludge, and a carbon/phosporus solution for denitrification requirements. The leachate was pumped at approximately 3 litres per day and entered the reactor via a glass pipe positioned just below the liquid surface,thus preventing unnecessary surface turbulence. The nitrified return sludge from the clarifier was also discharged from a glass tube just below the surface at a

continuous rate of about 12 litres per day. In the case of methanol, glucose, and acetate the carbon solution was administered continuously at a rate between 80 and 150 milliliters per day. The brewer's yeast waste was added at about 1 litre per day to prevent clogging of the lines by yeast solids. Tri-basic sodium phosphate was added to the methanol, glucose, and acetate carbon solutions to ensure that phosphorus was not a limiting nutrient. The yeast waste contained a high concentration of phosphate, so further addition was not necessary.

Denitrification occurred in this reactor, utilizing the carbon solution as a source of electron donors for nitrate and nitrite respiration. The filtered BOD_5 of the influent leachate and of the return sludge was low enough to be considered negligible.

3.1.2.1 Carbon Solutions

The carbon solutions of methanol, glucose, and acetate were prepared once a week and stored at four degrees Celsius until required. The appropriate carbon solution was pumped into the anoxic reactor from a glass 500mL graduated cylinder. No biological growth was observed in any of the cylinders over the course of the study. These three carbon solutions were prepared by adding the calculated mass of carbon chemical, liquid methanol, D-glucose, or sodium acetate, to one litre of distilled water. Tri-basic sodium phosphate was added at

approximately 3g/L. The solutions were mixed thoroughly until the carbon and phosphate had completely dissolved. No precipitate of any kind was observed in any of the solutions.

The yeast waste solution was prepared by diluting a calculated volume of brewer's yeast waste, a slurry of yeast solids, with distilled water. The yeast waste had been washed with phosphoric acid at the brewery to deactivate the yeast, thus phosphate addition was not necessary. The acidic nature of the waste necessitated that the yeast waste solution be buffered by sodium carbonate to bring the pH above 7. The yeast waste solution was prepared every second day and was kept at room temperature in a glass flask. The solution was pumped continuously from a glass flask that was kept completely mixed by means of a magnetic stir bar and a stir plate. The mixing was necessary in order to keep the yeast solids in suspension.

The brewer's yeast waste was collected from the Carling O'Keefe Brewery in Vancouver once every 5 weeks. Two litres of waste yeast were collected each time and stored in an airtight container at four degrees Celsius and at a pH<2 (due to the acid wash). The yeast waste was characterized by high COD and BOD_5, high phosphate and TKN, and moderately high FTKN and ammonia concentrations. Table 2 summarizes the yeast waste characteristics.

TABLE 2.

BREWER'S YEAST WASTE CHARACTERISTICS

| PARAMETER | CONCENTRATION (mg/L) | |
	MEAN	RANGE
TKN	13,000	11,800-13,500
FTKN	7,500	5,500-9,200
AMMONIA	2,500	1,850-3,800
ORTHOPHOSPHATE	2,500	1,800-3,500
COD UNFILTERED	300,000	250,000-350,000
FILTERED	115,000	110,000-150,000
BOD UNFILTERED	150,000	140,000-170,000
FILTERED	73,000	71,000-76,000
pH	< 2.0	

3.1.3 Aerobic Reactor

The aerobic reactor was a cylindrical plexiglass container connected to the anoxic reactor by a 8mm flexible tube, which had a three-way valve to permit wasting of mixed liquor from either the aerobic reactor or the anoxic reactor. The liquid volume of each aerobic reactor was 2 litres and was aerated by a porous stone air diffuser located in the bottom of the container. The reactor was kept completely mixed by a mechanical mixer. The dissolved oxygen concentration was monitored at least once a day, using a Dissolved Oxygen (DO) probe. The residual DO was maintained between 1 and 6 mg/L, to ensure sufficient DO for nitrification and carbon oxidation.

Nitrification occurred in this reactor, with ammonia oxidized first to nitrite and then to nitrate. Carbon oxidization occurred when excess carbon from the anoxic reactor bled into the aerobic reactor.

3.1.4 Clarifier

The clarifier was a 0.8L cylindrical plexiglass container with a conical bottom. The clarifier was connected to the aerobic reactor by 8mm flexible tubing. The clarifier had an open-ended inner cylindrical compartment into which the mixed liquor from the aerobic reactor flowed. The solids

settled down the inner compartment and then into the conical bottom where a mechanical scraper arm guided the solids into the recycle line. The recycle was operated for a recycle to influent ratio of 4:1, to produce a clarifier retention time of about 1.3 hours. The supernatant flowed around the bottom of the inner cylinder and up the sides of the clarifier to the outlet weir. The effluent was collected in large flasks.

Theoretically, no biological activity was supposed to occur in the clarifier, but, realistically, there most likely was a small amount of nitrification. Also, when carbon bled through both the anoxic and aerobic reactors into the clarifier, carbon oxidation could continue to use up the residual oxygen and, if no oxygen remained, then denitrification could occur.

3.2 OPERATION

The basic operating conditions for all four systems are shown in Table 3.

3.2.1 Methanol and Glucose

The methanol and glucose systems were started on October 17, 1987. The reactors were filled with waste sludge from the University of British Columbia's mobile sewage treatment pilot plant, and with waste from a similar biological leachate treatment system under the supervision of Dr. D.S.

TABLE 3.

BASIC OPERATING CONDITIONS

	METHANOL, GLUCOSE and ACETATE SYSTEMS	YEAST WASTE SYSTEM
VOLUME (LITRES) [1] ANOXIC AEROBIC CLARIFIER SYSTEM	1.0 2.0 0.8 3.8	1.0 2.0 0.8 3.8
SRT (DAYS) [2] AEROBIC SYSTEM	10 19	10 19
HRT (NOMINAL) [3] ANOXIC (HOURS) AEROBIC CLARIFIER SYSTEM	8 16 6.4 30.4	8 16 6.4 30.4
HRT (ACTUAL) [3] ANOXIC (HOURS) AEROBIC CLARIFIER SYSTEM	1.6 3.2 1.3 6.0	1.6 3.2 1.3 6.0
CARBON SOLUTION FLOW (mL/day)	100	1200
RECYCLE RATIO (RECYCLE:INFLUENT)	~ 4:1	~ 3.7:1
INFLUENT FLOW	3.0 L/DAY	3.0 L/DAY

[1]. VOLUMES DO NOT INCLUDE THE VOLUMES DUE TO PUMP HEADS OR RECYCLE LINES.

[2]. $SRT = \dfrac{\text{MASS SUSPENDED SOLIDS IN REACTOR}}{\text{MASS SUSPENDED SOLIDS WASTED PER DAY FROM THE REACTOR}}$

[3]. $HRT = \dfrac{\text{VOLUME}}{\text{FLOW RATE}}$ NOMINAL HRT IS BASED ON INFLUENT FLOW RATE
ACTUAL HRT IS BASED ON INFLUENT PLUS RECYCLE FLOW RATE
PLUS CARBON SOLUTION FLOW

Mavinic. A small amount of sludge from a bench-scale biological phosphorus removal system run by Nelson Lee was also added. Both systems were run at an infinite Solids Retention Time (SRT) until complete nitrification of the leachate was established; at this point, a wasting rate of 200mL per day was started. This wasting rate resulted in a 10 day aerobic SRT.

The designated carbon solution addition to the anoxic reactors was started on Oct. 24, 1987 at an approximate COD:NOx of 0.83:1 for methanol and 1.22:1 for glucose. This carbon loading was held around this level for 1 week and increased slightly each week after that, as shown in **Figure 4.**

The glucose system failed around Feb. 24, 1988 after reaching a COD:NOx of about 23:1. Failure was a loss of nitrification and denitrification. The glucose addition was halted at this point and complete nitrification was restored by Mar. 4, 1988. Both systems were shut down on March 7, 1988 after 143 days of operation. The methanol system had reached a COD:NOx of 56.5:1, without any operational problems.

3.2.2 Acetate and Yeast Waste

The acetate and yeast waste systems were started on Mar. 21, 1988. As in the first run with methanol and glucose, the reactors were filled with waste sludge from the mobile

Figure 4.

COD:NOx FOR METHANOL AND GLUCOSE

NUMBER OF DAYS SINCE START

□   GLUCOSE   +   METHANOL
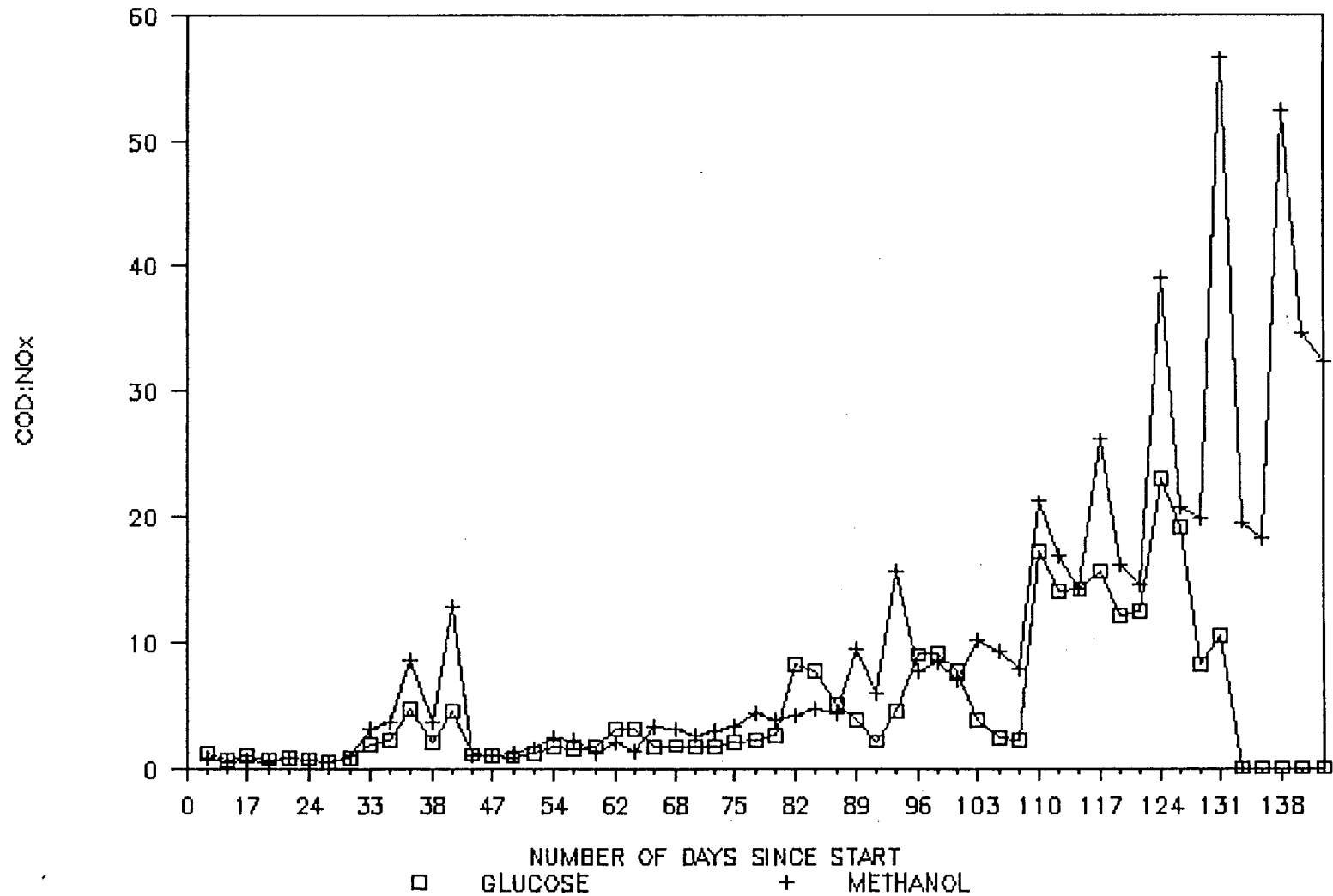
sewage treatment plant, the laboratory leachate treatment, and from the bench-scale biological phosphorus removal system. Both systems were run at infinite SRT until complete nitrification was achieved. Wasting of 200mL per day to maintain a 10 day aerobic SRT was started on Apr. 4, 1988.

Carbon addition commenced on Apr. 12,1988 at a COD:NOx 3.9:1 for acetate and 3.5:1 for the yeast waste. Pump problems caused the addition to rise up to 7.4:1 for acetate and 8.7:1 for the yeast waste system. This carbon loading was more than the system could handle, without acclimatization of the denitrifiers. The anoxic ORP, based on Ag-AgCl$_2$ ORP probes, dropped from above 0 mV to -428 mV for the acetate, and from +106 mV to -343 mV for the yeast waste. These ORP decreases occurred over the six days following the start of the carbon addition. Judging from the first run, the anoxic ORP should have been about -100mV for this COD:NOx. The COD:NOx was reduced back to 3.1:1 for the acetate, and 2.8:1 for the yeast waste. The COD:NOx was then increased weekly, as shown in **Figure 5**.

Both systems were terminated on June 20,1988, after 92 days of operation. The acetate system had reached a COD:NOx of 16.7:1, with 2 extreme values of 61.7:1 and 136.3:1. The yeast waste system had reached a COD:NOx of 41.9:1, with 3 extreme values of 82.2:1, 193.8:1, and 196.8:1. Neither nitrification or denitrification appeared to be

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Figure 5.

COD:NOx FOR ACETATE & YEAST WASTE

NUMBER OF DAYS SINCE START

□ ACETATE   +   YEAST WASTE
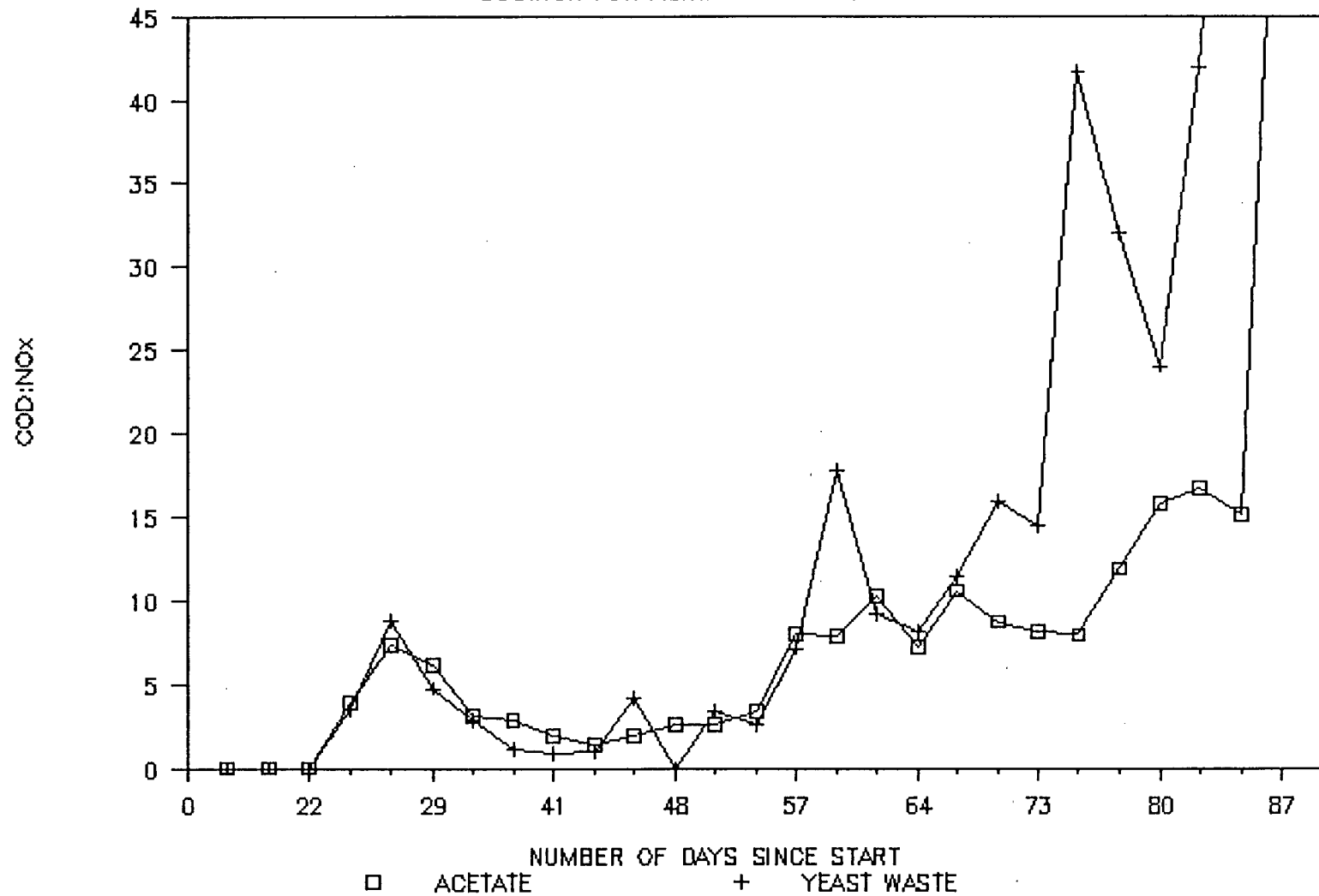
significantly hindered at these COD:NOx levels, but severe rising sludge in the clarifiers caused blockage of the outlet weirs.

4. ANALYTICAL METHODS

The following tests and analyses were performed on each of the four systems, with the exception of the filtered TKN analysis which was done only for the yeast waste system samples.

4.1 DISSOLVED OXYGEN (DO)

Dissolved oxygen measurements were taken daily in the aerobic reactors using a Yellow Springs Instruments Co. Model 54 ARC Dissolved Oxygen meter with a submersible dissolved oxygen probe. The probe membrane was changed and calibrated every two weeks. The DO of the aerobic reactors was maintained between 1 and 6 mg/L by the use of flow regulators on the laboratory air supply.

4.2 pH

Aerobic and anoxic pH measurements were recorded daily using a Fisher Accumet Mode 320 Expanded Scale Research pH meter with an Orion Combination pH probe. The pH of the influent leachate was also recorded on a daily basis. The pH probe was calibrated once a week with a pH 7 standard buffer.

4.3 OXIDATION-REDUCTION POTENTIAL (ORP)

ORP measurements, in mV, of the anoxic reactors were recorded daily using an Ag-AgCl$_2$ Broadle/James Corp. ORP electrode.

The probes were submersed in the anoxic mixed liquor throughout both runs and were cleaned once a week with distilled water. There was no attempt to calibrate the probes, thus absolute values are not exact, and cannot be used with any degree of accuracy.

4.4 TEMPERATURE

The aerobic reactor liquid temperatures were recorded daily with a standard mercury thermometer. The methanol and glucose systems had a temperature range between 17 and 22 degrees Celsius and an average temperature of 19 degrees Celsius. The acetate and yeast waste systems recorded a high and low temperature of 17.5 and 23 degrees Celsius, with an average of 20 degrees Celsius.

4.5 SOLIDS

Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) were analyzed three times a week on samples from the influent leachate, anoxic and aerobic mixed liquors, and the effluents. The solids testing was conducted in accordance with Standard Methods (1985).

4.6 BIOCHEMICAL OXYGEN DEMAND (BOD)

Samples of the influent leachate, anoxic and aerobic mixed liquors, and effluents were filtered through Whatman #4 filter paper and then tested for 5 day BOD. The test was performed twice a week and the procedure was in accordance

with Standard Methods (1985). The dilution water used in the test was seeded with 0.5 mL of each of the aerobic mixed liquors tested. A Yellow Springs Instrument Co. Ltd. Model 54 Dissolved Oxygen meter with self-mixing DO probe was used to measure the initial and final DO concentrations. The probe was calibrated each day by the azide modified Winkler titration as described by Standard Methods (1985).

4.7 CHEMICAL OXYGEN DEMAND (COD)

Weekly COD tests were performed as described in Standard Methods (1985) on filtered (Whatman #4) samples of the influent leachate, anoxic and aerobic mixed liquors, and the effluents. The samples were preserved with concentrated sulfuric acid and stored in plastic bottles at 4 degrees Celsius. The leachate had a high chloride concentration which could have interfered with the COD test, so mercuric sulphate was added to each sample before testing to suppress the chloride interference.

COD analysis was also conducted on the unfiltered yeast waste solution to determine the actual COD. This testing was performed three times a week.

4.8 METAL CONCENTRATION

Total and dissolved zinc, iron, and manganese concentrations were determined weekly for the influent leachate, anoxic and aerobic mixed liquors, and the effluents. Dissolved metal

samples were first filtered through Whatman #4 filter paper, acidified with concentrated nitric acid, boiled down to less than half the original volume, refiltered through Whatman #54 filter paper, and finally made up to half the original volume with distilled water. The total metal (unfiltered) samples were dried at 103 degrees Celsius, fired at 550 degrees Celsius to remove the organic content, acidified with nitric acid and boiled to redissolve the metals, filtered (Whatman #54), and finally made up to the original volume with distilled water. The samples were stored in plastic bottles at room temperature until analyzed.

The metal analyses were performed on a Jarrel Ash Video 22L Atomic Absorption Spectrophotometer using a lean acetylene/air flame. The metal analysis was undertaken to observe metal concentrations and ensure that any failure of a system was not due to a sudden influx or buildup of metals.

4.9 ORTHOPHOSPHATE

Orthophosphate samples were collected three times a week on filtered (Whatman #4) samples of the influent leachate, anoxic and aerobic mixed liquors, and effluents. The samples were preserved with mercuric acetate and refrigerated in plastic bottles at 4 degrees Celsius. The analysis was run once a week on a Technicon Auto Analyzer II Colorimeter in accordance with the methods described in Technicon Industrial Method No. 94-70W.

4.10 NITRITE

Samples for nitrite were collected three times a week on the influent leachate, anoxic and aerobic mixed liquors, and effluents. The samples were filtered (Whatman #4), preserved with mercuric acetate, and stored at 4 degrees Celsius in plastic bottles until analyzed. The analysis was performed weekly on the Technicon Auto Analyzer II Colorimeter in accordance with the analytical guidelines of Technicon Industrial Method No. 100-70W.

4.11 NITRITE + NITRATE (NOx)

Filtered (Whatman #4) NOx samples were taken three times a week for the influent leachate, anoxic and aerobic mixed liquors, and effluents. The samples were preserved with mercuric acetate and stored in plastic bottles at 4 degrees Celsius until analyzed. The analysis was performed once a week on the Technicon Auto Analyzer II Colorimeter as described in Technicon Industrial Method No. 100-70W. The Auto Analyzer was fitted with a cadmium-silver alloy reducing column to reduce nitrate to nitrite for detection by the colorimeter.

4.12 AMMONIA

Ammonia was analyzed by two different methods, by colorimetry and by distillation.

4.12.1 Colorimetry

This analysis used the Technicon Auto Analyzer II Colorimeter as outlined in Technicon Industrial Method No. 98-70W. Filtered (Whatman #4) samples of the influent leachate, anoxic and aerobic mixed liquors, and effluents were collected three times a week and preserved with concentrated sulfuric acid and refrigerated in plastic bottles at 4 degrees Celsius until analyzed. The ammonia analysis was done once a week. The results of this analysis were used for data analysis.

4.12.2 Distillation

This ammonia analysis was performed daily on the influent leachate and effluents, which were filtered through Whatman #4 filter paper. The analysis was conducted in accordance with **Standard Methods (1980)** and involved diluting the sample with distilled water, raising the sample pH above 10, adding a borate buffer, and distillation into a boric acid indicator. The ammonia concentration was determined by titration with an N/50 sulfuric acid. This testing was used as an operational parameter, to monitor daily influent and effluent ammonia concentrations. A rise in effluent ammonia concentration would indicate a problem with nitrification in the aerobic reactor.

4.13 TOTAL KJELDAHL NITROGEN (TKN)

TKN was analyzed weekly on the Technicon Auto Analyzer II

Colorimeter in accordance with the methods given in Technicon Industrial Method No. 146/71A.

Unfiltered samples of influent leachate, anoxic and aerobic mixed liquors, and effluents were preserved with concentrated sulfuric acid and stored in plastic bottles at 4 degrees Celsius until needed for digestion. The samples were digested in accordance with the Technicon Industrial Method No. 146/71A before analysis. The greatest concern was that the influent TKN was comprised of ammonia. This was verified when compared to the influent ammonia results. This can be seen in **Table 4.**

Filtered (Whatman #4) samples of the influent leachate, and mixed liquors, effluent, and yeast waste solution from the yeast waste system were preserved, stored, digested, and analyzed in the same manner as the unfiltered samples. The filtered TKN was analyzed because the yeast waste solution ammonia was only part of the filtered TKN value. The organic nitrogen portion of the TKN of the yeast waste solution could be hydrolysed to ammonia, which then could be nitrified.

TABLE 4.

INFLUENT AMMONIA, TKN, AND FILTERED TKN

DATE	CONCENTRATION (mg/L)			
	AMMONIA COLORIMETRIC METHOD	AMMONIA DISTILLATION METHOD	TKN	FTKN
NOV 21	182	175	346	N/A
NOV 28	192	181	198	N/A
DEC 5	187	179	185	N/A
DEC 12	212	189	181	N/A
DEC 19	216	193	201	N/A
DEC 26	206	188	223	N/A
JAN 2	198	178	204	N/A
JAN 9	227	211	297	N/A
JAN 16	224	207	210	N/A
JAN 23	148	140	140	N/A
JAN 30	215	202	185	N/A
FEB 6	228	216	208	N/A
FEB 13	179	189	186	N/A
FEB 20	178	195	203	N/A
FEB 27	209	214	249	N/A
MAR 5	211	214	246	N/A
APR 9	194	189	229	N/A
APR 16	193	177	191	N/A
APR 23	180	181	175	190
APR 30	228	234	260	252
MAY 7	215	221	211	244
MAY 14	223	237	254	249
MAY 21	210	206	199	214
MAY 28	190	189	223	212
JNE 4	264	243	266	272
JNE 11	223	206	236	244
JNE 20	188	185	211	211

5. <u>RESULTS AND DISCUSSION</u>

In this section, the results of all four biological nitrogen removal systems will be discussed. Where applicable, the results have been correlated with the COD:NOx. For the acetate and yeast waste systems, extreme COD:NOx data points have been discarded if the COD:NOx was more than twice nearest COD:NOx. Two points were discarded for the acetate system, 61.7:1 and 136.3:1, and three points were discarded for the yeast waste system, 82.2:1, 193.8:1, and 196.8:1. Only the glucose system failed with respect to nitrogen removal.

Data analysis was done on an IBM PC-XT personal computer using Lotus 123 software. Best fit straight lines, where applicable, were generated by the linear regression function of the Lotus 123 software package.

5.1 pH

The behaviour of the aerobic and anoxic pH values differed for each of the four systems. The pH of the leachate was fairly consistent in the range of 7.4 to 7.6. The pH of the leachate did not appear to greatly influence the anoxic or aerobic pH of any of the systems.

5.1.1 Methanol

The pH of both the aerobic and anoxic reactors increased

initially until complete denitrification was achieved. The pH then held steady at pH 7.5 for the aerobic reactor and pH 7.7 for the anoxic reactor. The pH of both reactors appeared to decrease somewhat at a COD:NOx of over 25:1, as illustrated in **Figure 6**. At all times, the anoxic pH remained higher than the aerobic pH; this was expected as denitrification produces alkalinity while nitrification consumes alkalinity.

5.1.2 Glucose

The pH of the glucose system was very erratic when compared to the other three systems. The anoxic pH was consistently lower than the aerobic system, until failure of the nitrogen removal mechanism. This indicates that the anoxic reactor was more acidic than the aerobic reactor. This may be attributed to the production of volatile fatty acids by facultative anaerobes which could ferment the glucose. Best fit straight lines were applied to the anoxic and aerobic pH in **Figure 7**; the aerobic pH appeared to increase with increasing COD:NOx, while the anoxic pH appeared to decrease. The increase of the aerobic pH and the decrease of the anoxic pH are just marginal trends. At failure, the pH of both reactors plummeted from about 7.2 to 6.6, but recovered with several days after the glucose addition was halted. After failure and without glucose, the anoxic pH was consistently higher than the aerobic pH.

Figure 6.

COD:NOX vs AEROBIC AND ANOXIC pH

METHANOL SYSTEM COD:NOx
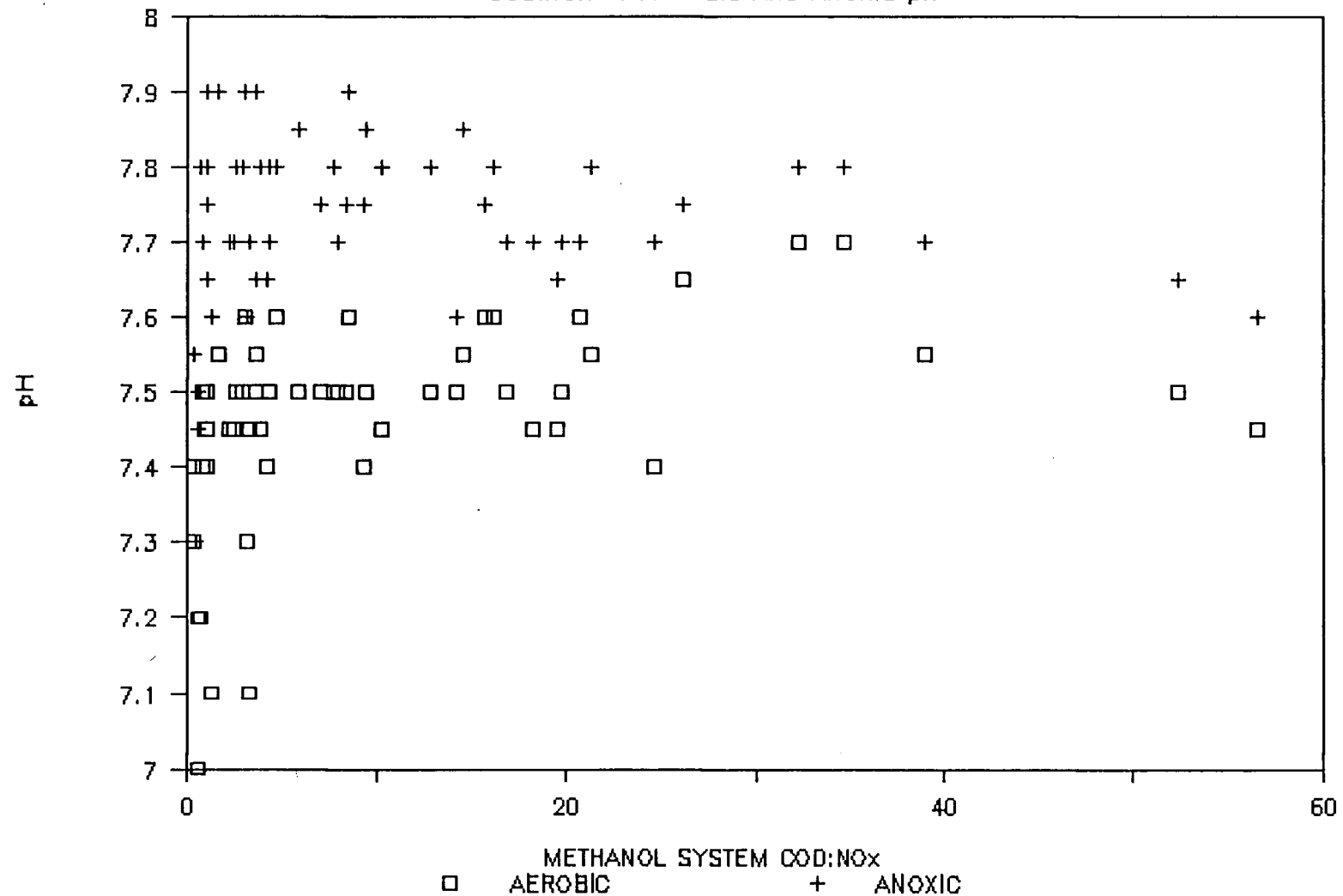
□   AEROBIC   +   ANOXIC

Figure 7.

COD:NOx vs ANOXIC AND AEROBIC pH

GLUCOSE SYSTEM COD:NOx

□ AEROBIC   + ANOXIC

51
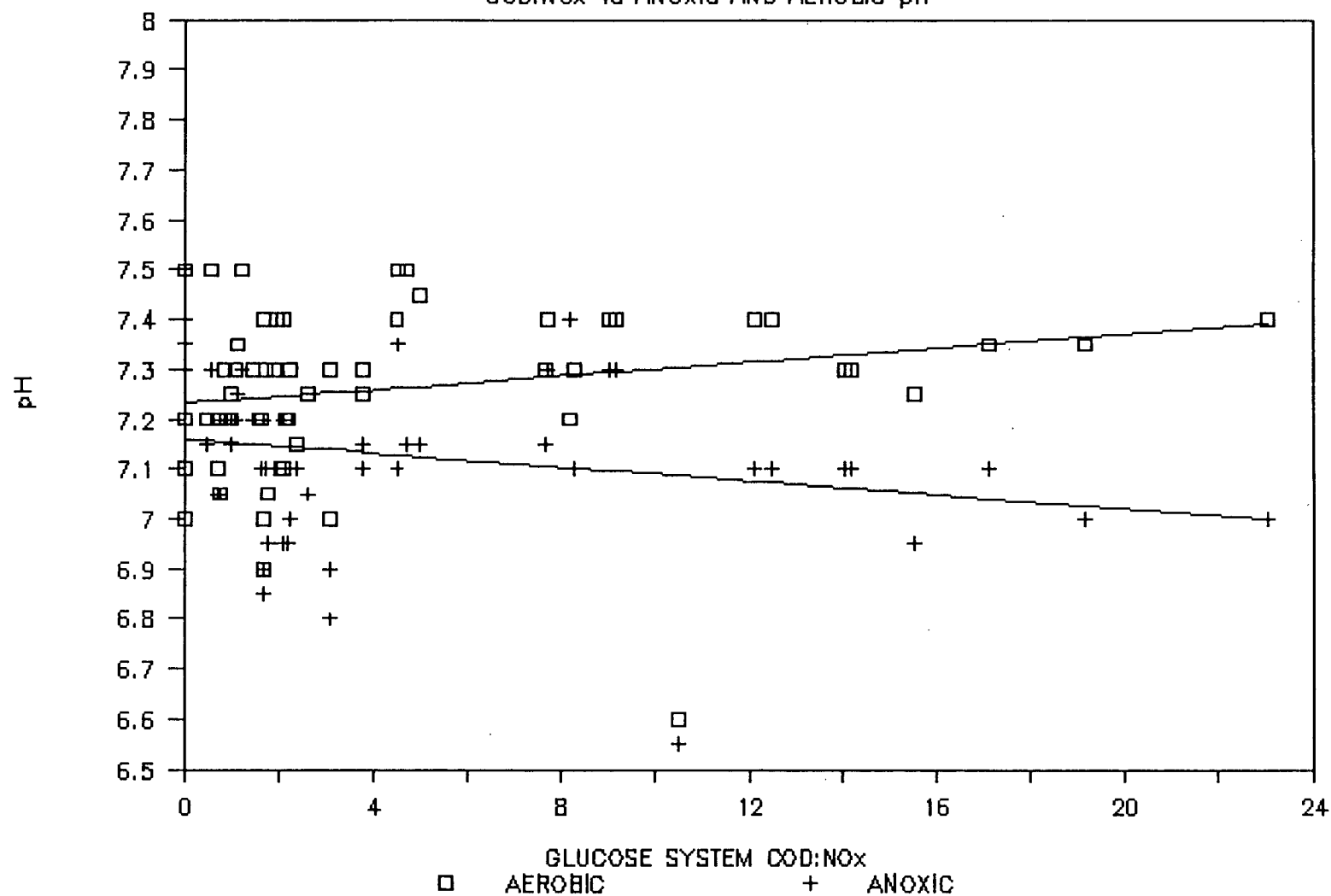
5.1.3 Acetate

Initially, the pH of both reactors increased, then levelled off when complete denitrification was reached. The anoxic pH reached 8.2 and held steady, while the aerobic pH continued to increase slightly from 7.8 to 8.2, with the increase in COD:NOx. As expected, the anoxic pH was consistently higher than the aerobic pH (**Figure 8**).

5.1.4 Yeast Waste

As with the methanol and acetate systems, the pH of both reactors increased with the increase in the percentage of denitrification, and levelled off when complete denitrification was achieved. The aerobic pH held steady after reaching pH 7.4, while the anoxic pH decreased with the increase in COD:NOx (as seen in **Figure** 9). The anoxic pH was higher than the aerobic pH for most of the study, but became lower at higher COD:NOx values. The decrease in anoxic pH may have been due to fermentative conditions in the anoxic reactor, due to excess carbon. The aerobic pH remained around 7.4 for COD:NOx above 10:1.

5.2 OXIDATION-REDUCTION POTENTIAL (ORP)

The behaviour of the anoxic ORP followed two distinct patterns; the first exhibited by the methanol and acetate systems, and the second by the glucose and yeast waste systems. The ORP probes were not calibrated, thus the patterns and relative changes of the anoxic ORP are

Figure 8.

COD:NOx vs AEROBIC AND ANOXIC pH

ACETATE SYSTEM COD:NOx

□ AEROBIC   + ANOXIC   ◇ INFLUENT
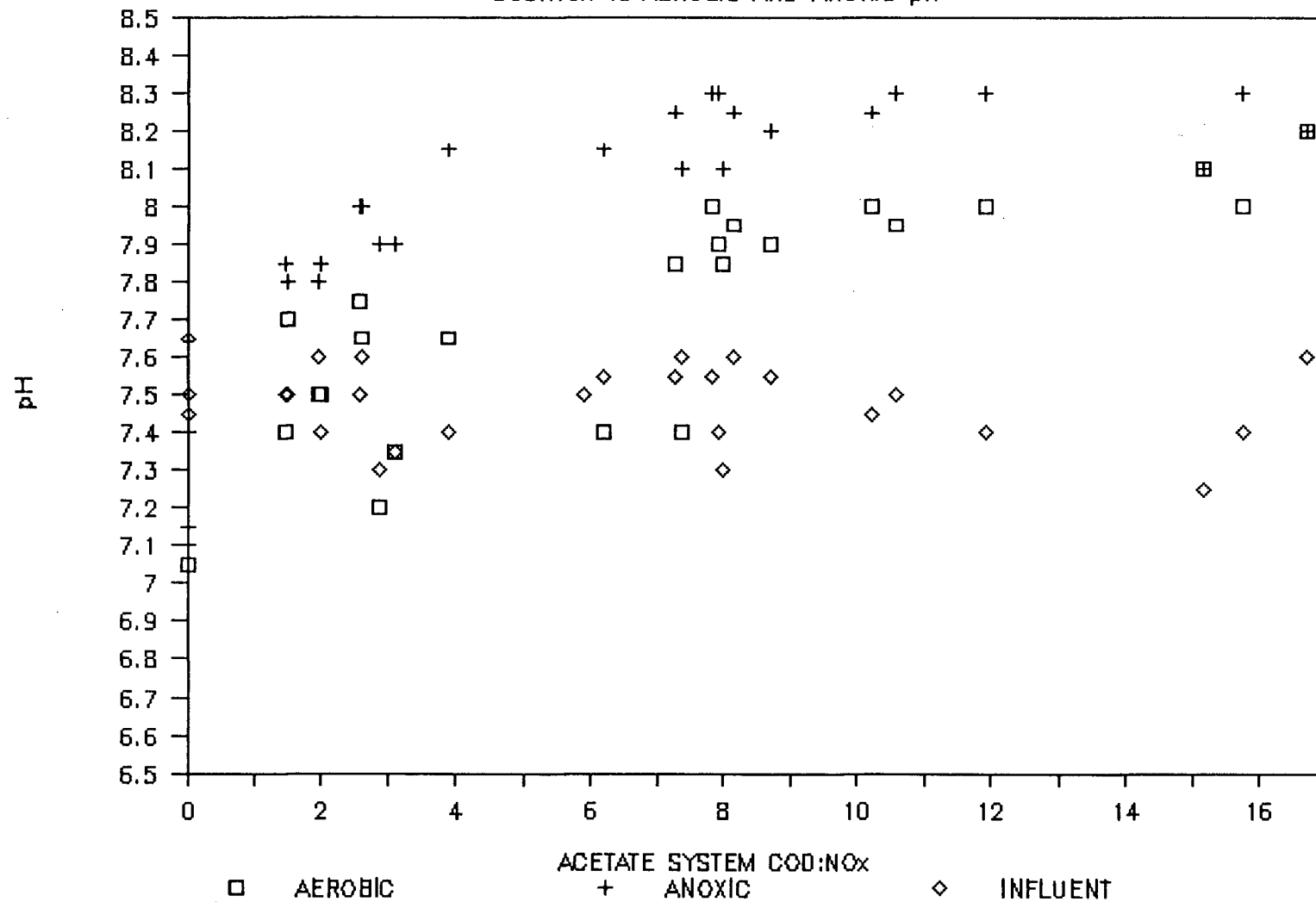
Figure 9.

COD:NOx vs AEROBIC AND ANOXIC pH

YEAST WASTE SYSTEM COD:NOx

□   AEROBIC   +   ANOXIC
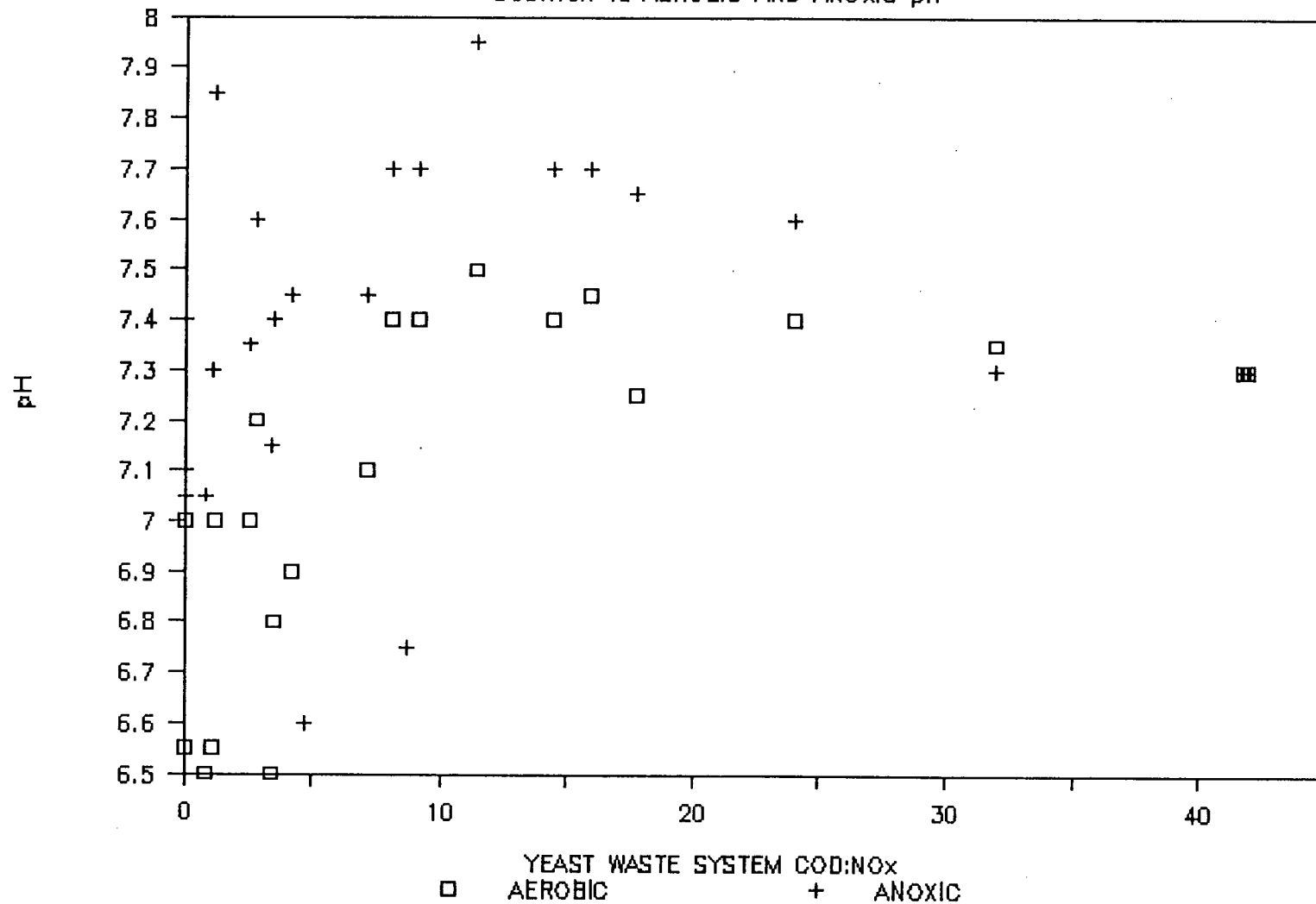
qualitative, rather than the absolute values.

5.2.1 Methanol and Acetate

The anoxic ORP for both of these systems showed an immediate drop, as soon as the carbon addition was started. The ORP then continued to drop as the COD:NOx increased and then leveled off (**Figure 10**). The methanol anoxic ORP leveled off at a COD:NOx of 20:1, while the acetate system anoxic ORP leveled off around 6:1. Both systems leveled off at around-300 to -350 mV.

5.2.2 Glucose and Yeast Waste

The anoxic ORP pattern for these systems was characterized by relatively high ORP values for COD:NOx of up to and even exceeding 5:1 (**Figure 11**). There was not the initial decrease in ORP when the carbon addition was started, as observed in the methanol and acetate systems. This apparent lag in ORP response may be due to microbial acclimatization to these carbon sources, since the initial bacterial seed came from systems which either used methanol (the biological leachate system) or acetate (the phosphorus removal system). The glucose and yeast waste carbons were also more complex than the other two carbons and thus required a longer acclimatization period. The anoxic ORP then dropped and leveled off. The glucose system dropped to -200 mV for a COD:NOx of over 8:1, and the yeast waste system dropped to about -400 mv for over 15:1 values.

Figure 10.
COD:NOx vs ANOXIC ORP

ANOXIC ORP (mV)

COD:NOx

□ METHANOL   + ACETATE
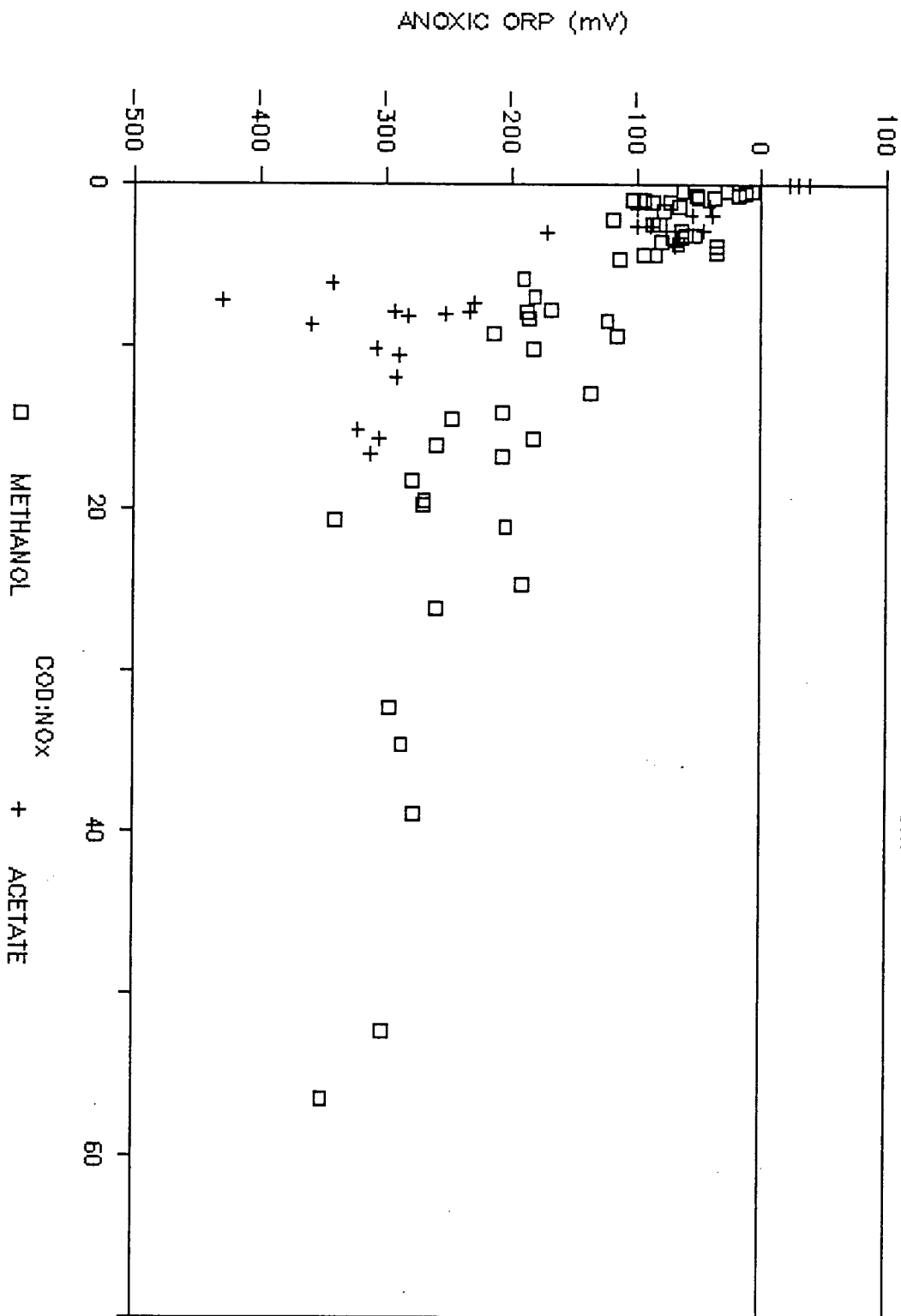
5.3 METALS

The metals that were analyzed for, zinc, iron, and manganese were found to be at low levels. The metal concentrations were found to be fairly constant in the influent leachate throughout the study. The metals were of such low concentrations that there would not to have any significant impact on the operation of the biological nitrogen removal system.

5.4 SOLIDS

As with anoxic ORP, two distinctive patterns emerged with regard to volatile suspended solids in the mixed liquor. Once again, the methanol and acetate systems showed similar behaviour, while the glucose and yeast waste systems behaved in a like fashion. The anoxic and aerobic VSS values were very close, within each system, due to the completely mixed nature of the reactors.

All four systems exhibited rising sludge in the clarifier, but the second run, using acetate and yeast waste, exhibited very high VSS, between 100 mg/L and 2000 mg/L, in the effluents near the end of the study. Rising sludge occurred in the clarifiers as a result of denitrification. The rising sludge occurred when carbon bled through both the anoxic and aerobic reactors into the clarifier. The oxygen was removed through carbon oxidation and resulted in anoxic conditions,

under which denitrification could become established. The denitrification produced minute nitrogen gas bubbles, causing the sludge to float rather than settle. Rising sludge was also observed in the first run, using methanol and glucose, resulting in effluent VSS concentrations between 40 and 80 mg/L. The effluent VSS of all four systems, before rising sludge occurred, ranged between 5 and 30 mg/L.

5.4.1 Methanol and Acetate

The pattern exhibited by the mixed liquor VSS in relation to the COD:NOx is almost a linear relationship. The anoxic and aerobic VSS of both systems rose consistently as the COD:NOx was increased. The VSS values of both systems were similar up to a COD:NOx of 16:1, after which the acetate study was terminated. See (**Figures 12a and 12b**). The rate of VSS increase was reduced after a COD:NOx of about 25:1.

Another characteristic of this pattern was the behaviour of the ratio of volatile suspended solids to total suspended solids (VSS:TSS) in the mixed liquor. The VSS:TSS ratio increased throughout the study and leveled off around 0.87, as shown in **Figure** 13, for the anoxic reactors. The increase in the VSS:TSS ratio may be due to increases in biomass while the non-volatile solids, mainly from the leachate, did not increase.

Figure 12a.

COD:NOx vs ANOXIC & AEROBIC VSS

METHANOL SYSTEM COD:NOx

□ ANOXIC   + AEROBIC

Figure 12b.

COD:NOx vs ANOXIC & AEROBIC VSS

ACETATE SYSTEM COD:NOx

◇ ANOXIC   △ AEROBIC
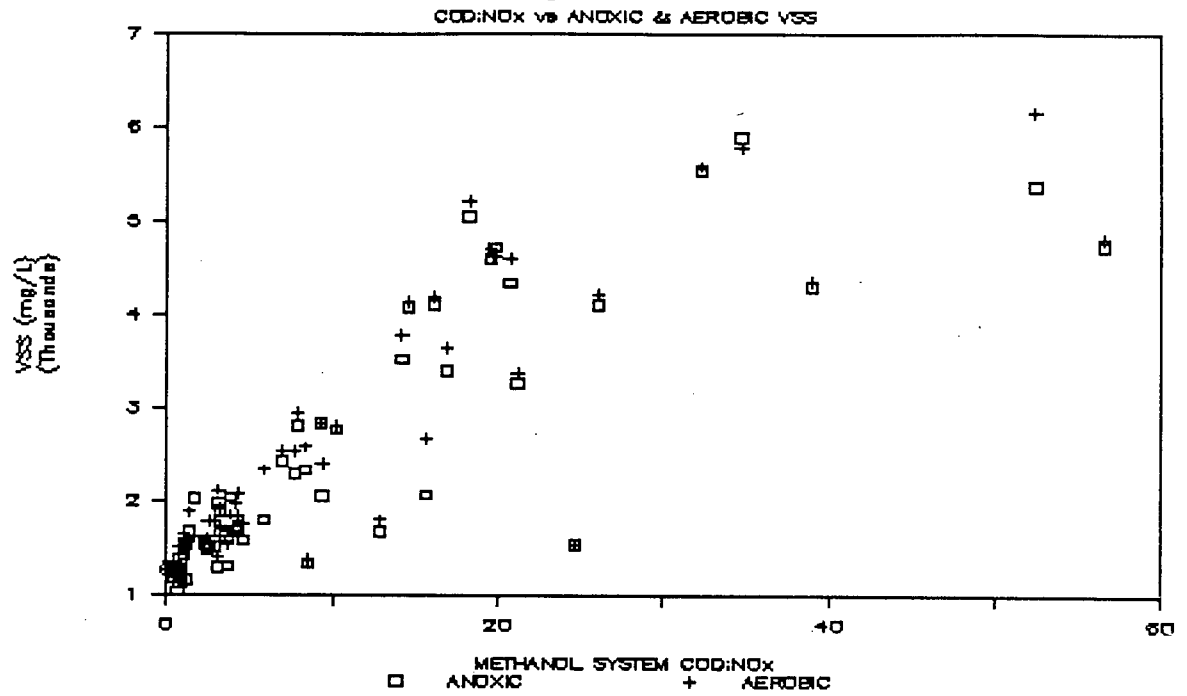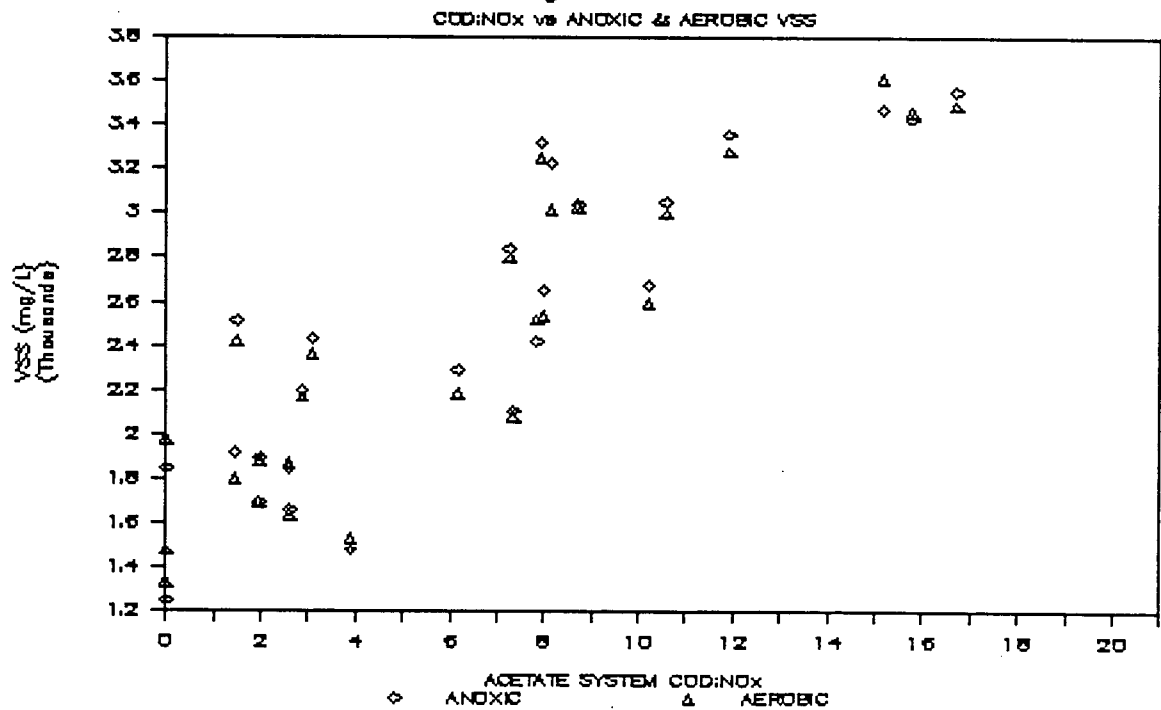
Figure 13.

COD:NOx vs ANOXIC VSS/TSS

ANOXIC VSS/TSS (y-axis)

COD:NOx (x-axis)

□ METHANOL   + ACETATE
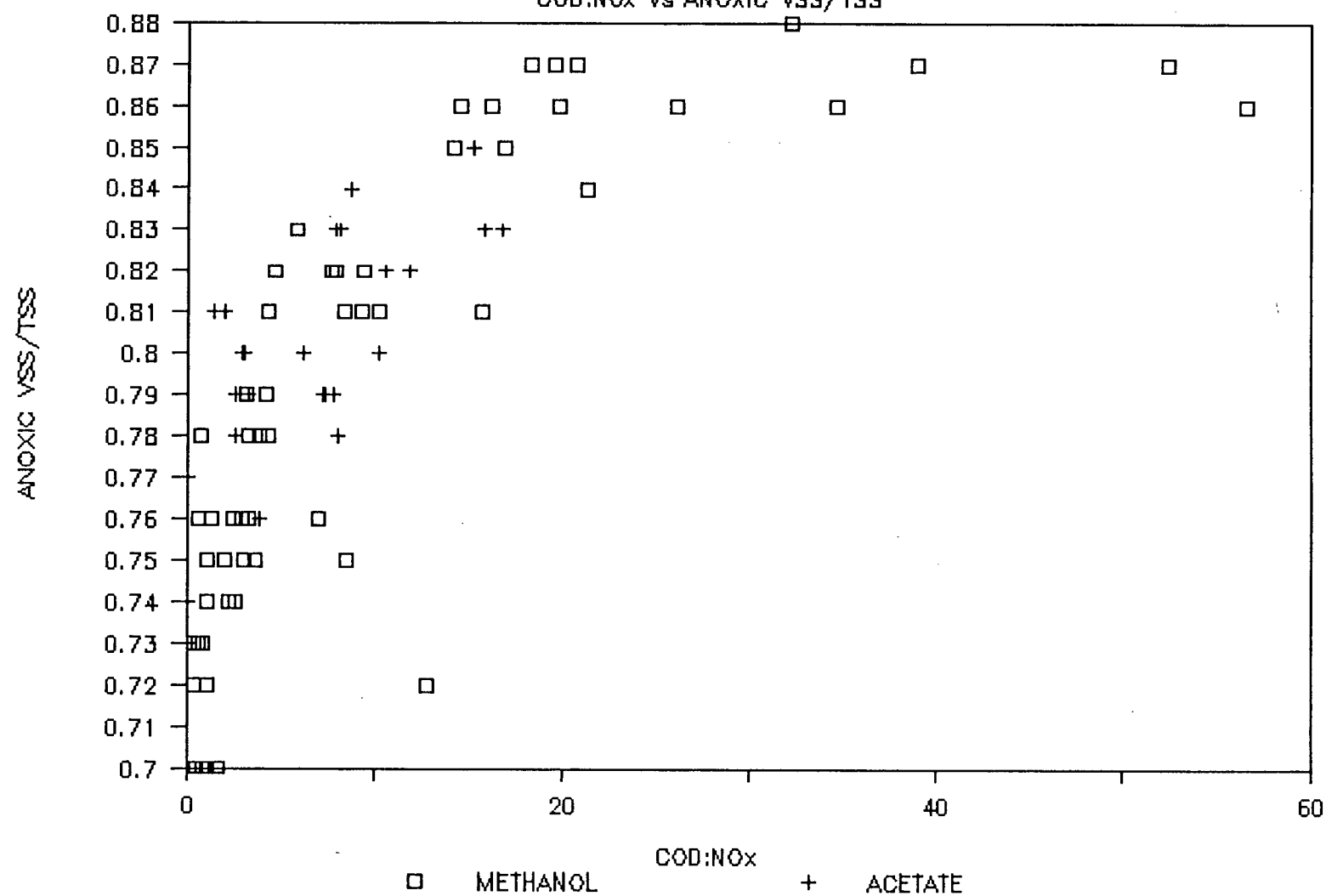
5.4.2 Glucose and Yeast Waste

The main characteristic of this pattern, in relation to COD:NOx, was that both systems showed an initial rapid increase in VSS, followed by a much slower VSS increase as COD:NOx increased (**Figures 14a and 14b**). The rapid increase slowed at COD:NOx of 4:1 and 10:1 for the glucose and yeast waste systems respectively. The VSS at this carbon loading was about 4000 mg/L for glucose, and 6000 mg/L for the yeast waste system. The rapid initial increase appears to contradict the earlier theory that the microbial population needed time to acclimatize to these carbon solutions.

A possible explanation for this contradiction may be that the methanol and acetate are such simple organic compounds that they could be more easily used or stored as energy. The glucose and yeast waste are more complex in terms of their organic structure and were used more for cellular growth rather than for energy production or storage. The bacteria in the glucose and yeast waste systems may have used the glucose, or saccharides in the yeast waste, to produce an extracellular polymeric substance (EPS). The EPS could be in the form of a capsule for protection, and may possibly be triggered by metals in the leachate. This would account for a rise in the VSS, without an increase in the bacterial population. An EPS is commonly comprised of saccharides, such as glucose, and cannot be produced directly from simple organic compounds, such as methanol or acetate (**Boyd 1984**).

Figure 14a.

COD:NOx vs ANOXIC & AEROBIC VSS

VSS (mg/L) {Thousands}

GLUCOSE SYSTEM COD:NOx

□ ANOXIC   + AEROBIC

Figure 14b.

COD:NOx vs ANOXIC & AEROBIC VSS

VSS (mg/L) {Thousands}
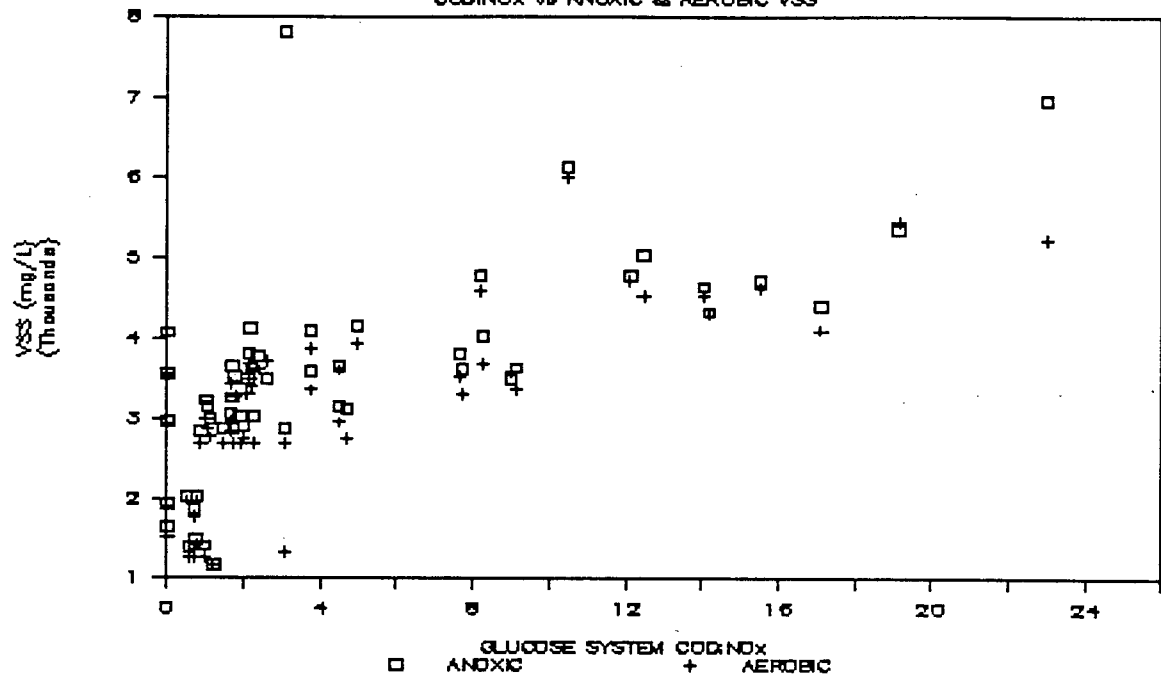
YEAST WASTE SYSTEM COD:NOx

◇ ANOXIC   △ AEROBIC
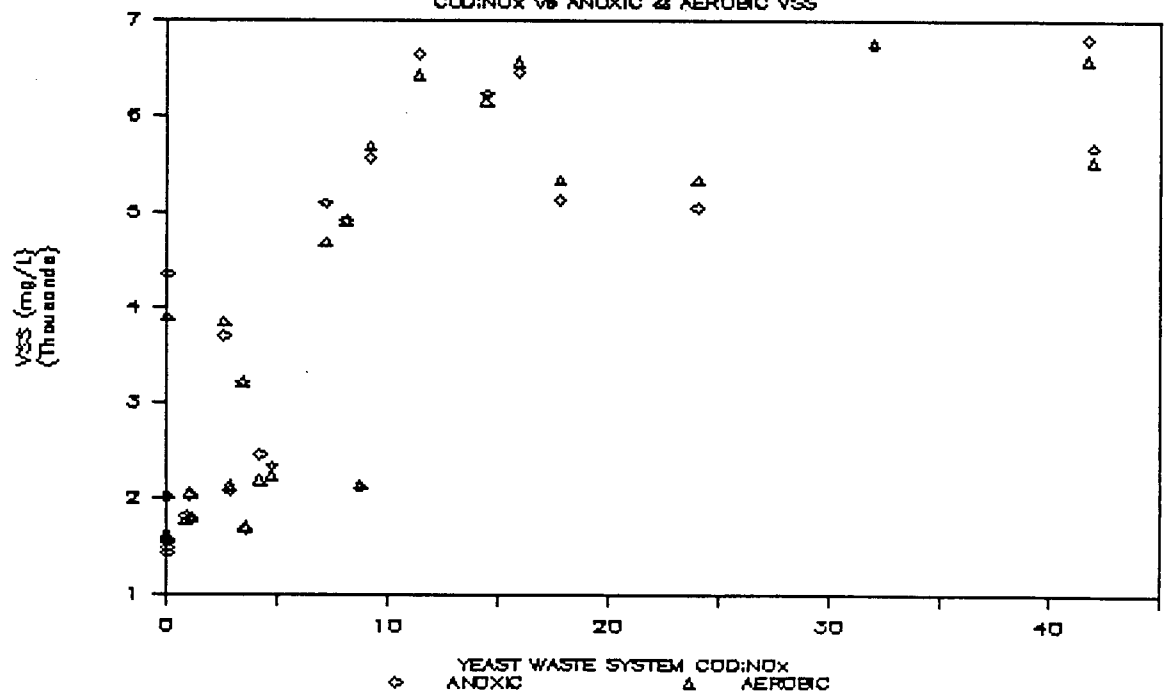
For the glucose system, the measured VSS was assumed to be mostly biomass, due to the soluble nature of the glucose. The yeast waste system had a higher measured VSS than the glucose system, possibly due to yeast solids. The VSS analysis does not distinguish between viable biomass and suspended organics that may be used as substrate.

The VSS:TSS was much more erratic than that of the methanol and acetate systems, fluctuating between 0.75:1 and 0.85:1 for the glucose system, and 0.65:1 and 0.90:1 for the yeast waste system. The glucose showed a very rapid increase before reaching steady state. **Figure 15** shows this trend for the anoxic basin.

5.5 COLOUR

The colour of the mixed liquor in each system changed over the course of the study. The original colour was a light reddish brown. Unlike the trends in pH and ORP, the methanol did not behave the same as acetate, and glucose did not behave the same as the yeast waste. The methanol and yeast waste systems became a dark brown, and the acetate and glucose systems took on a light grey-brown colour. At higher COD:NOx, near the end of the respective experimental runs, the methanol and yeast waste systems changed to a dark grey-brown. After the failure of the glucose system and the glucose addition halted, the mixed liquor changed to dark brown.

Figure 15.

COD:NOx vs ANOXIC VSS/TSS
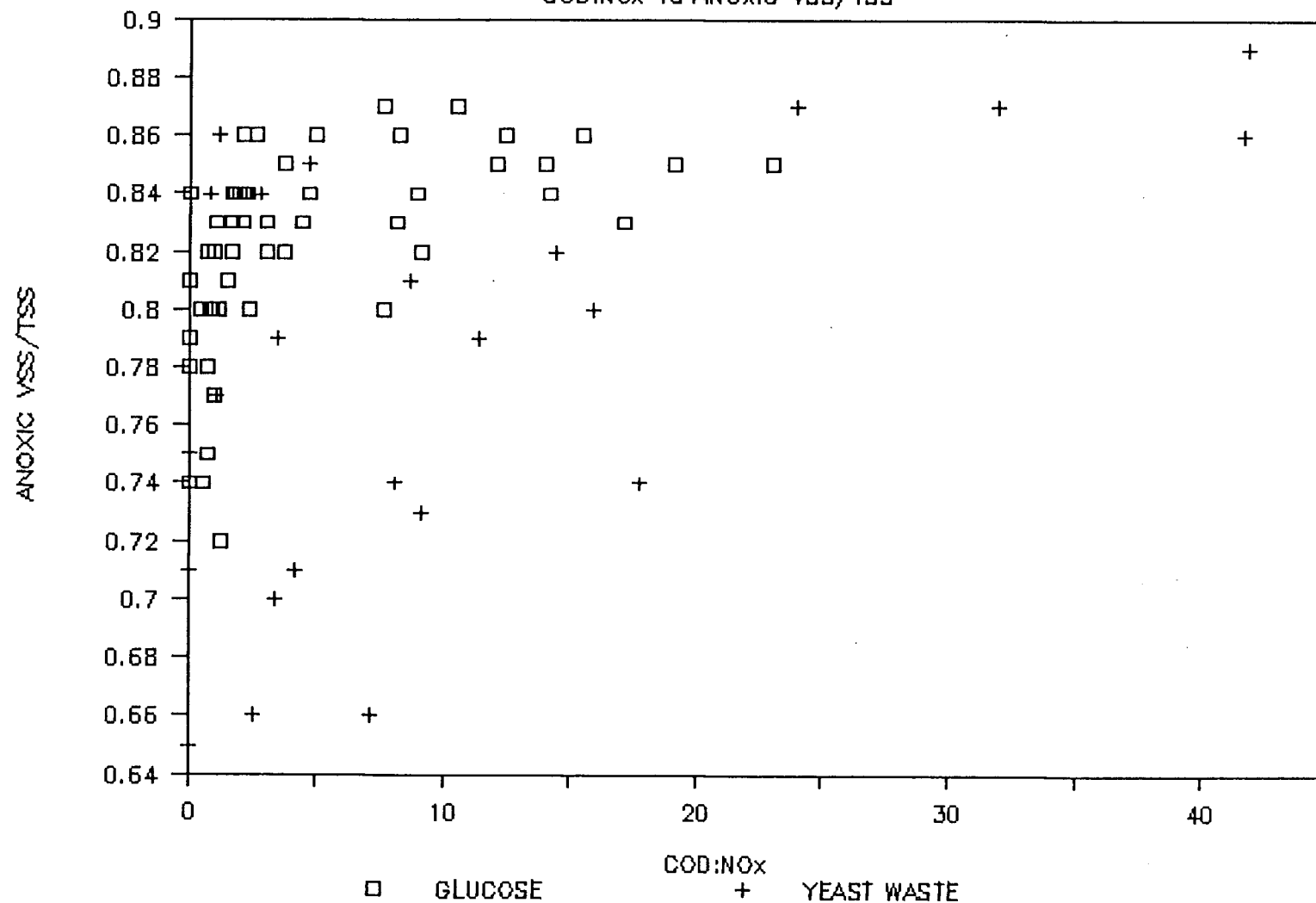
An interesting anomaly occurred between day 36 and day 82 of the methanol study. Small white flocs appeared in the mixed liquor and on the sides of the anoxic reactor. The flocs were analyzed and determined to be microbial in nature. This did not occur in the glucose system which received leachate from the same bucket as the methanol system. The mysterious white flocs became very numerous before disappearing. The white flocs did not appear to affect the performance of the methanol system in any way. A possible explanation is that the methanol was contaminated with something that either produced or encouraged the growth of the white flocs. The white flocs also appeared at the same time in the study by **Mavinic and Randall (unpublished)**, which used the same leachate and methanol.

5.6 CARBON REMOVAL

All systems exhibited similar trends for carbon removal, and thus, for discussion purposes, they will be discussed together. Carbon was measured by COD and BOD_5. The leachate BOD_5 and COD were fairly consistent at 25 mg/L and 325 mg/L respectively. The BOD_5:COD ratio remained around 1:13.

5.6.1 COD Removal

The percent COD removal was calculated for the total system, and over the anoxic and aerobic reactors. For the anoxic and aerobic reactors, the percent removal was calculated for

removal over the reactor rather than as a percentage of the total system removal in order to better understand the removals in each reactor. **Figures 16 to 19** show the percent COD removal for the four systems.

5.6.1.1 TOTAL COD REMOVAL

The total system COD removal held fairly steady at between 70% and 90% after the carbon additions were started. The influent leachate had a high refractory COD, as evidenced by the high effluent COD and by the low influent BOD_5, thus 100% COD removal was unlikely. All four systems exhibited an increase in total COD removal as each run progressed, probably due to acclimatization of the bacterial populations to the respective carbon sources.

When the glucose addition was halted after failure, the total COD removal dropped to about 10%, which was about the percentage of the BOD_5 to COD in the leachate.

5.6.1.2 ANOXIC COD REMOVAL

The percent COD removal across the anoxic reactors was relatively steady in the range of 30-60%, until carbon breakthrough occurred and a decrease in anoxic removal after this. Carbon breakthrough occurred when the amount of carbon entering the anoxic reactor exceeded the carbon removal capacity of the reactor, resulting in carbon bleeding into the aerobic reactor. This is characterized by a decrease in

Figure 16.

METHANOL: PERCENT COD REMOVAL

67

89
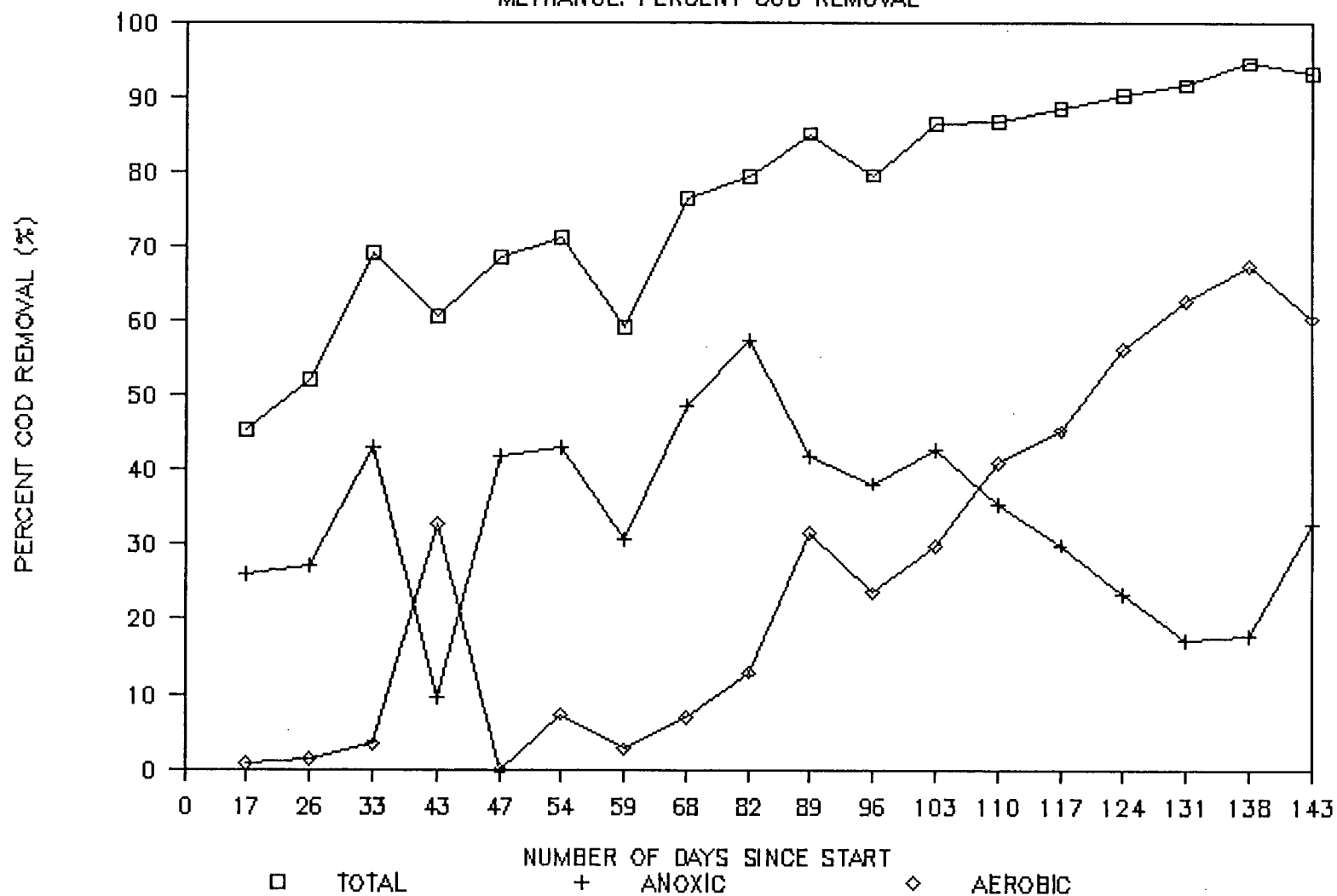
Figure 17.
GLUCOSE: PERCENT COD REMOVAL
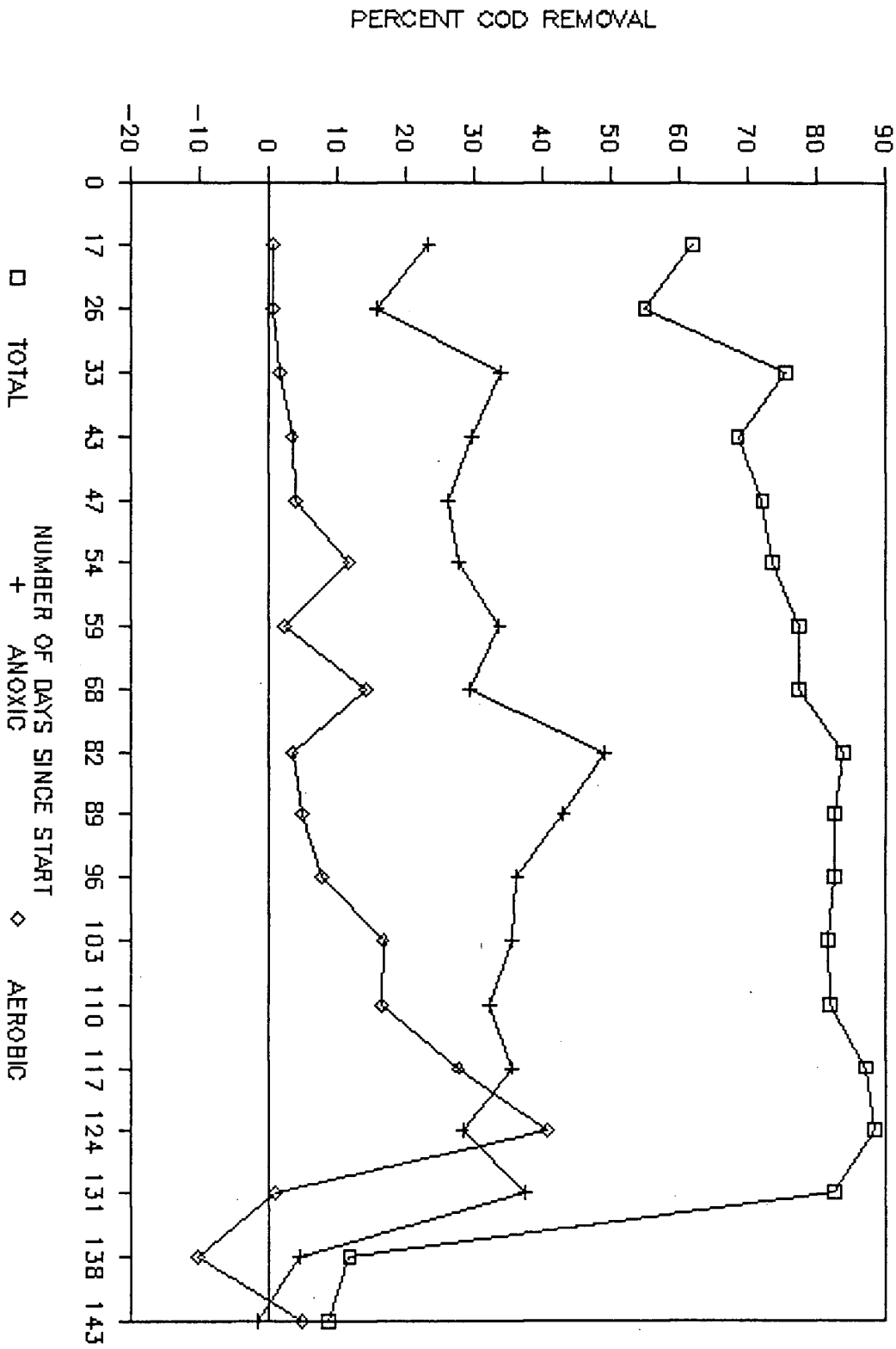
Figure 18.

ACETATE: PERCENT COD REMOVAL

PERCENT COD REMOVAL

NUMBER OF DAYS SINCE START

□ TOTAL + ANOXIC ◇ AEROBIC
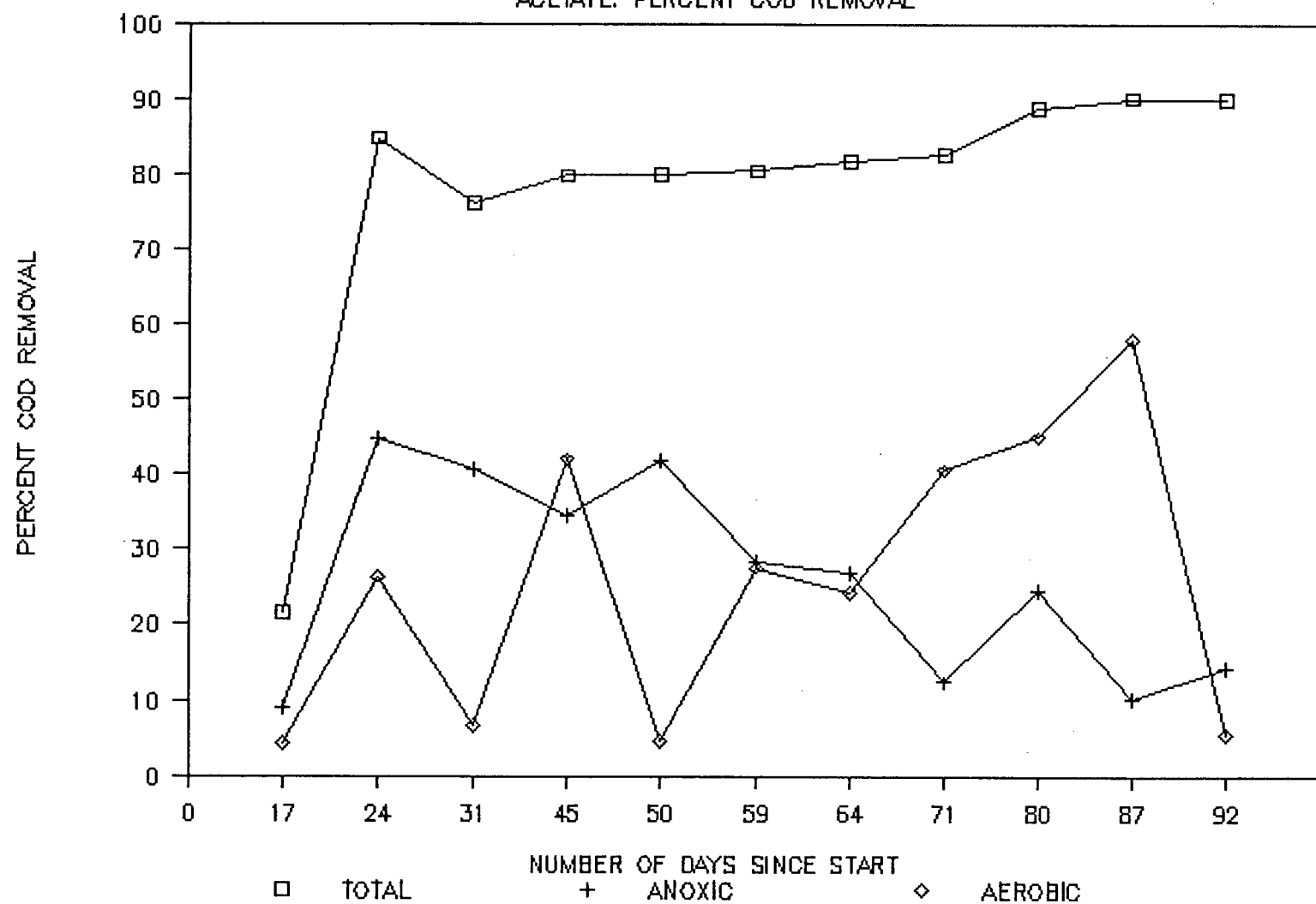
Figure 19.
YEAST WASTE: PERCENT COD REMOVAL

PERCENT COD REMOVAL (%)

NUMBER OF DAYS SINCE START

□   TOTAL   +   ANOXIC   ◇   AEROBIC
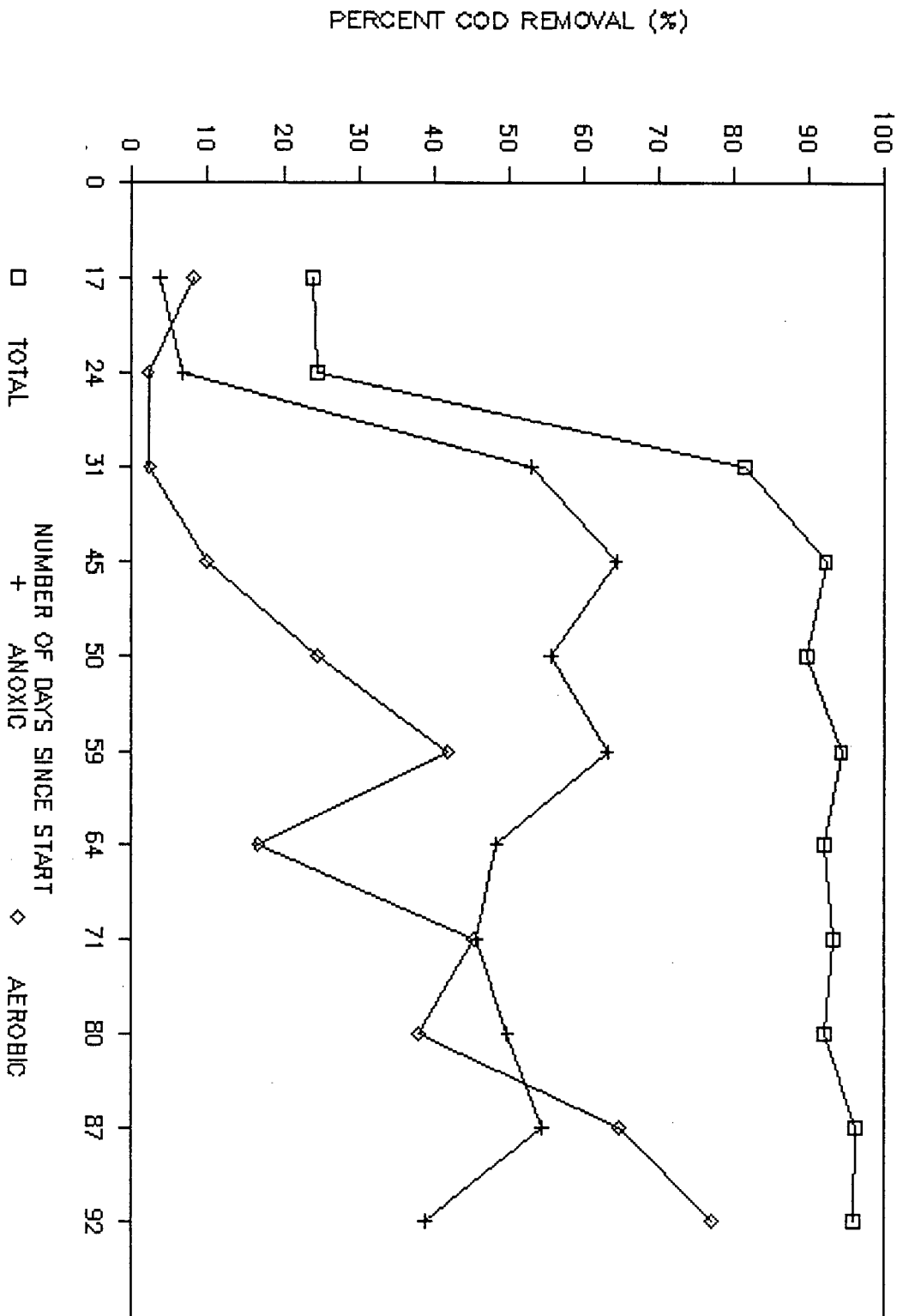
the anoxic removal percentage and an increase in the aerobic percentage removal; a rough estimate can be made, using the COD data, to determine when carbon breakthrough started. Figures 16 to 19, show that carbon breakthrough started around day 89 for methanol, day 110 for glucose, and day 59 for both the acetate and yeast waste systems. These dates are useful as a comparison with those determined using BOD_5 data.

5.6.1.3 AEROBIC COD REMOVAL

The percent COD removal across the aerobic reactors remained relatively low, below 20%, until carbon breakthrough started. Before carbon breakthrough, the aerobic reactors received mainly refractory COD, accounting for the low removal percentage.

The negative anoxic and aerobic removal percentages encountered after the failure of the glucose system indicate that carbon was being liberated from within the reactors (see Figure 17). This internal carbon generation coincides with a sharp decline in the VSS, leading to the conclusion that endogenous respiration and cell lysis were occurring.

5.6.2 BOD_5 Removal

The BOD_5 results were very similar to the COD removal results for the total, anoxic, and aerobic removals. The BOD_5 percentage removals were decidedly higher than those for COD removal. This higher removal percentage is due to the BOD_5

71

test measuring only the biodegradable carbon and not the refractory carbon. The same trends that were observed for COD removal were observed for BOD_5 removal and will not be discussed in detail. **Figures 20 to 23** show the percent BOD_5 removal for the four systems.

The BOD_5 results are more accurate for determining the date of carbon breakthrough since BOD_5 was tested twice a week, rather than just once a week; also the increase in the actual anoxic BOD_5 is so much more pronounced than that of the anoxic COD, due to the refractory carbon content measured by the COD test. Carbon breakthrough can be determined by observing the dramatic increase in anoxic BOD_5 (**Figures 24 to 27**), the decreased anoxic BOD_5 removal percentage, and the increased aerobic removal percentage. Carbon breakthrough was observed to start on day 91 for methanol, day 119 for glucose, day 54 for acetate, and day 62 for the yeast waste system. These results are similar, but probably more accurate than those determined from the COD results.

5.7 NITROGEN REMOVAL

The primary objective of this study was to observe the effect of COD:NOx on the ability of a biological pre-denitrification system to remove nitrogen from a landfill leachate. The three topics of interest in this section are the removal of ammonia, nitrification, and denitrification.

Figure 20.

METHANOL: PERCENT 5-DAY BOD REMOVAL

NUMBER OF DAYS SINCE START

□ TOTAL   + ANOXIC   ◇ AEROBIC

Figure 21.

GLUCOSE: PERCENT 5-DAY BOD REMOVAL

□ TOTAL   + ANOXIC   ◇ AEROBIC

74

Figure 22.

ACETATE: PERCENT 5-DAY BOD REMOVAL

NUMBER OF DAYS SINCE START

□ TOTAL   + ANOXIC   ◇ AEROBIC

Figure 23.

YEAST WASTE: PERCENT 5-DAY BOD REMOVAL
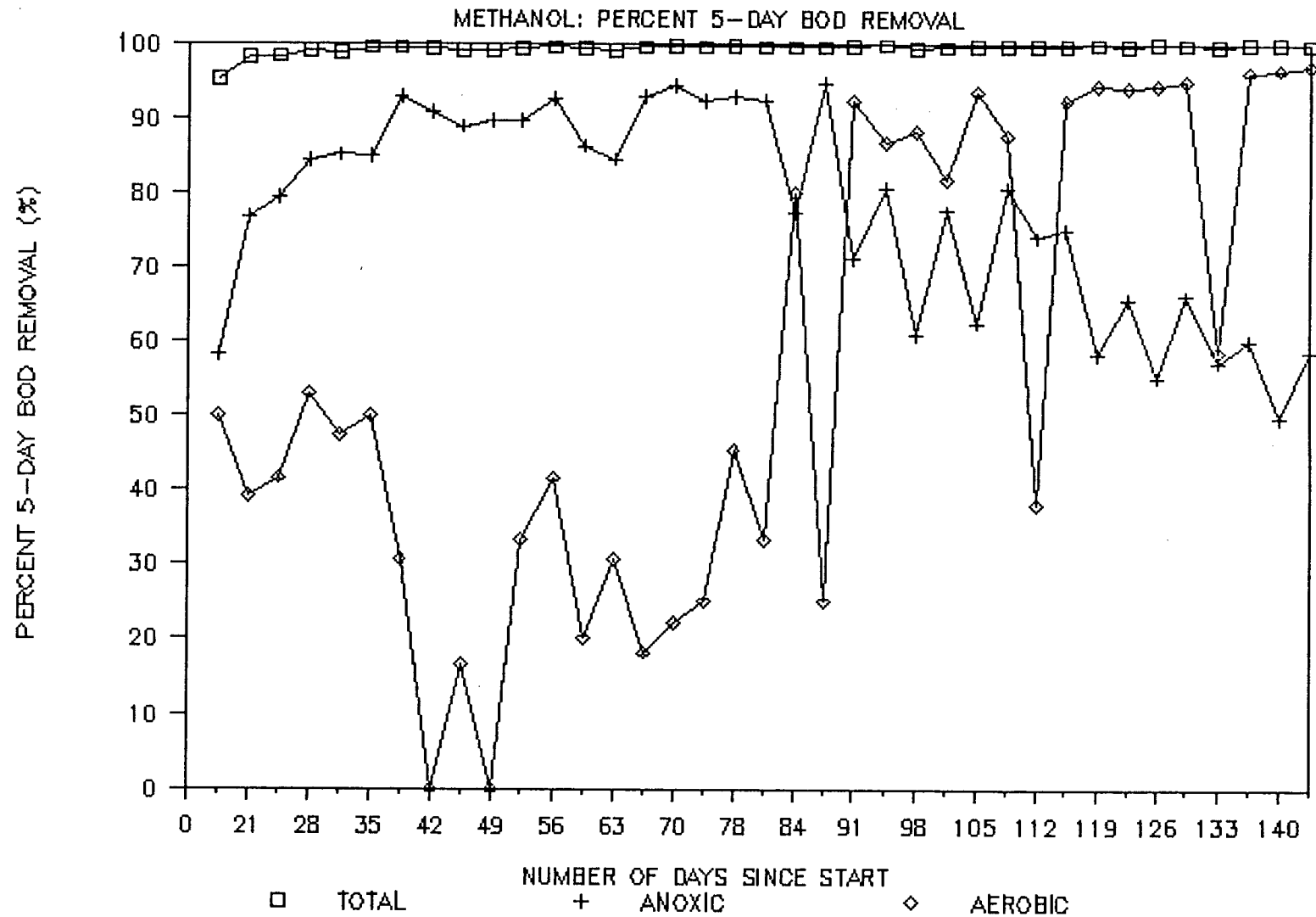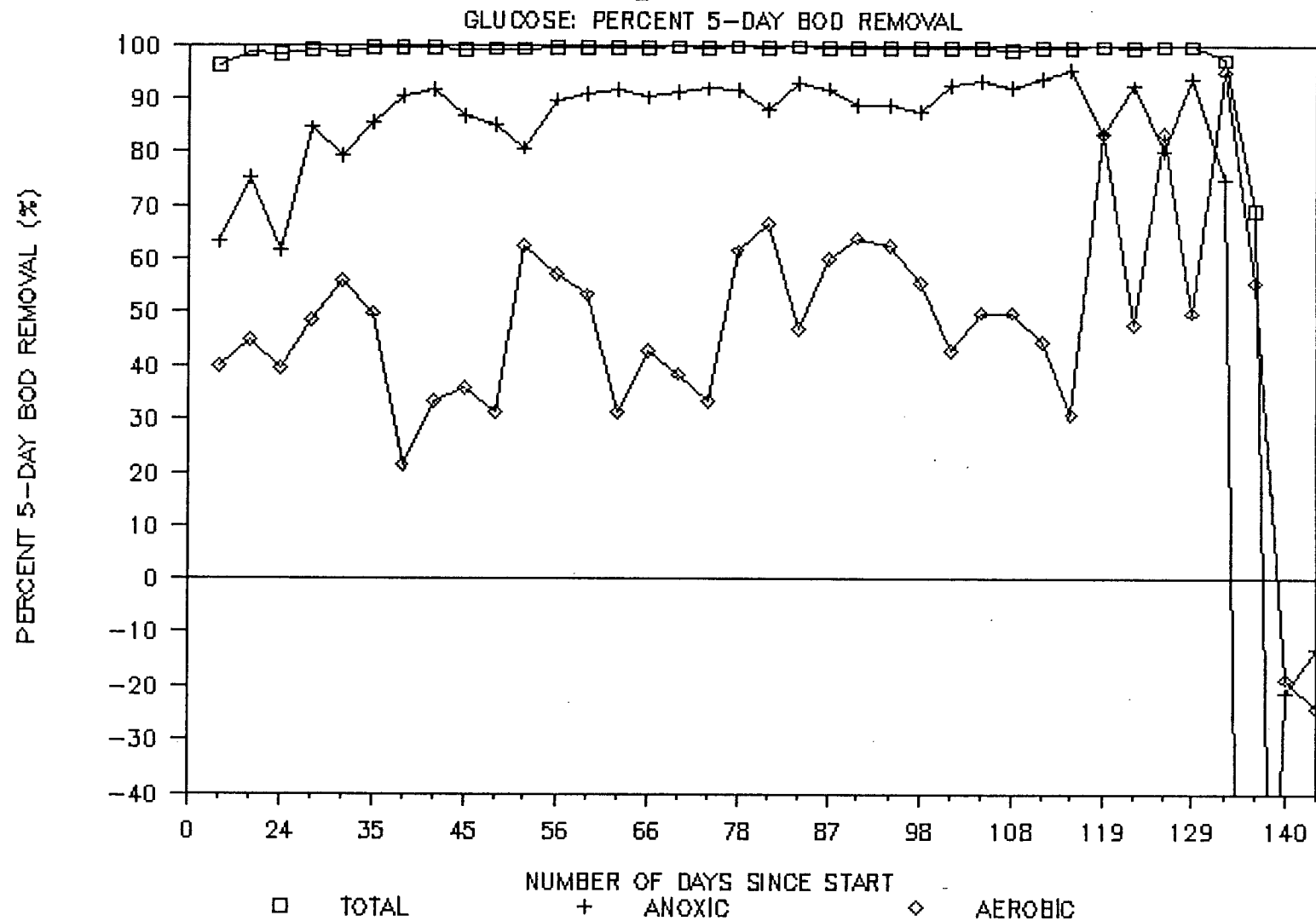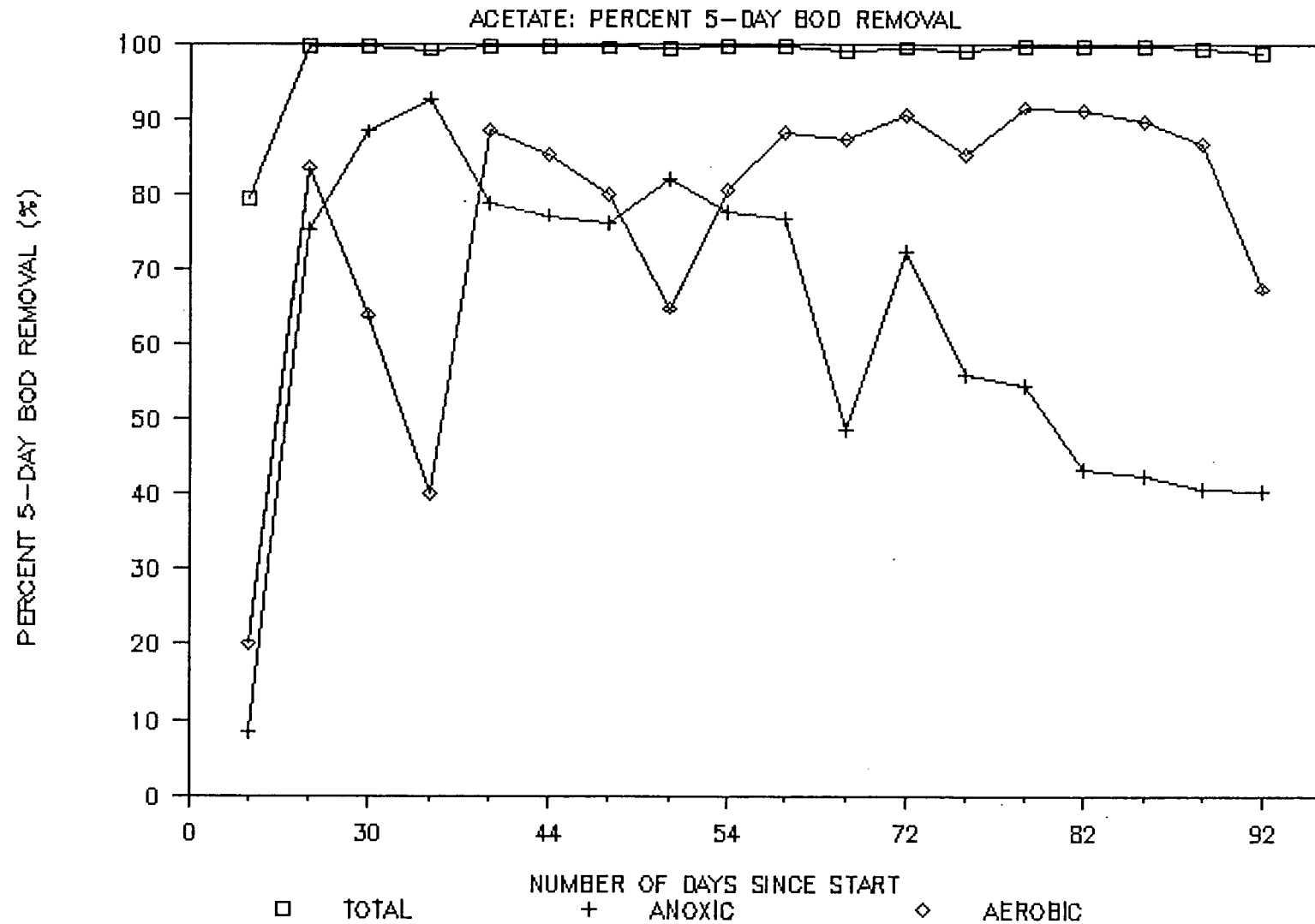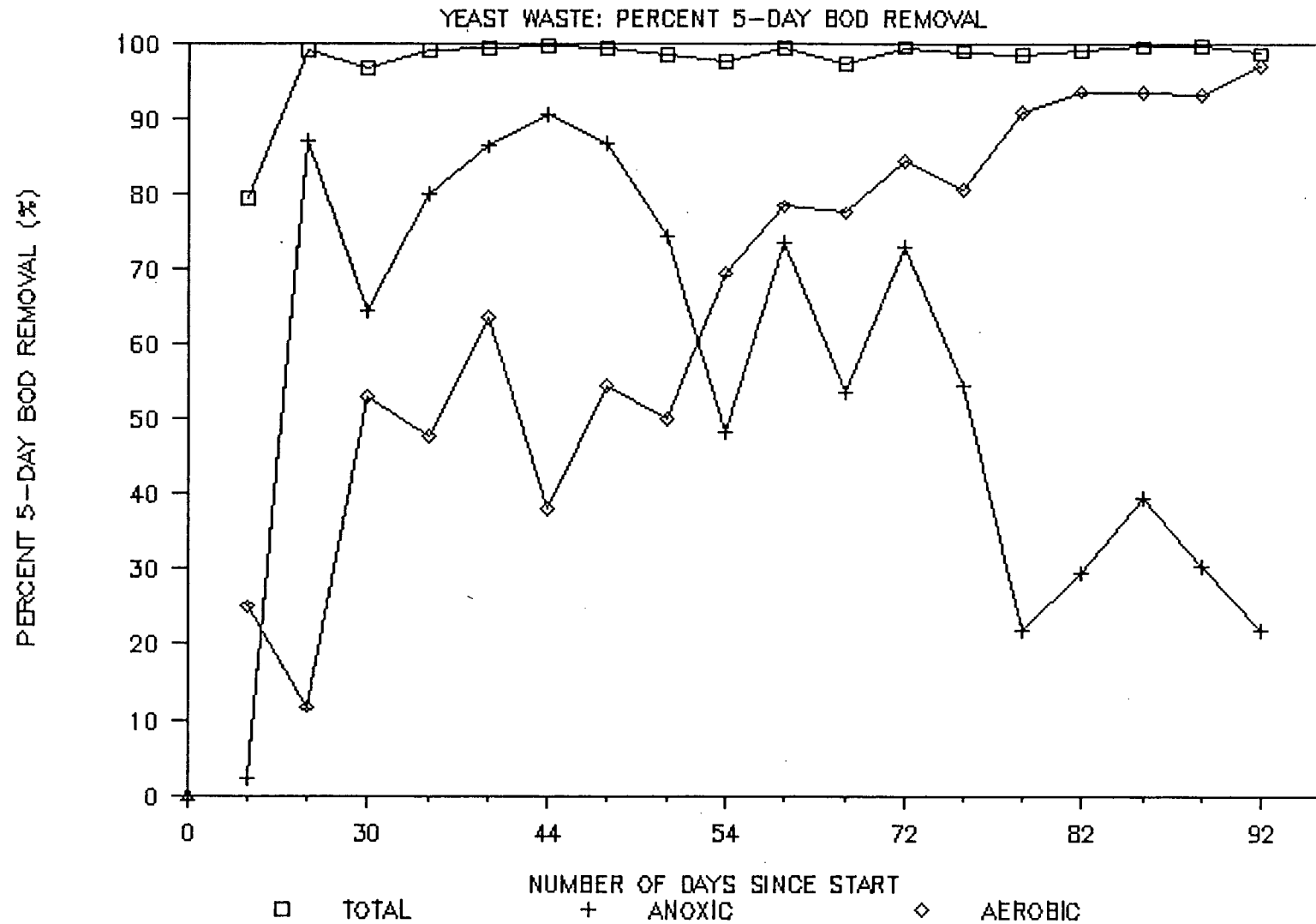
Figure 24.

METHANOL: 5-DAY BOD (mg/L)

NUMBER OF DAYS SINCE START

□ INFLUENT   + ANOXIC   ◇ AEROBIC
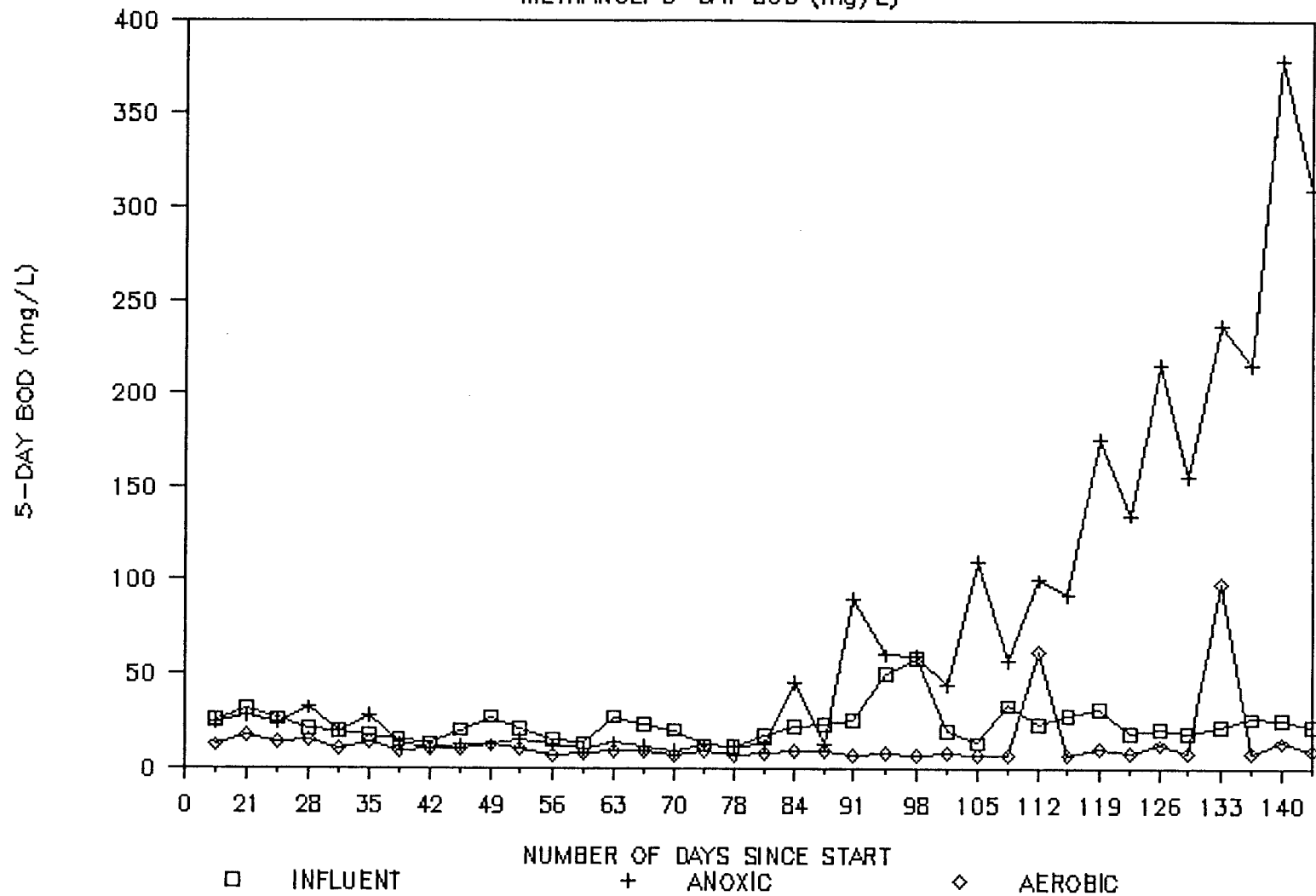
Figure 25.

GLUCOSE: 5-DAY BOD (mg/L)

NUMBER OF DAYS SINCE START

□ INFLUENT + ANOXIC ◇ AEROBIC
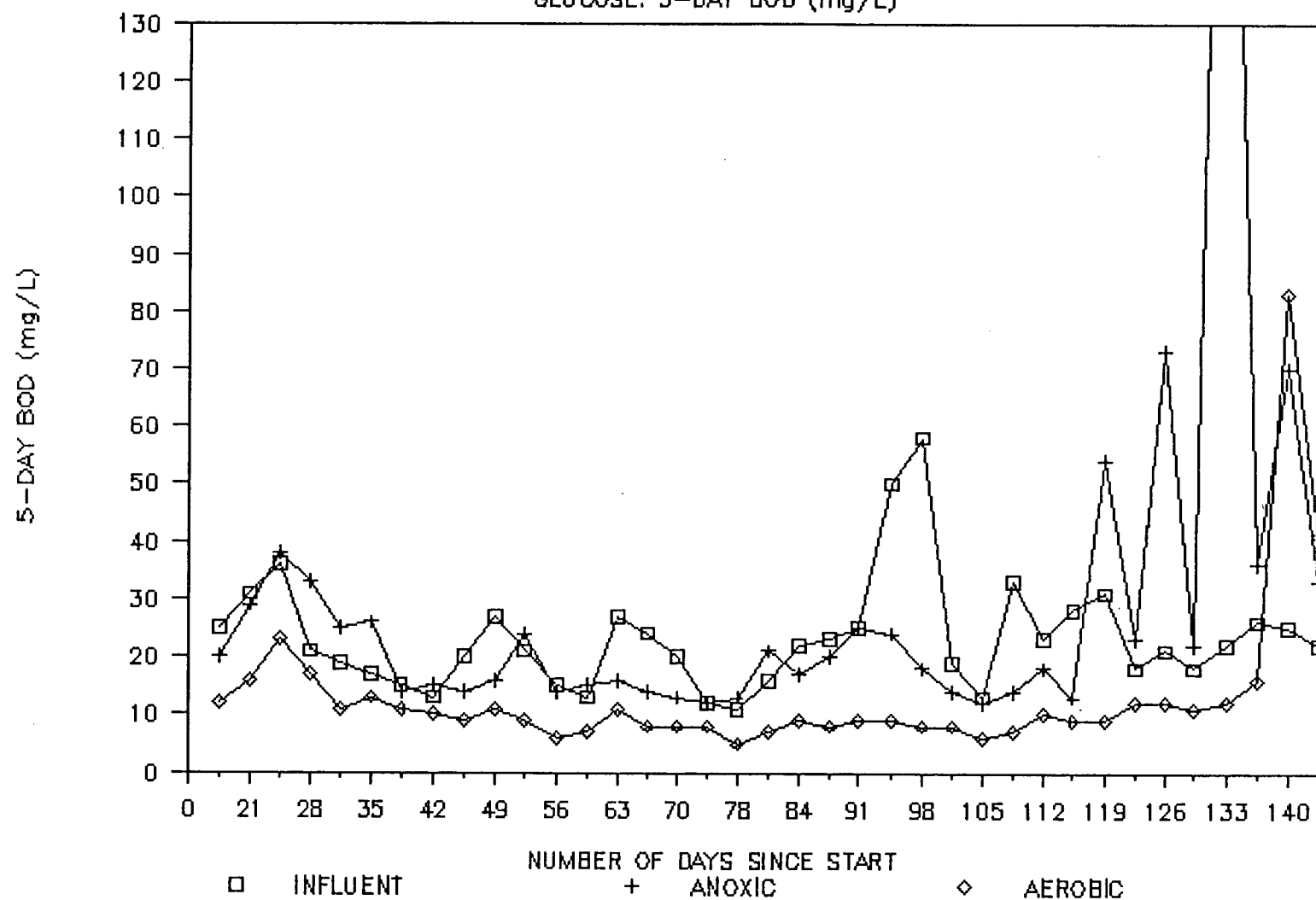
Figure 26.
ACETATE: 5-DAY BOD
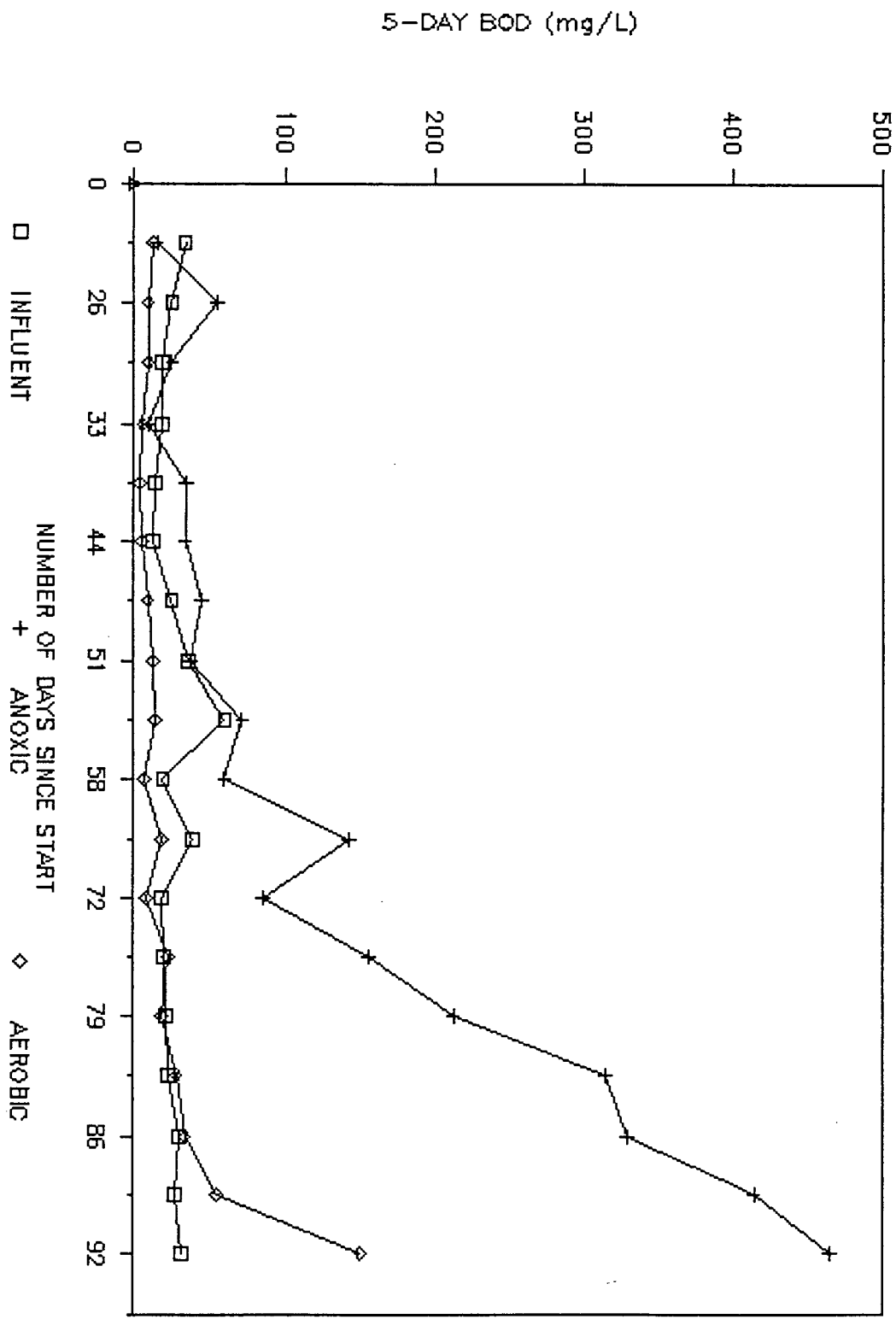
Figure 27.

YEAST WASTE: 5-DAY BOD
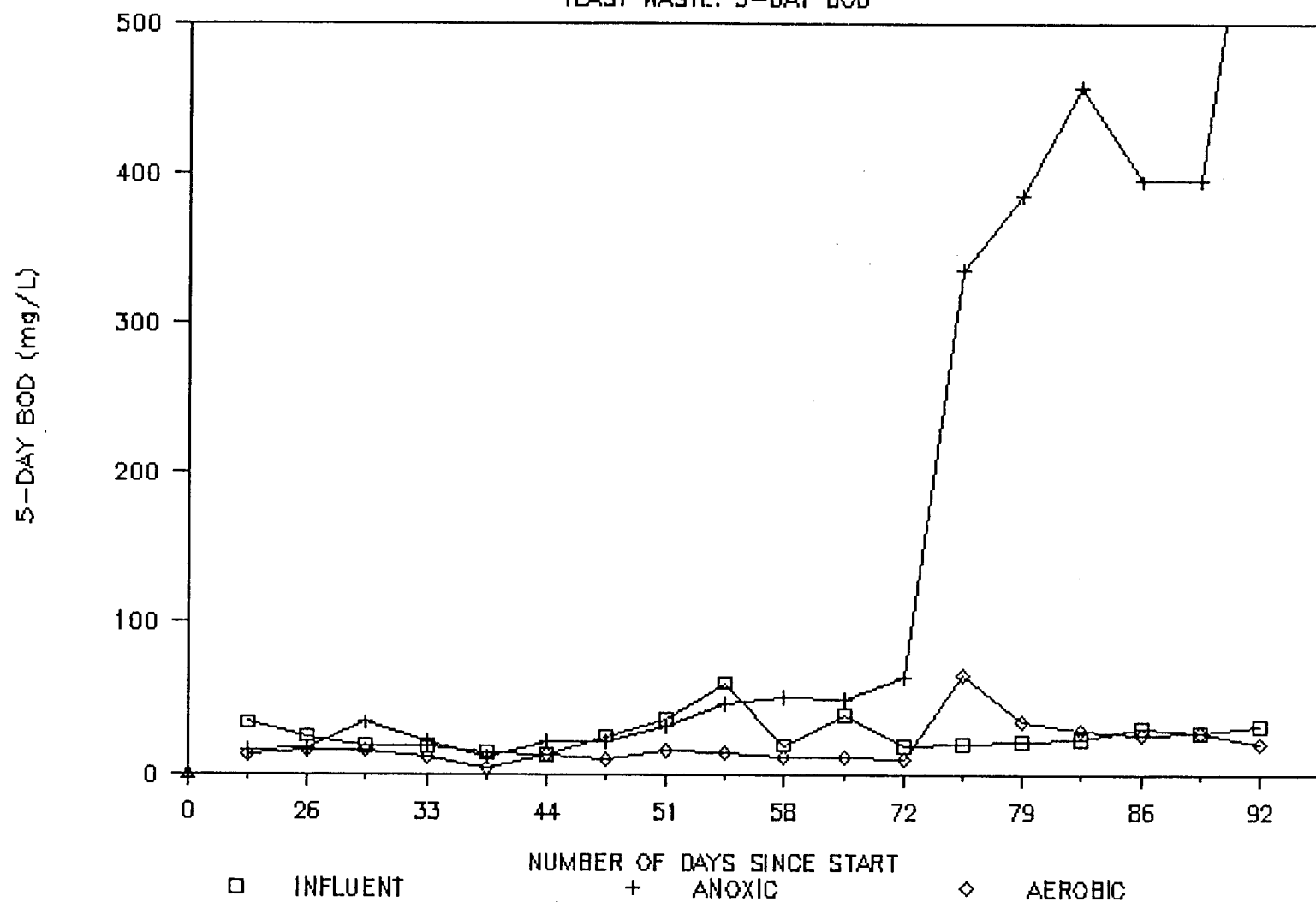
The ammonia in the yeast waste was only a fraction of the filtered TKN (FTKN) due to the biological nature of the yeast waste. FTKN was reported in place of ammonia for the yeast waste system. The yeast waste had a fairly high FTKN (40-300 mg/L), resulting in a greater demand on the nitrification system.

5.7.1 Ammonia Removal

Ammonia may be removed either by assimilation into the biomass, or by nitrification in the aerobic reactor. Ammonia loss by air stripping was assumed to be negligible, since the aerobic pH values were kept below pH 8. At 20 degrees celcius, the percentage of un-ionized ammonia is about zero percent at pH 7, 5% at pH 8, 50% at pH 10, and 100% at pH 12 (U.S.EPA,1975).

All four systems were efficient at removing ammonia with total ammonia removals consistently above 99% once complete nitrification was established. Ammonia removals for methanol, glucose, and acetate are shown in **Figures** 28 to 30, and FTKN removal for the yeast waste system is shown in **Figure 31**. The removals were calculated for the removal percentage of the ammonia that entered each reactor. Only the glucose system exhibited failure of the ammonia removal system near the end of the study, with complete recovery being achieved within 13 days after halting the glucose addition (see **Figure 29**).

Figure 28.

METHANOL: PERCENT AMMONIA REMOVAL

AMMONIA REMOVAL (%)

NUMBER OF DAYS SINCE START

□ TOTAL   + ANOXIC   ◇ AEROBIC

82

PERCENT AMMONIA REMOVAL (%)

Figure 29.

GLUCOSE: PERCENT AMMONIA REMOVAL

NUMBER OF DAYS SINCE START

□   TOTAL   +   ANOXIC   ◇   AEROBIC

Figure 30.

ACETATE: PERCENT AMMONIA REMOVAL
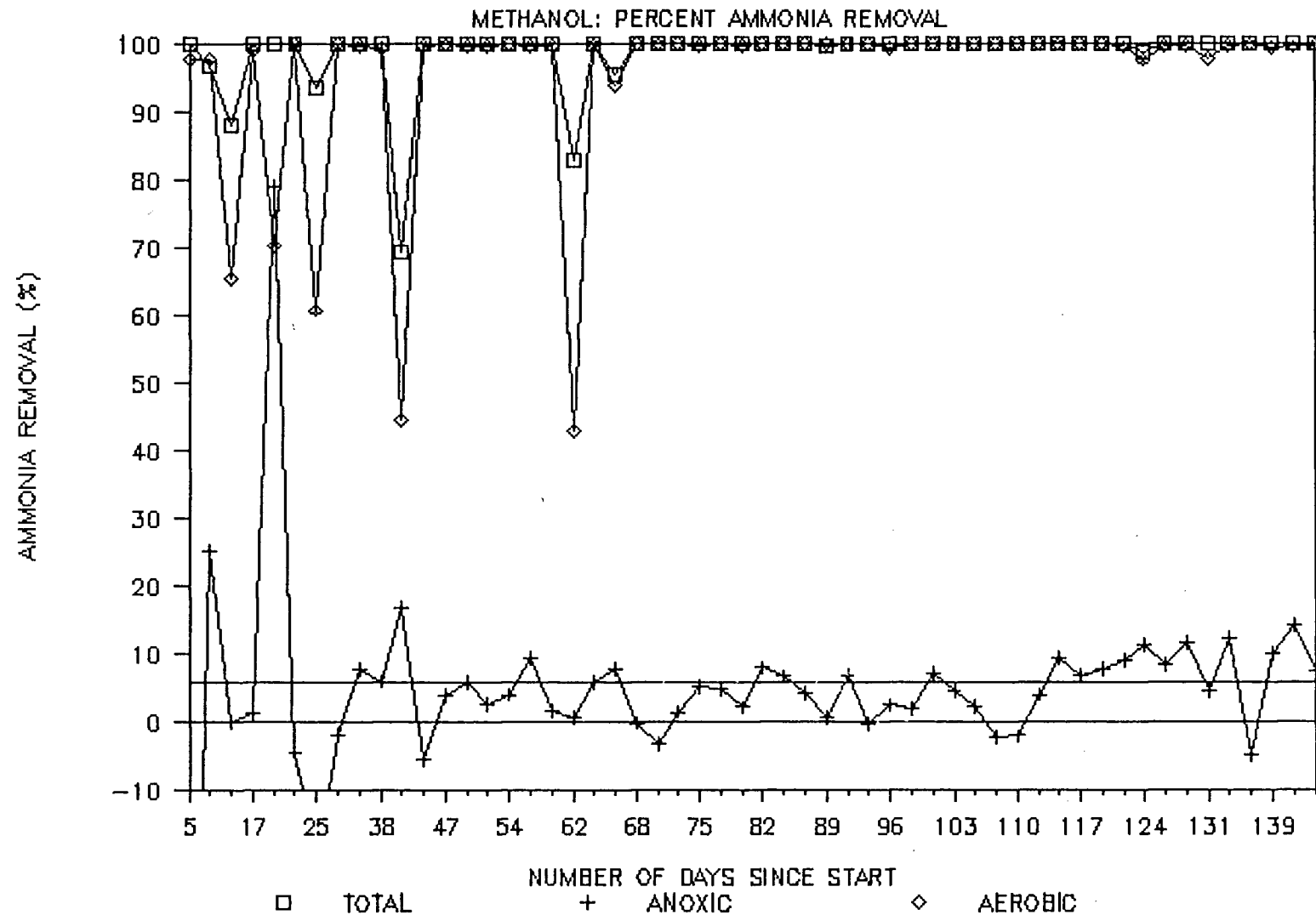
Figure 31.
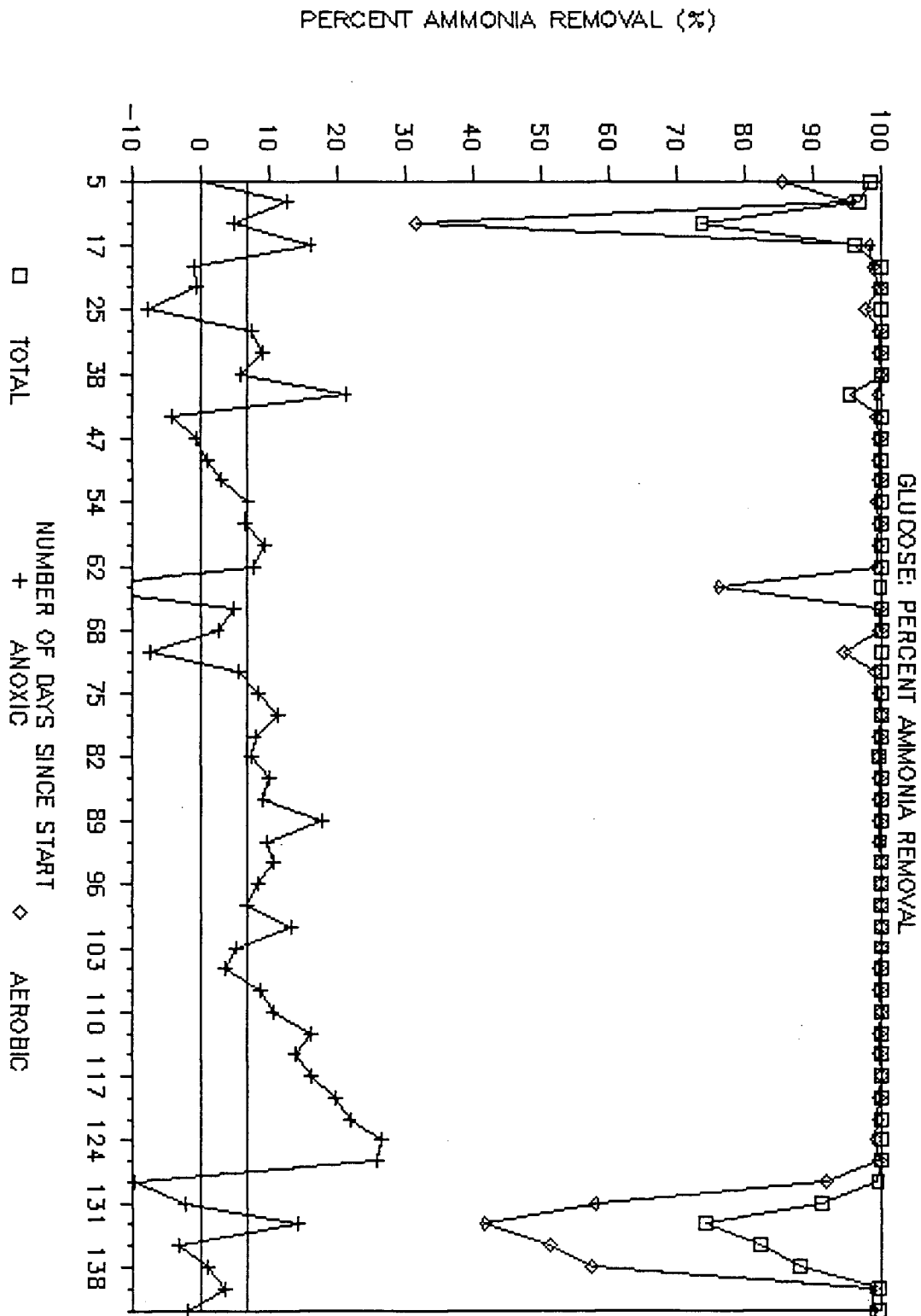
YEAST WASTE: PERCENT FTKN REMOVAL
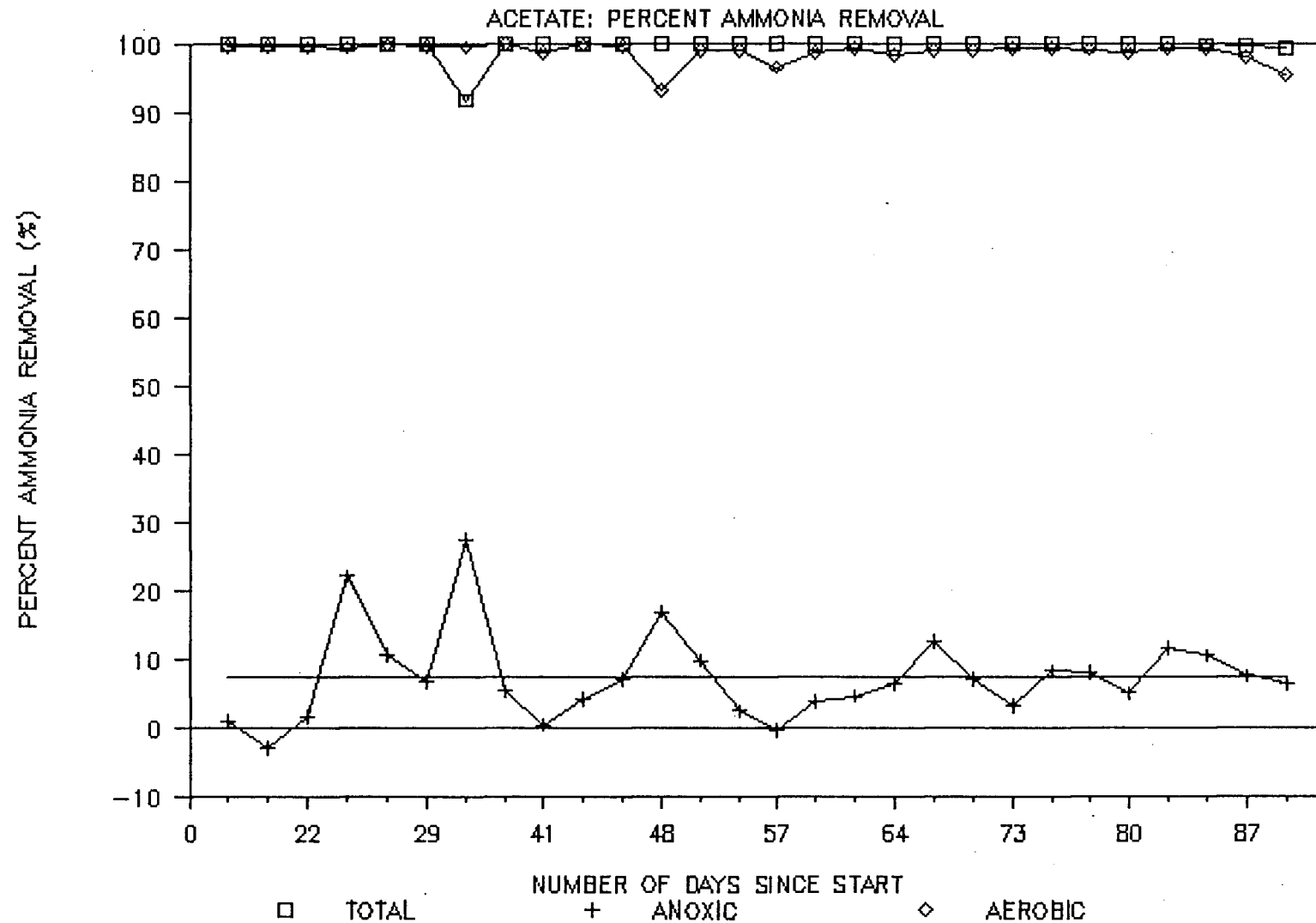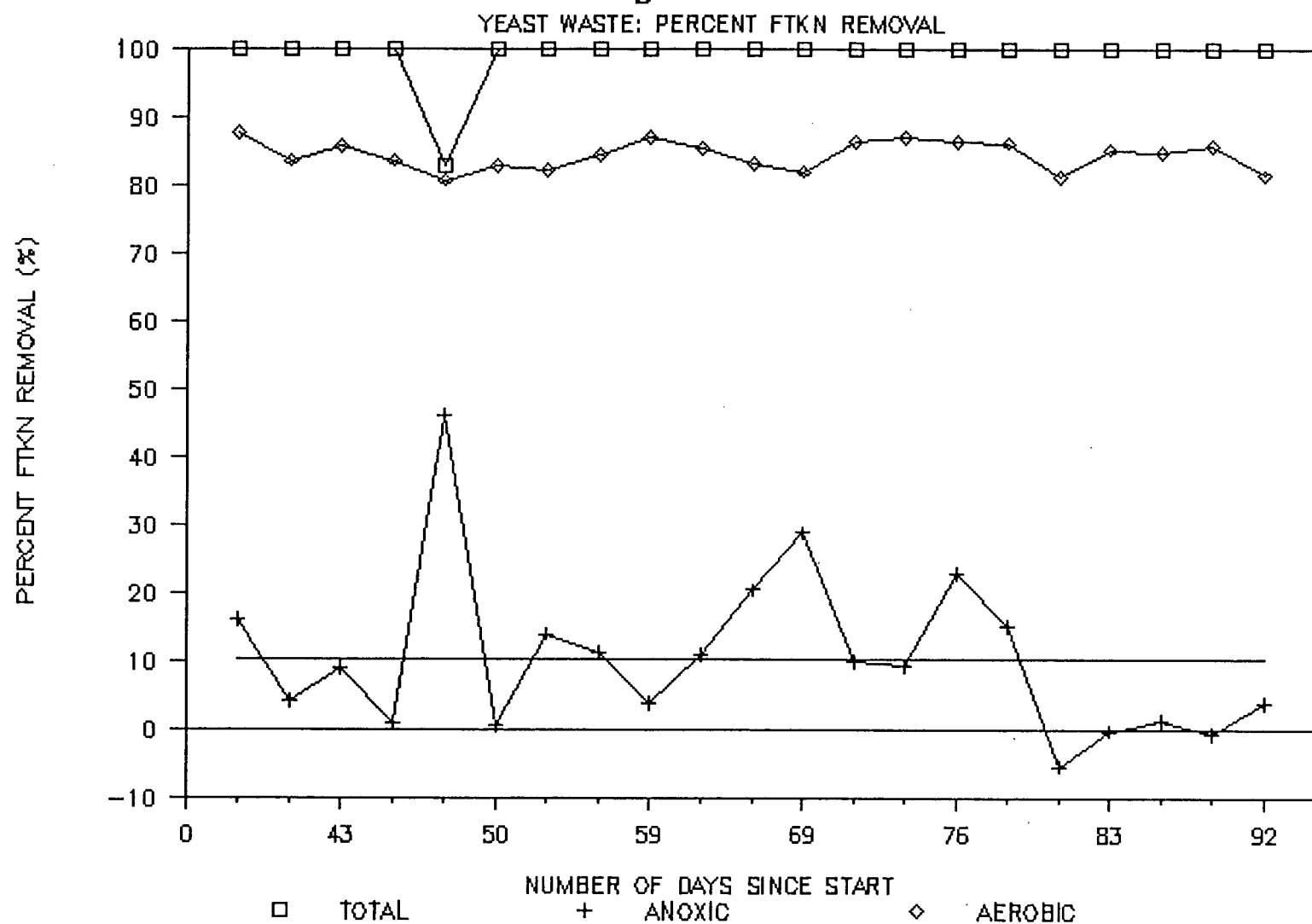
The ammonia removals over the aerobic reactors were also consistently high, with the yeast waste aerobic FTKN removal over 80% and the other three systems with over 99% aerobic ammonia removal. The ammonia nitrogen concentration entering the aerobic basin was consistently in the 30-40 mg/L range for the methanol, glucose, and acetate systems. The aerobic reactor of the yeast waste system received FTKN in the range of 40-80 mg/L, reflecting the FTKN added by the yeast waste.

The ammonia removal over the anoxic reactors was assumed to be entirely due to assimilation. The average percentage removal across the anoxic reactor was 6-8%. Methanol was the lowest at 6%, glucose and acetate averaged 7%, and The yeast waste system was the highest with 8% removal. These removals are slightly lower than the approximate 10% anoxic ammonia removal found in the control side of a similar biological leachate treatment system using the same leachate (**Mavinic and Randall, unpublished**).

5.7.2 Nitrification

The percent nitrification across the aerobic reactor was calculated by dividing the net NOx nitrogen produced in the aerobic reactor by the ammonia nitrogen entering the aerobic reactor. Ammonia removal by air stripping and aerobic assimilation was neglected, as was ammonia leaving the aerobic reactor, so that the values calculated for nitrification would be on the conservative side.

Nitrification percentages of over 100% were still observed, probably due to slight errors in the ammonia and NOx analyses.

Nitrification was somewhat erratic, but generally stayed above 80%. The important observation was that nitrification appeared to decrease as the COD:NOx increased. This effect was most prominent in the methanol system and about equal in the other three systems. **Figures 32 to 35** have a best fit straight line fitted to the data points and the percent nitrification can be seen to decrease with an increase in COD:NOx. The approximate rate of nitrification loss is 1.5 percent per unit increase in COD:NOx for methanol, 0.75 percent per unit COD:NOx increase for glucose, and less than 0.3 percent per unit COD:NOx increase for the acetate and yeast waste systems. These loss rates are for comparative purposes only, in order to highlight the magnitude of loss for each system.

The decrease in nitrification may be the result of greater ammonia assimilation by the increase in heterotrophs, rather than actual inhibition of the nitrifiers. The nitrification calculation was based on the amount of NOx produced from the amount of ammonia entering the aerobic reactor. If the heterotrophs were removing greater amounts of ammonia by assimilation, then less ammonia would be available for NOx production, resulting in an apparent decrease in

Figure 32.

COD:NOX vs PERCENT NITRIFICATION
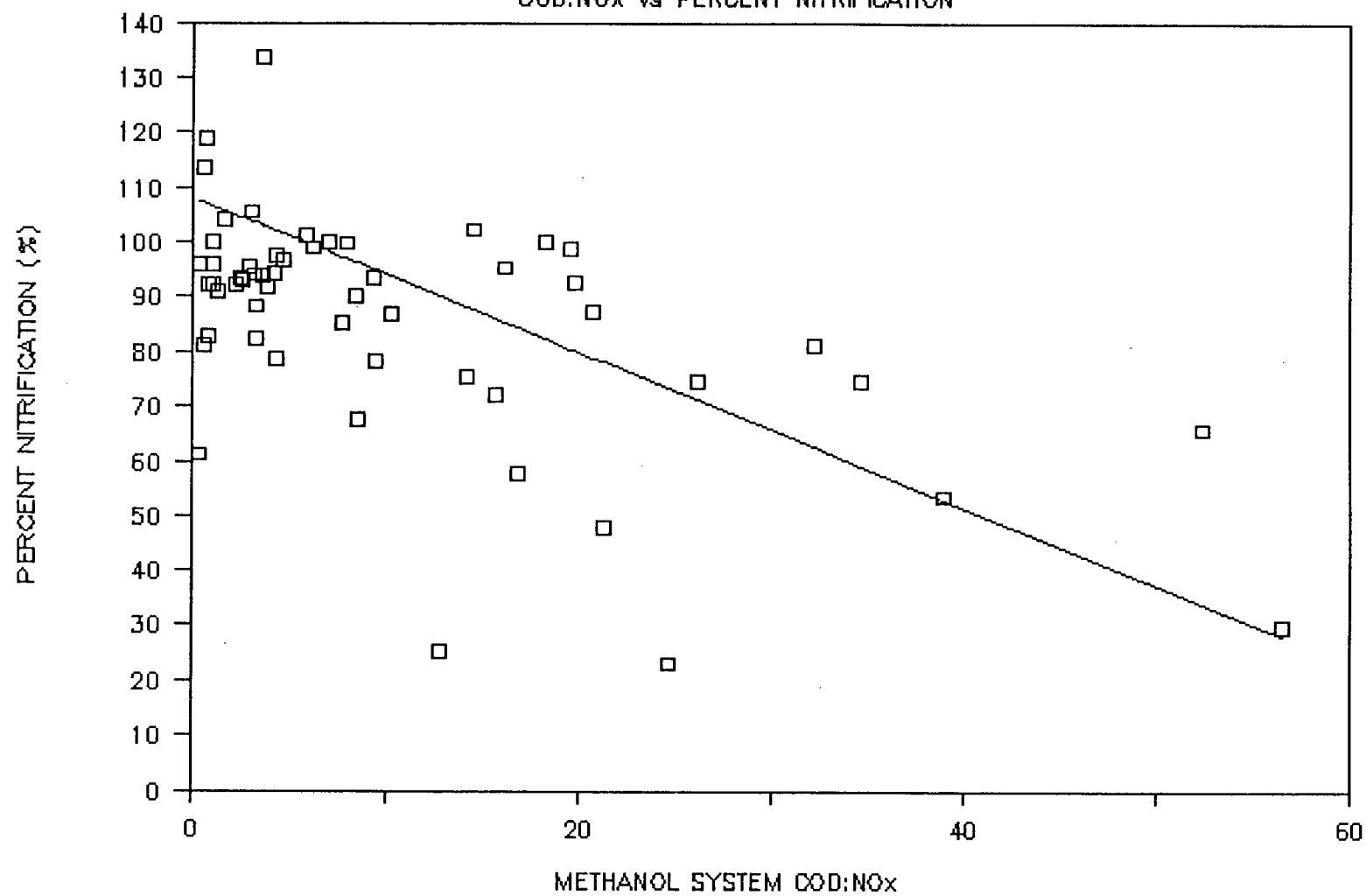
Figure 33.

COD:NOx vs PERCENT NITRIFICATION

68
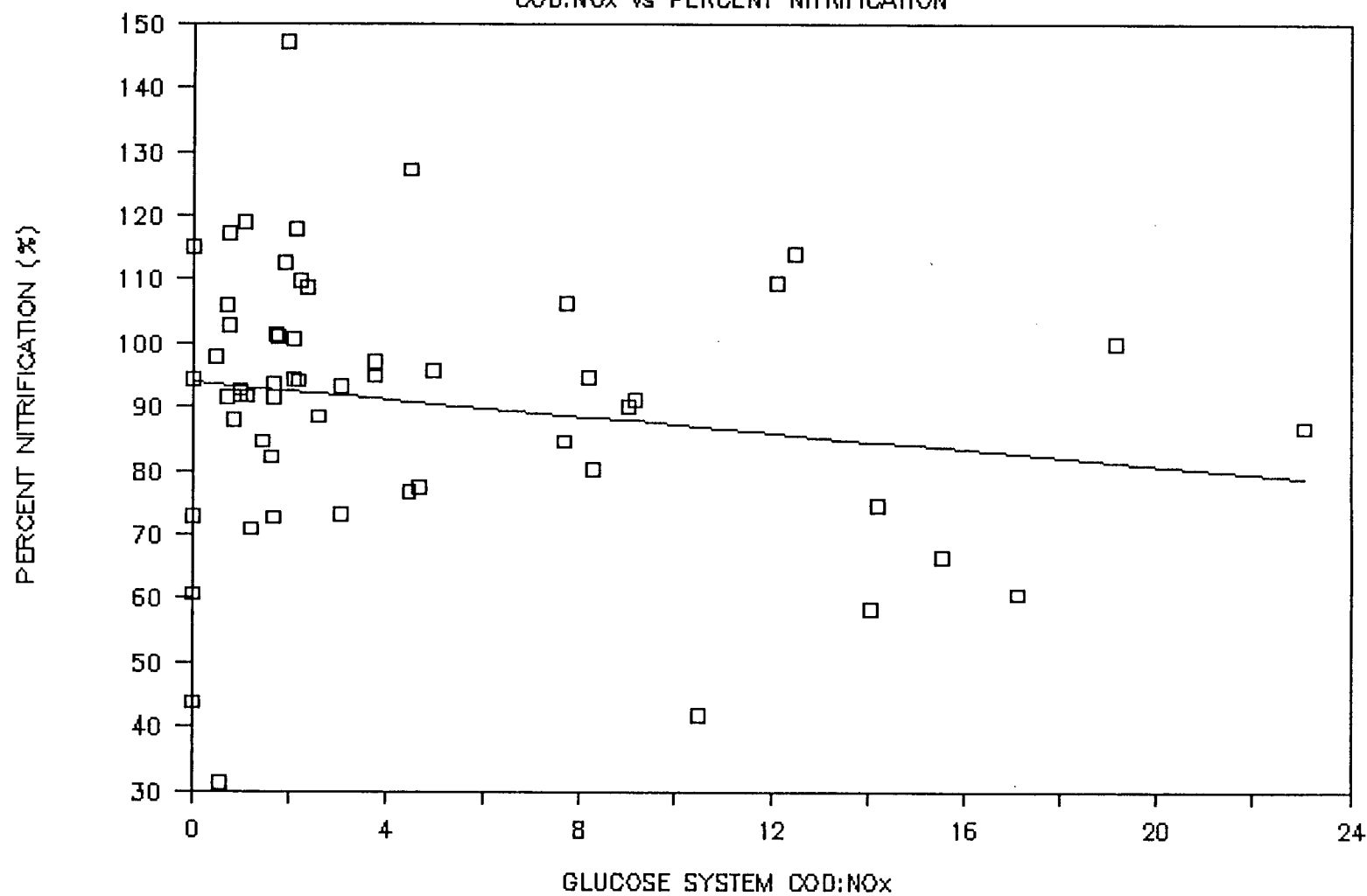
Figure 34.

COD:NOx vs PERCENT NITRIFICATION
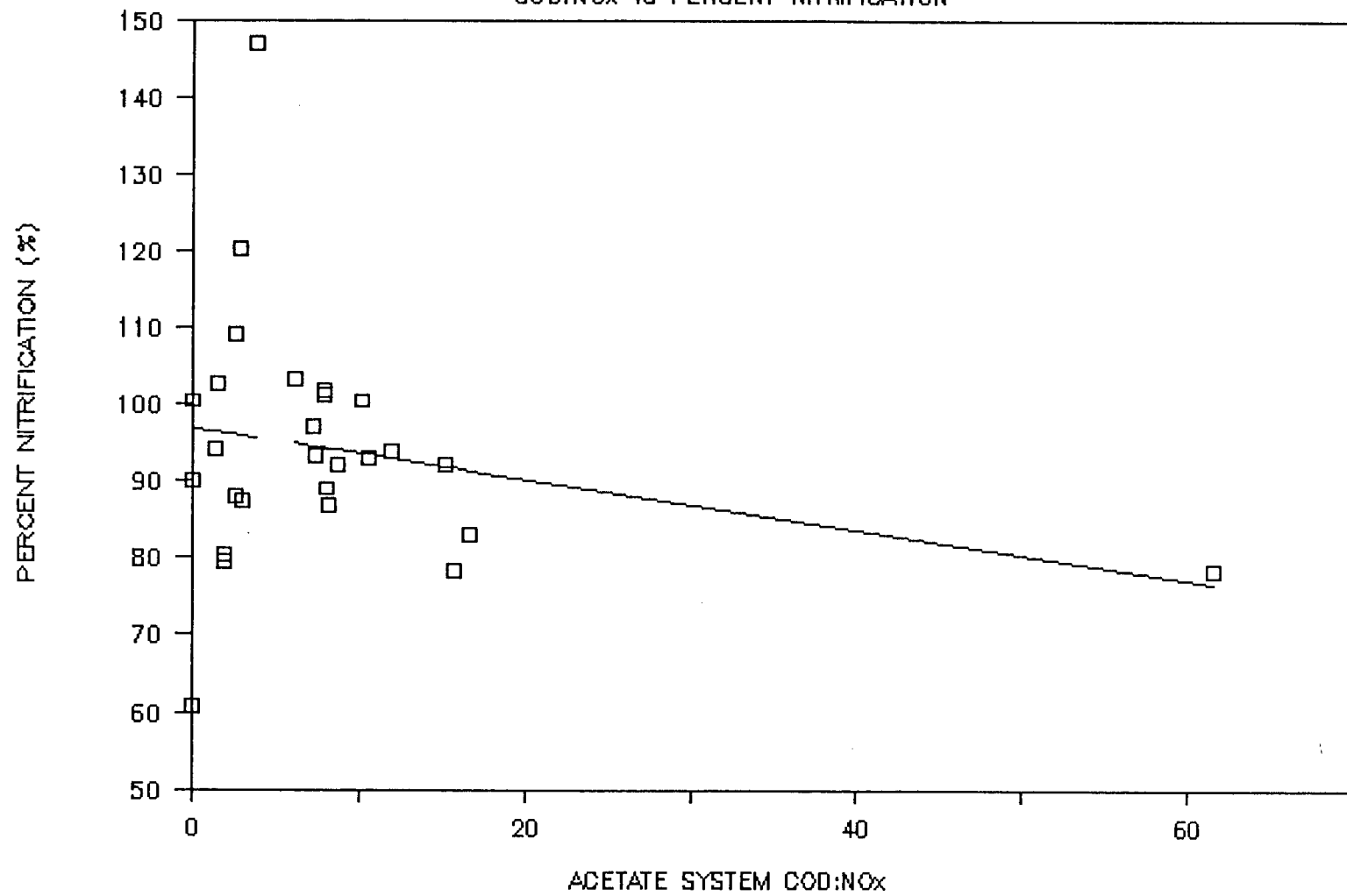
Figure 35.

COD:NOx vs PERCENT NITRIFICATION
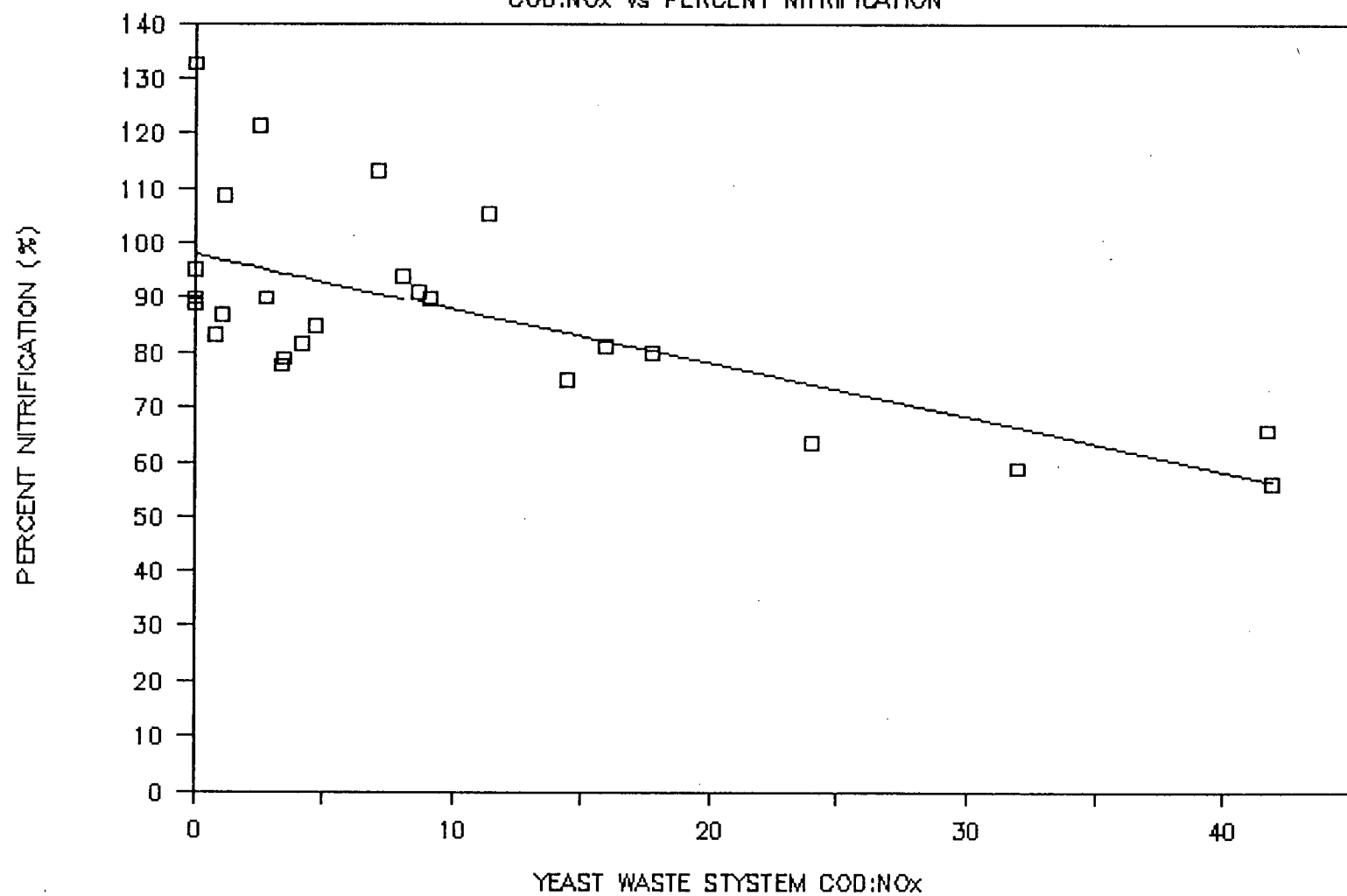
nitrification. This hypothesis is supported by the fact that ammonia did not increase in the aerobic reactor, as would be expected if nitrification was inhibited. The VSS, a good indicator of biomass growth, increased with the COD:NOx. The increased biomass and increased available carbon support the hypothesis of increased heterotrophic growth.

5.7.3 Denitrification

Denitrification was calculated by dividing the net NOx removed over the anoxic reactor by the amount of NOx entering the reactor. NOx removal was assumed to be by denitrification only. Denitrification showed a two part relationship with COD:NOx, with an initial linear section up to complete denitrification, after which the COD:NOx had no further effect. **Figures 36 to 39** illustrate this two part relationship.

The initial increase in denitrification exhibited a linear relationship with the increase in COD:NOx. By fitting a best fit straight line to data points of less than 100% denitrification, the minimum COD:NOx required for complete denitrification could be extrapolated. This is shown in **Figures 40 to 43**. The minimum COD:NOx required for complete denitrification was around 6.2:1 for methanol, 9:1 for glucose, 5.9:1 for acetate, and about 8.5:1 for the yeast waste. These ratios are approximate. Over this value of COD:NOx, denitrification remained at 100%, and was no longer

Figure 36.

COD:NOX vs PERCENT DENITRIFICATION
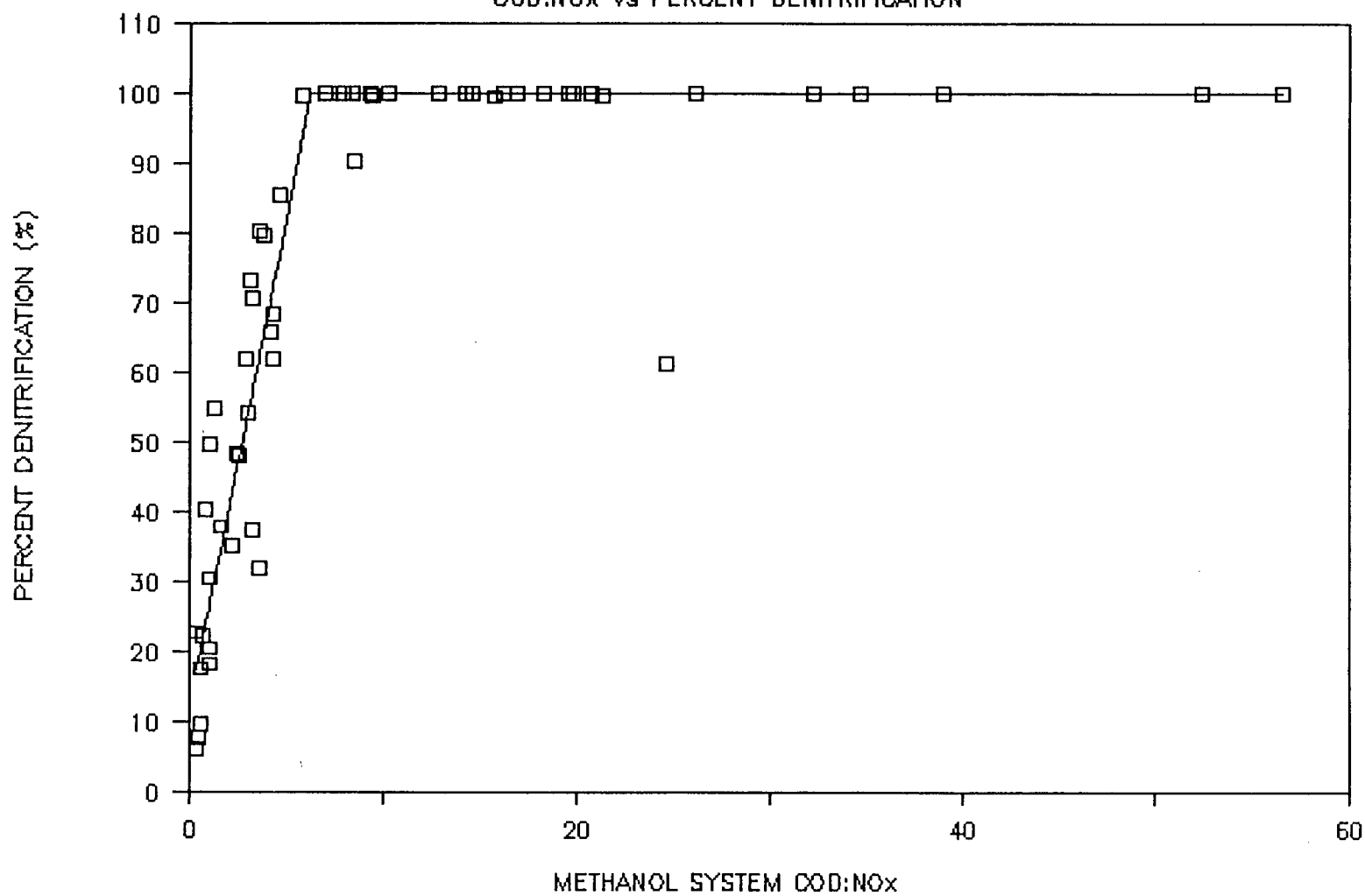
Figure 37.

COD:NOx vs PERCENT DENITRIFICATION
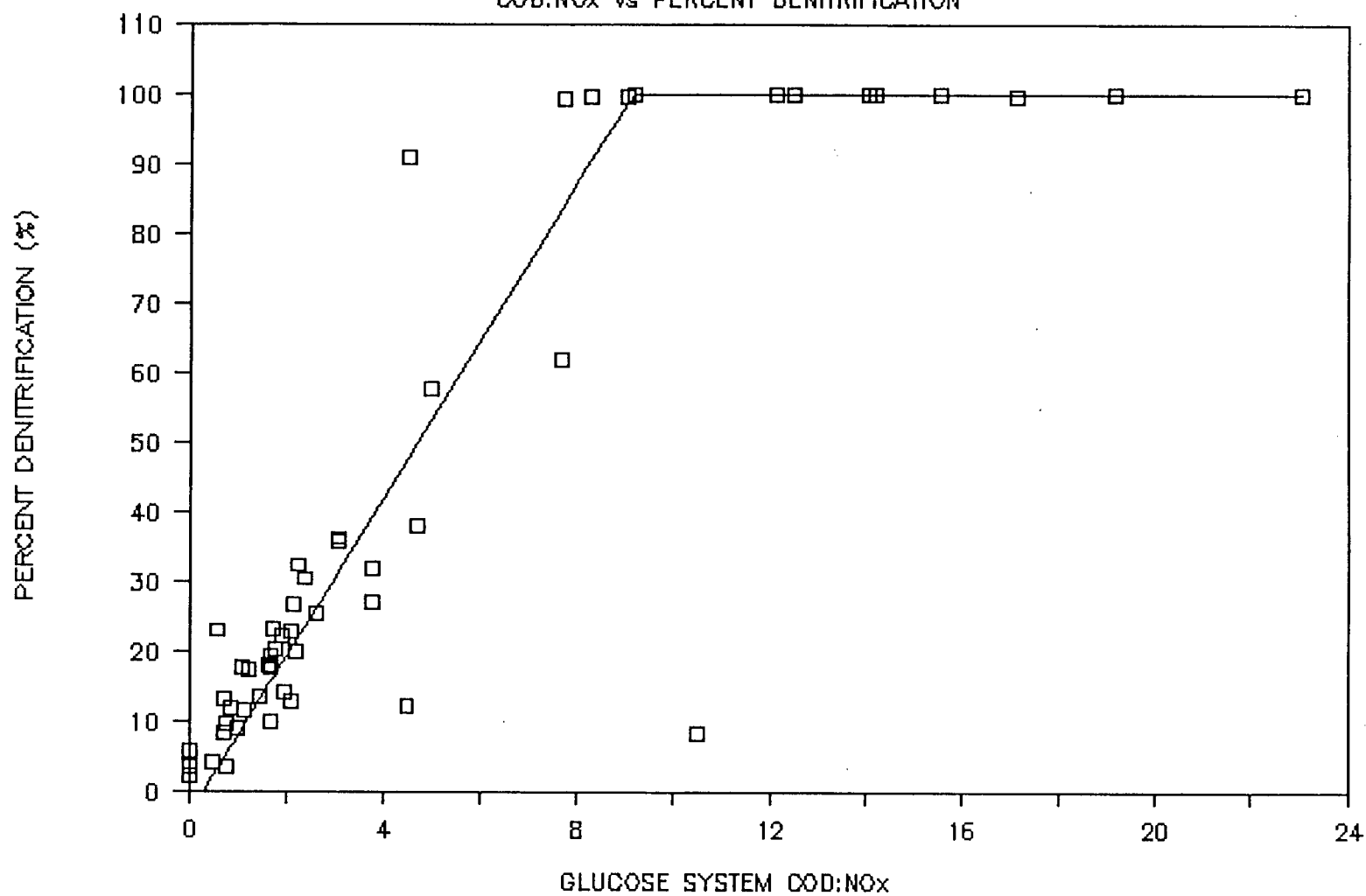
Figure 38.

COD:NOx vs PERCENT DENITRIFICATION
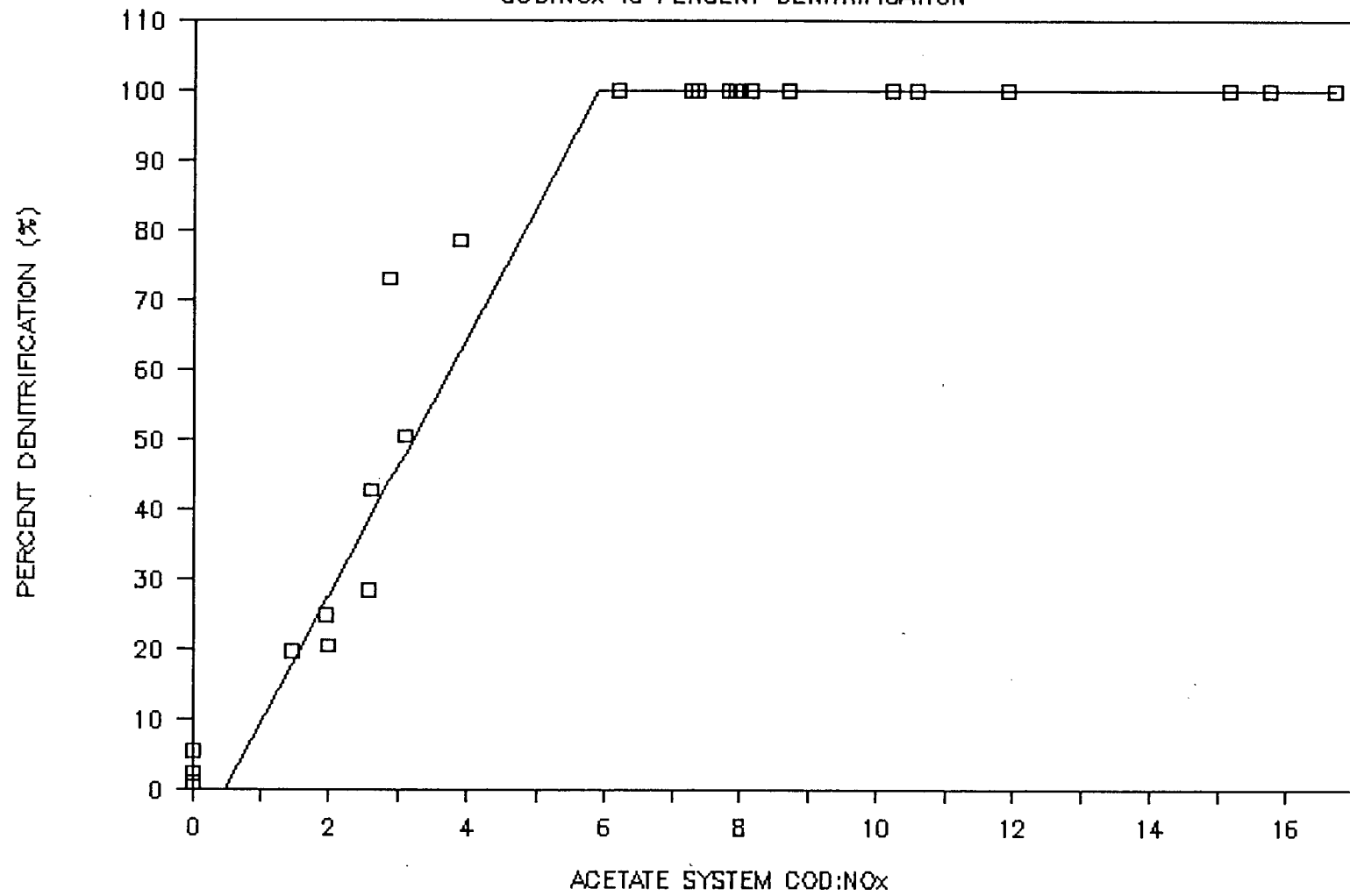
Figure 39.

COD:NOx vs PERCENT DENITRIFICATION
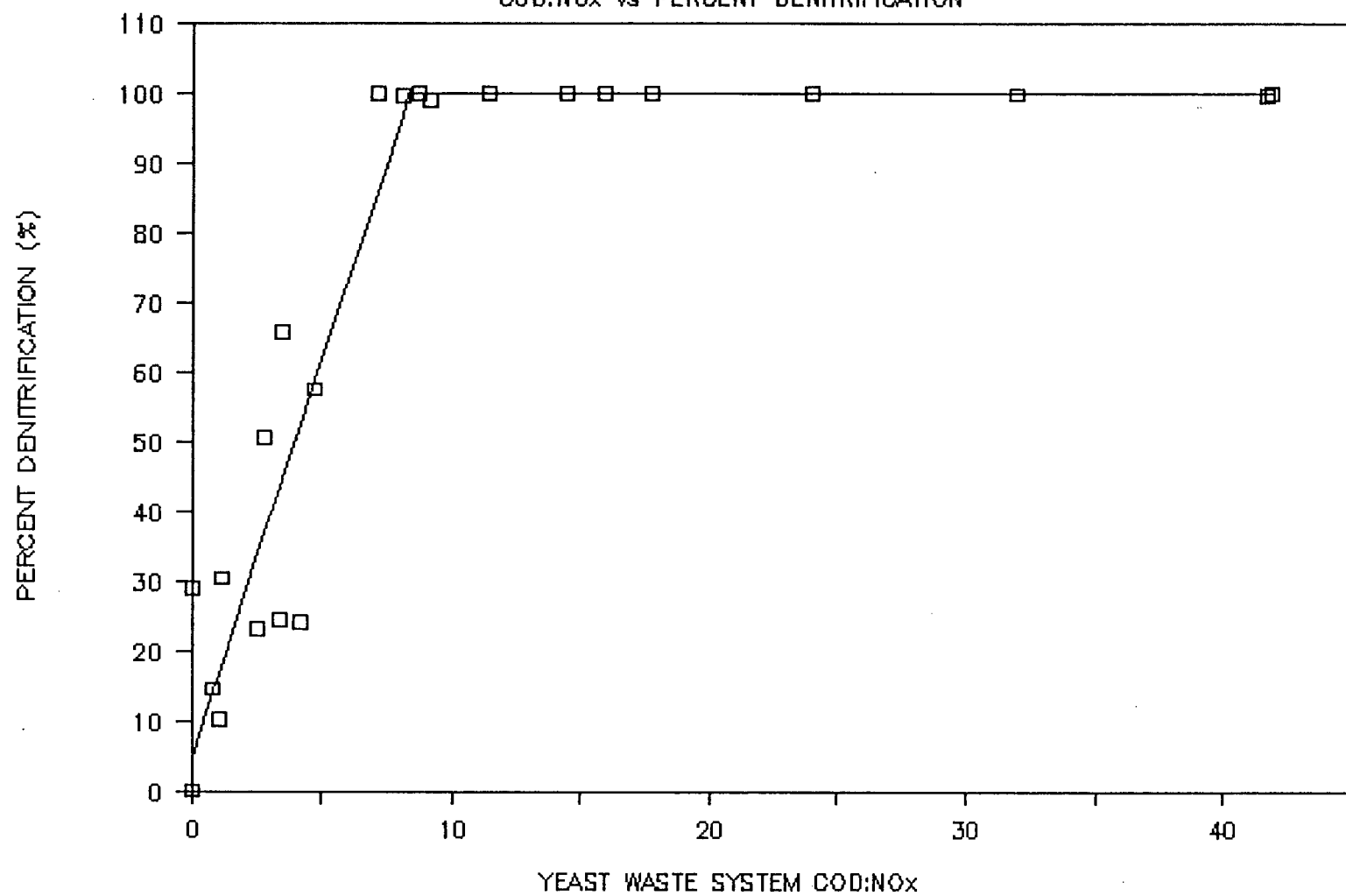
Figure 40.

COD:NOX<6:1 vs PERCENT DENITRIFICATION
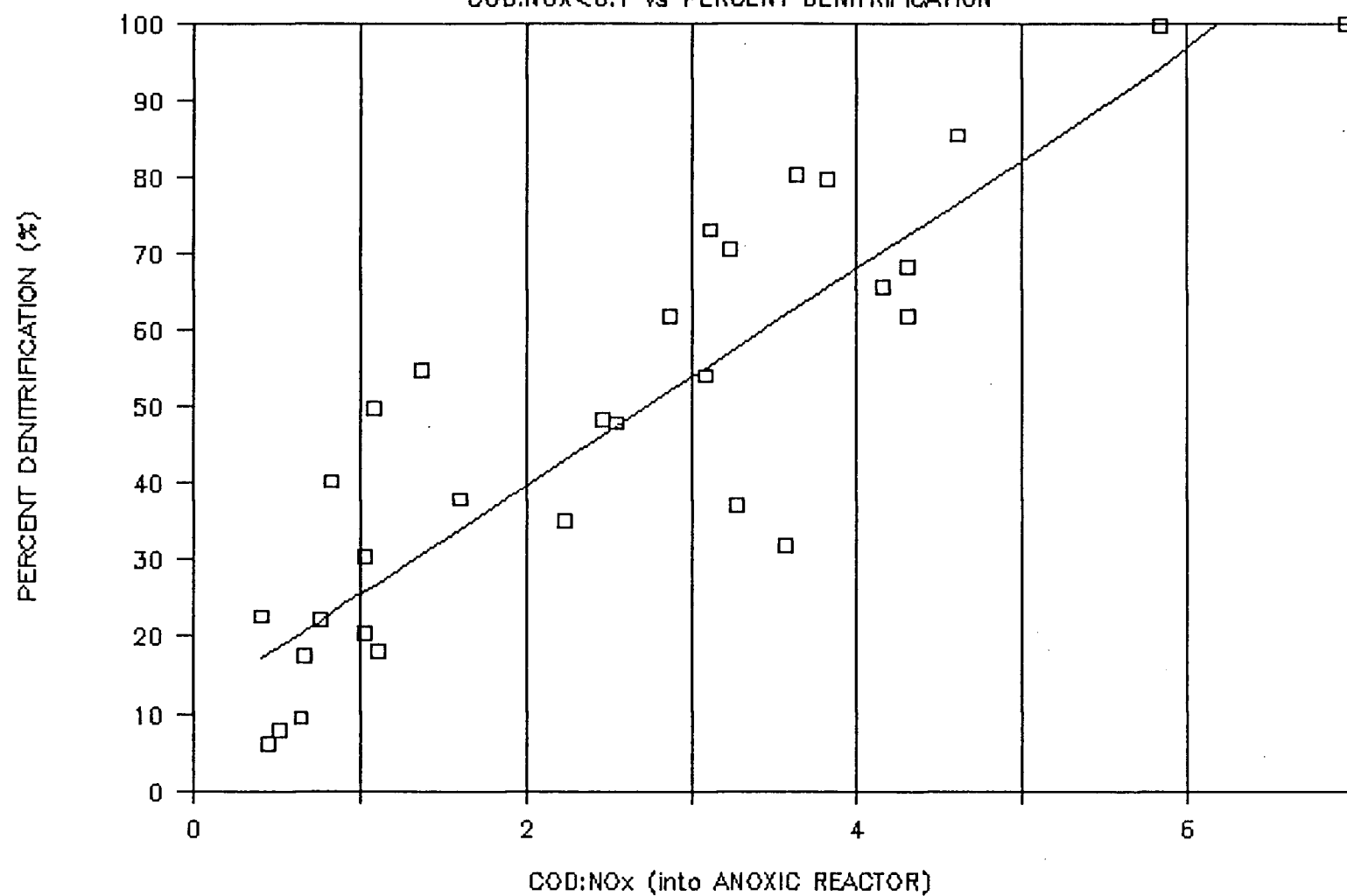
Figure 41.

COD:NOx<10:1 vs PERCENT DENITRIFICATION
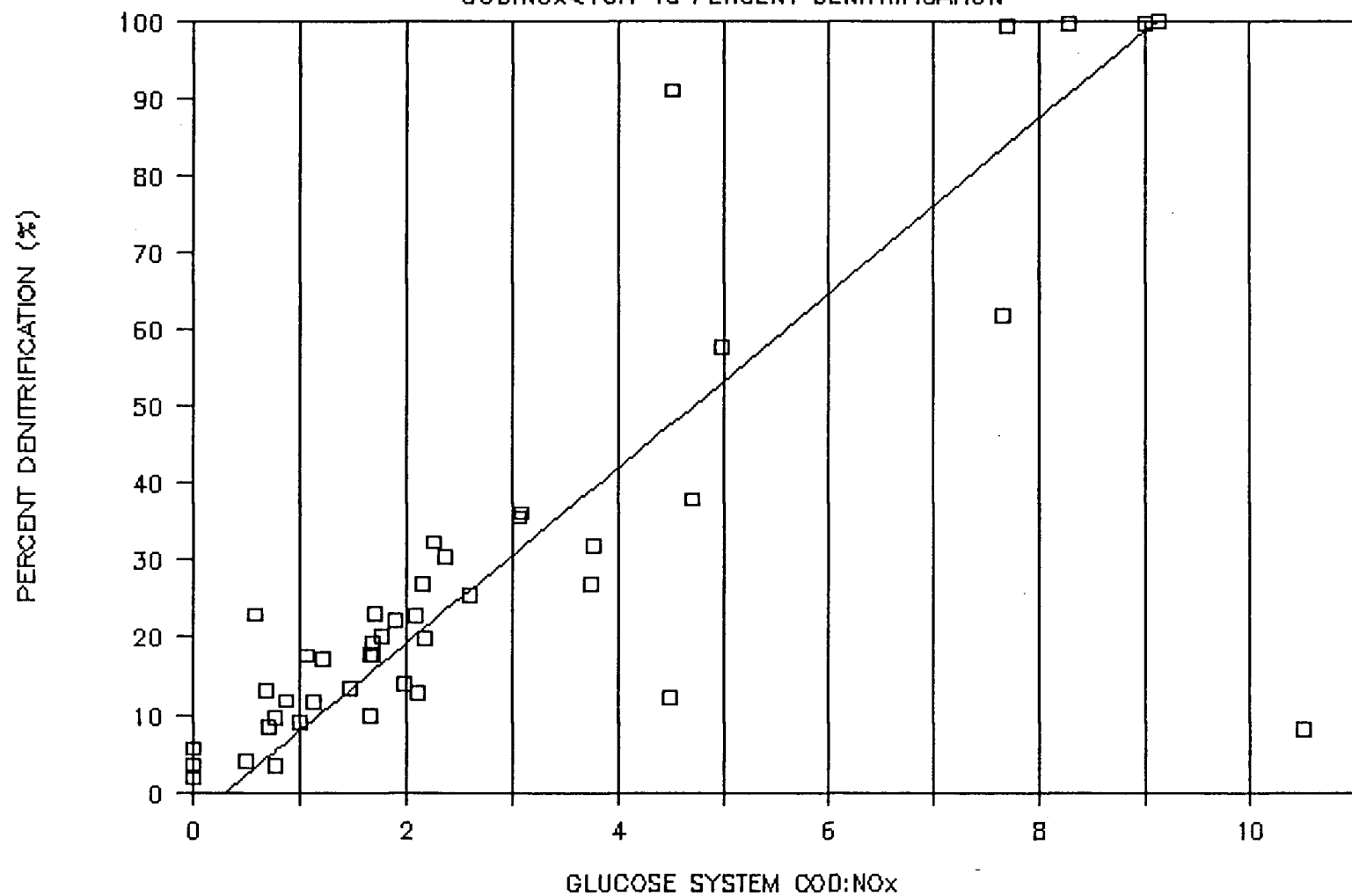
Figure 42.

COD:NOx<6:1 vs PERCENT DENITRIFICATION

66
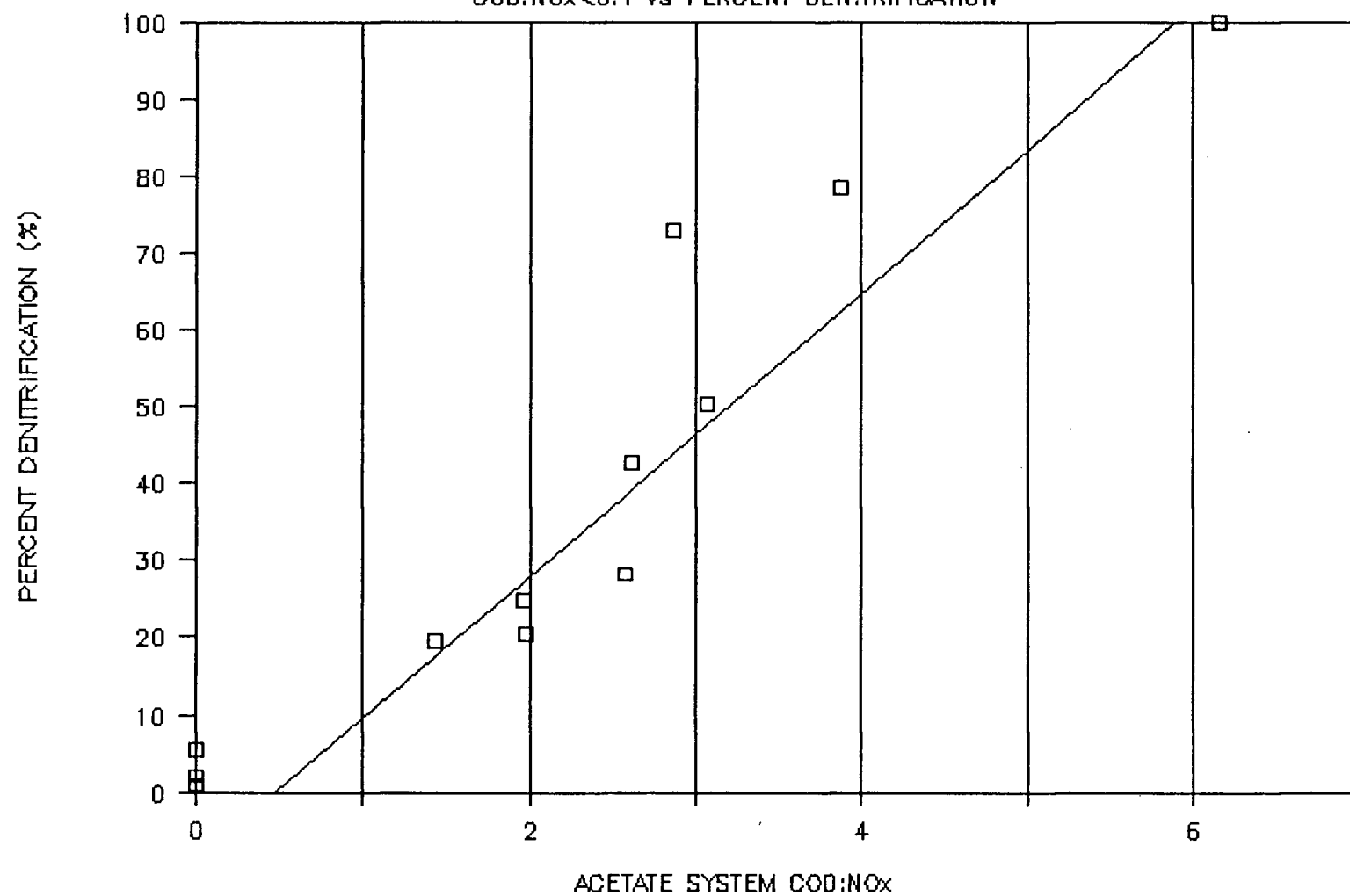
Figure 43.

COD:NOx<9:1 vs PERCENT DENITRIFICATION

100
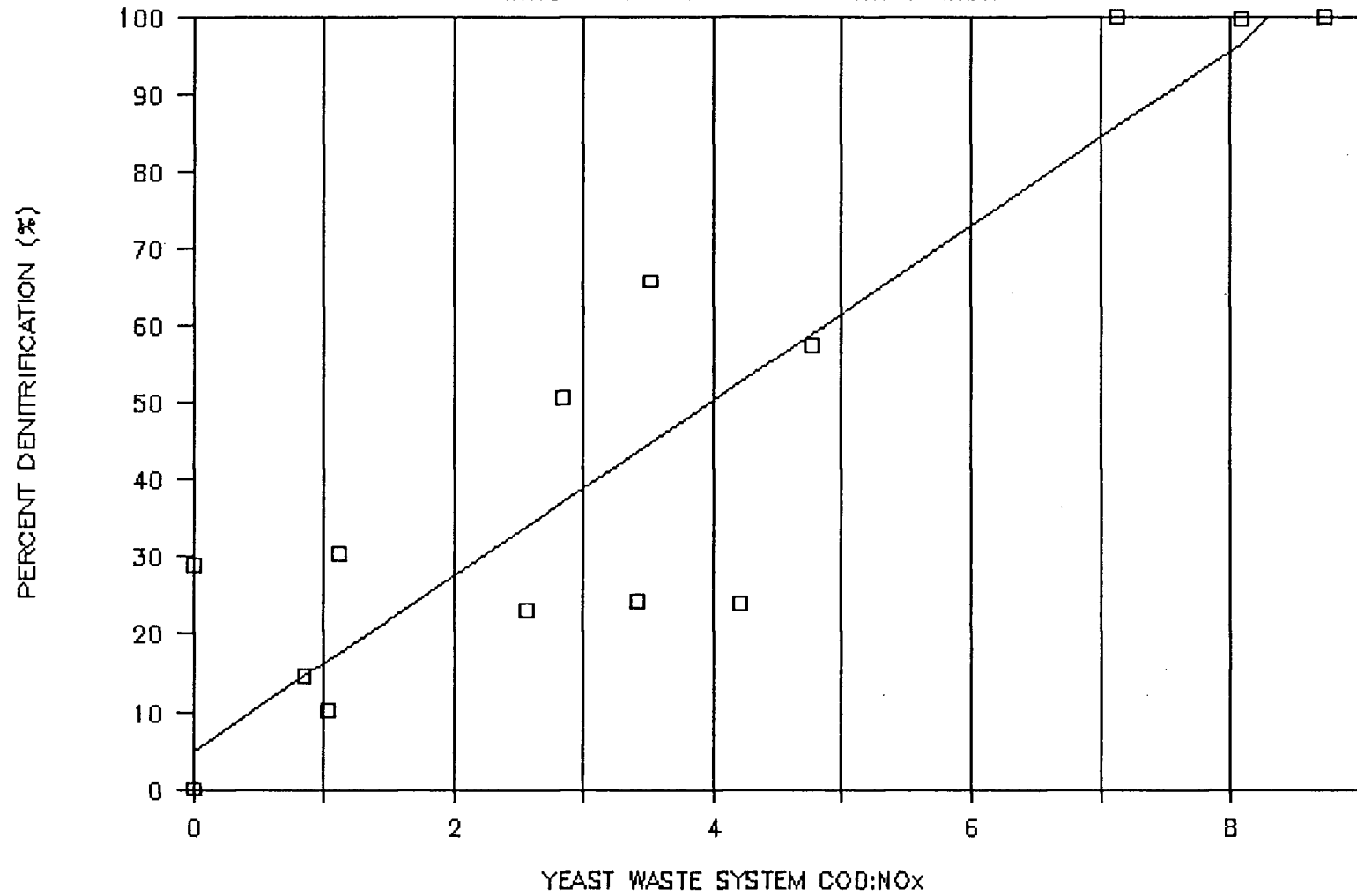
affected by increasing COD:NOx. Complete denitrification occurred on day 89 for methanol, day 110 for glucose, day 57 for both the acetate and yeast waste systems. These dates are very close to the dates observed for the start of carbon breakthrough; this was to be expected, since no additional carbon was required in the anoxic reactors.

At failure, the glucose system lost the ability to denitrify. The denitrification and nitrification processes failed in a period of under twelve hours. This occurred after an approximate COD:NOx loading of 24:1 had been applied, but ,at the beginning of failure, a loading of about 12:1 was recorded. Exact COD:NOx was difficult to maintain, due to fluctuations in pump speeds, changes in influent NOx and ammonia, and lag time for bacterial response to increased COD:NOx. The 23:1 loading is assumed to have been more responsible for failure than the 12:1 loading. After failure, denitrification continued at about 10%, even though no carbon was added; this indicates that endogenous respiration was providing enough carbon to sustain denitrification at this rate.

5.8 UNIT REMOVAL RATES

Unit removal rates, calculated as mg/hr/gVSS, were analyzed for COD and BOD_5 removal, ammonia removal, nitrification, and denitrification. The unit removal rates were primarily

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dependent on VSS, which was constantly increasing; thus no attempt was made to relate unit rates to COD:NOx.

5.8.1 COD & BOD Removal

The aerobic COD and BOD_5 unit removal rates of all four systems behaved in the same manner. The aerobic rate remained low until carbon breakthrough started, then rapidly increased as greater amounts of degradable carbon entered the reactor. The BOD_5 rates show this better than the COD rates, due to the refractory carbon of the leachate. Carbon breakthrough can be clearly seen as a dramatic increase in the aerobic BOD_5 unit removal rates. **Figures 44** to **51** show the COD and BOD_5 unit removal rates for the four systems.

The anoxic COD and BOD_5 unit removal rates were fairly constant and close in value for all systems, averaging between 30 and 40 mg/hr/gVSS for the entire study. The glucose anoxic unit removal rates were very erratic at the time of failure, and, after failure, the negative rates indicate carbon release by lysing cells (see **Figures 46** and **47**).

5.8.2 Ammonia Removal

The aerobic unit ammonia removal rates all showed a decline over each run, except that of the yeast waste system. The decline was due to the increase in VSS, which in turn was probably due to heterotrophic growth rather than nitrifying

102

Figure 44.
METHANOL: UNIT COD REMOVAL
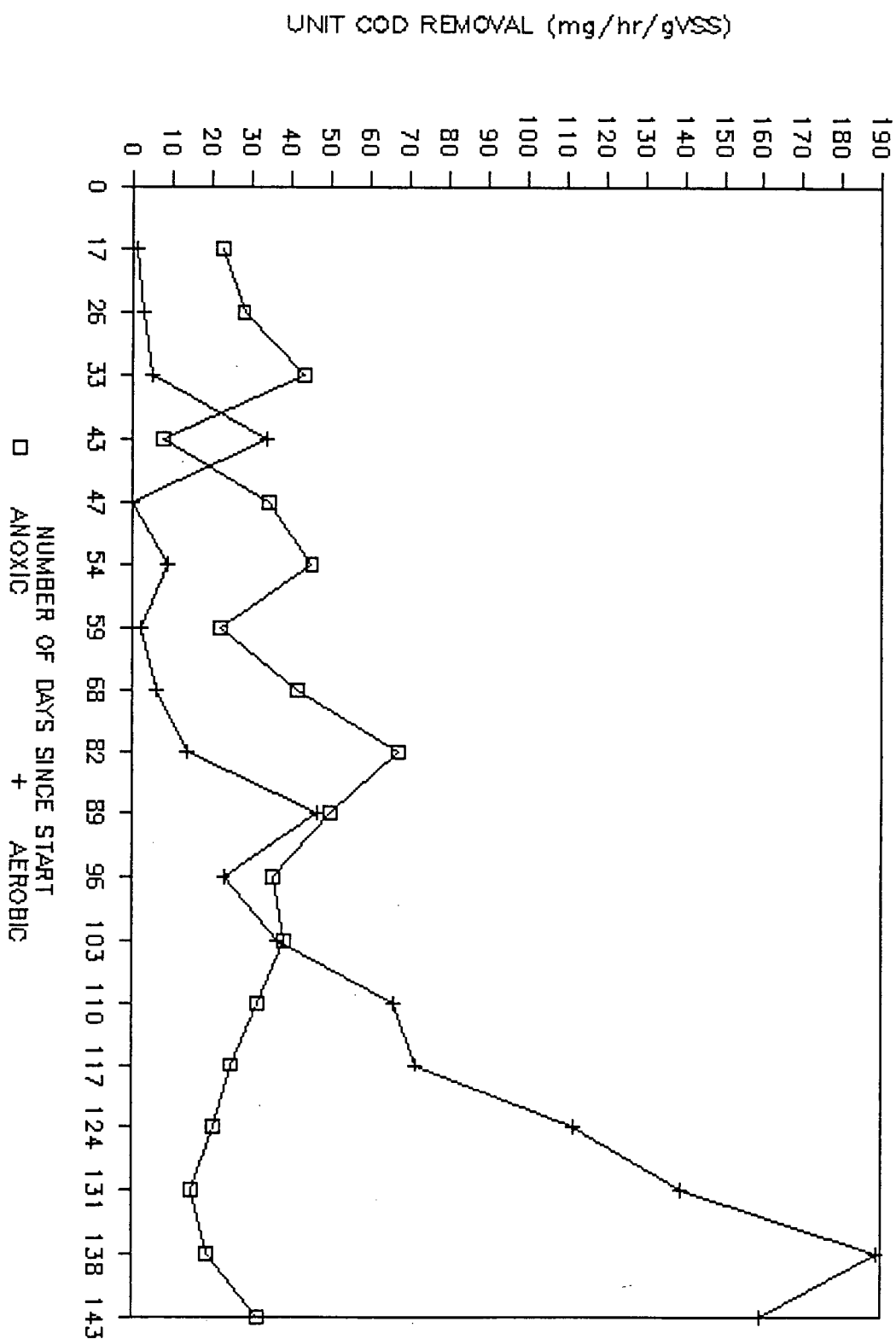
Figure 45.

METHANOL: UNIT 5-DAY BOD REMOVAL RATES

NUMBER OF DAYS SINCE START

□   ANOXIC   +   AEROBIC
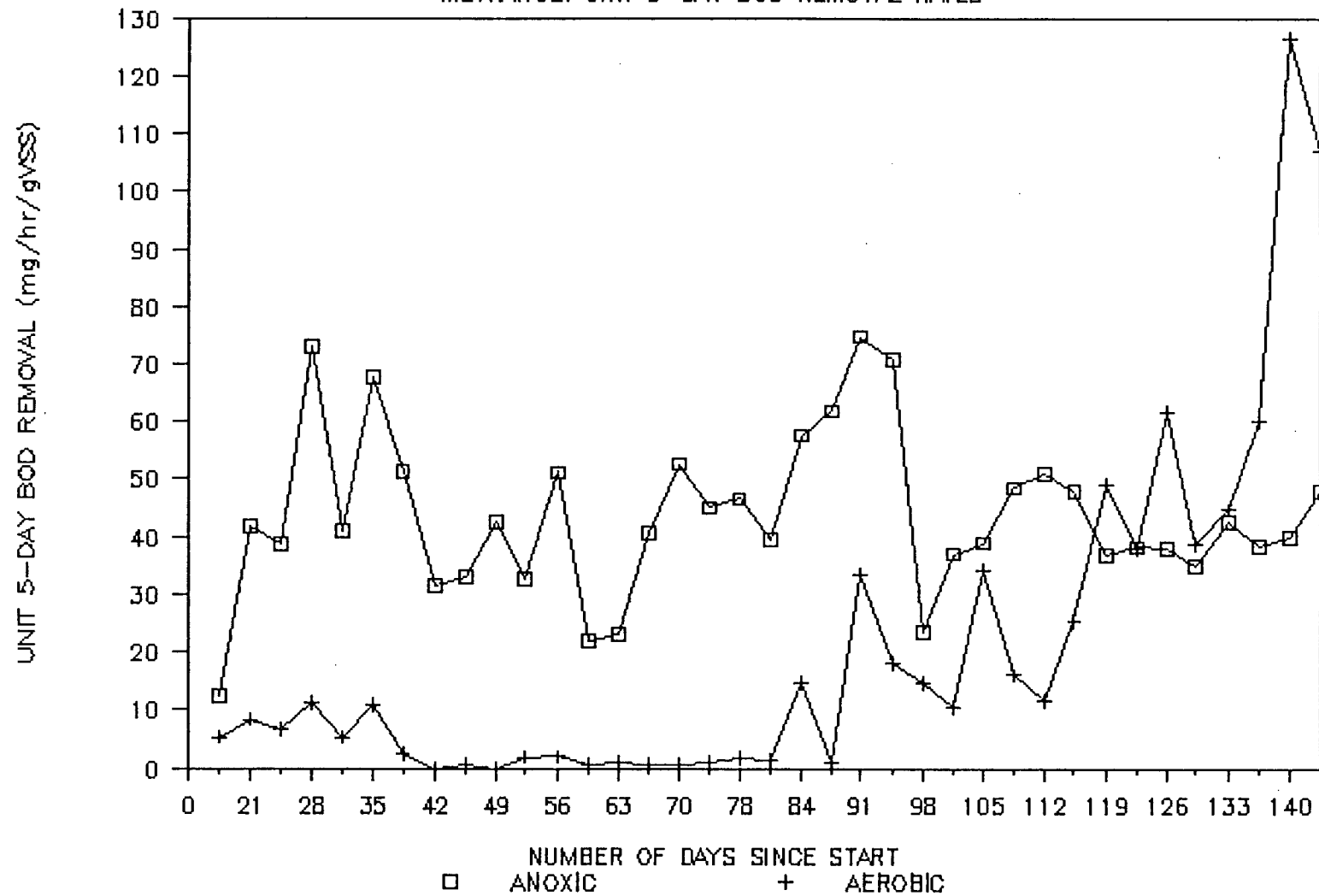
Figure 46.
GLUCOSE: UNIT COD REMOVAL

UNIT COD REMOVAL RATE (mg/hr/gVSS)

NUMBER OF DAYS SINCE START

□   ANOXIC   +   AEROBIC
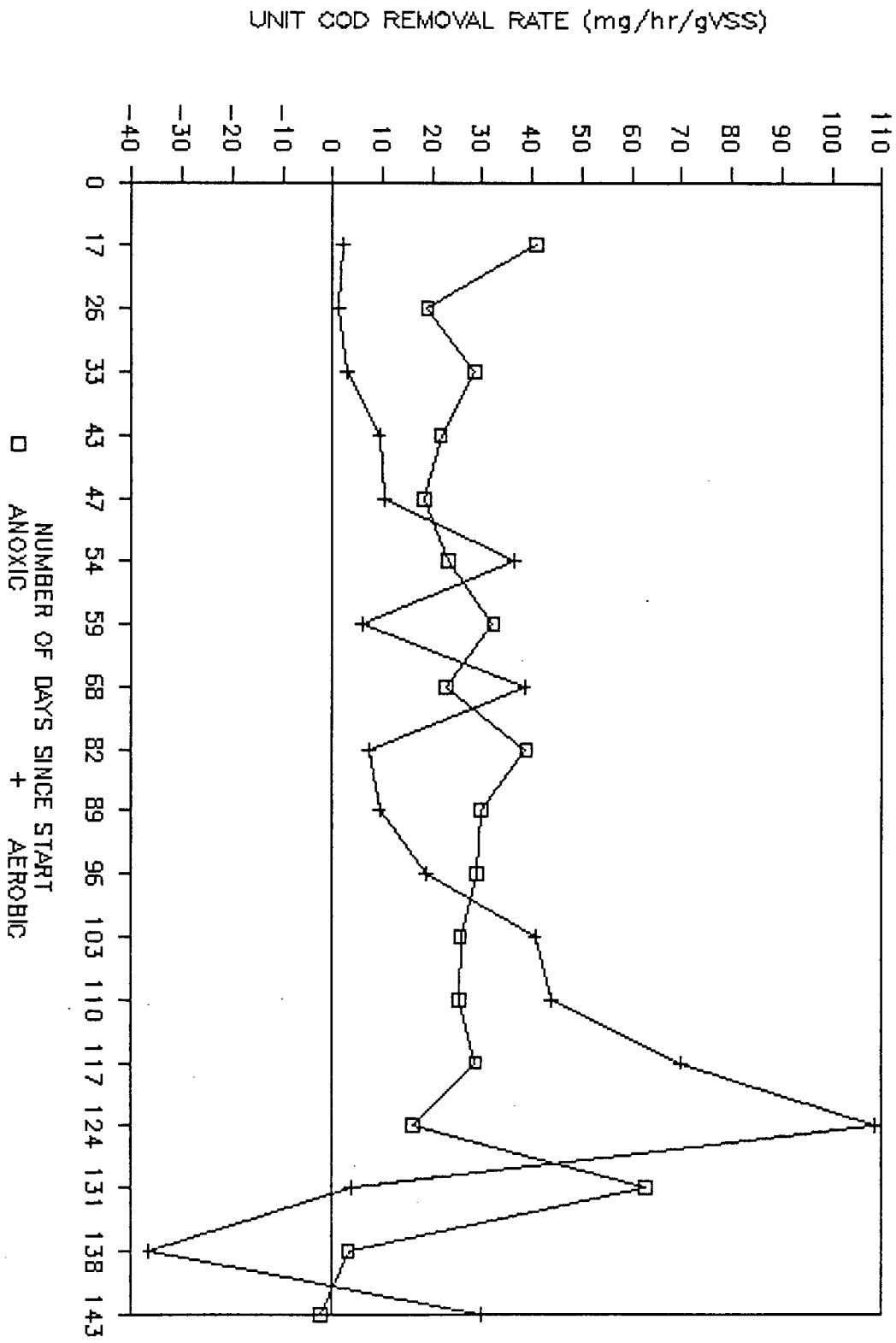
Figure 47.

GLUCOSE: UNIT 5-DAY BOD REMOVAL

NUMBER OF DAYS SINCE START

□   ANOXIC   +   AEROBIC
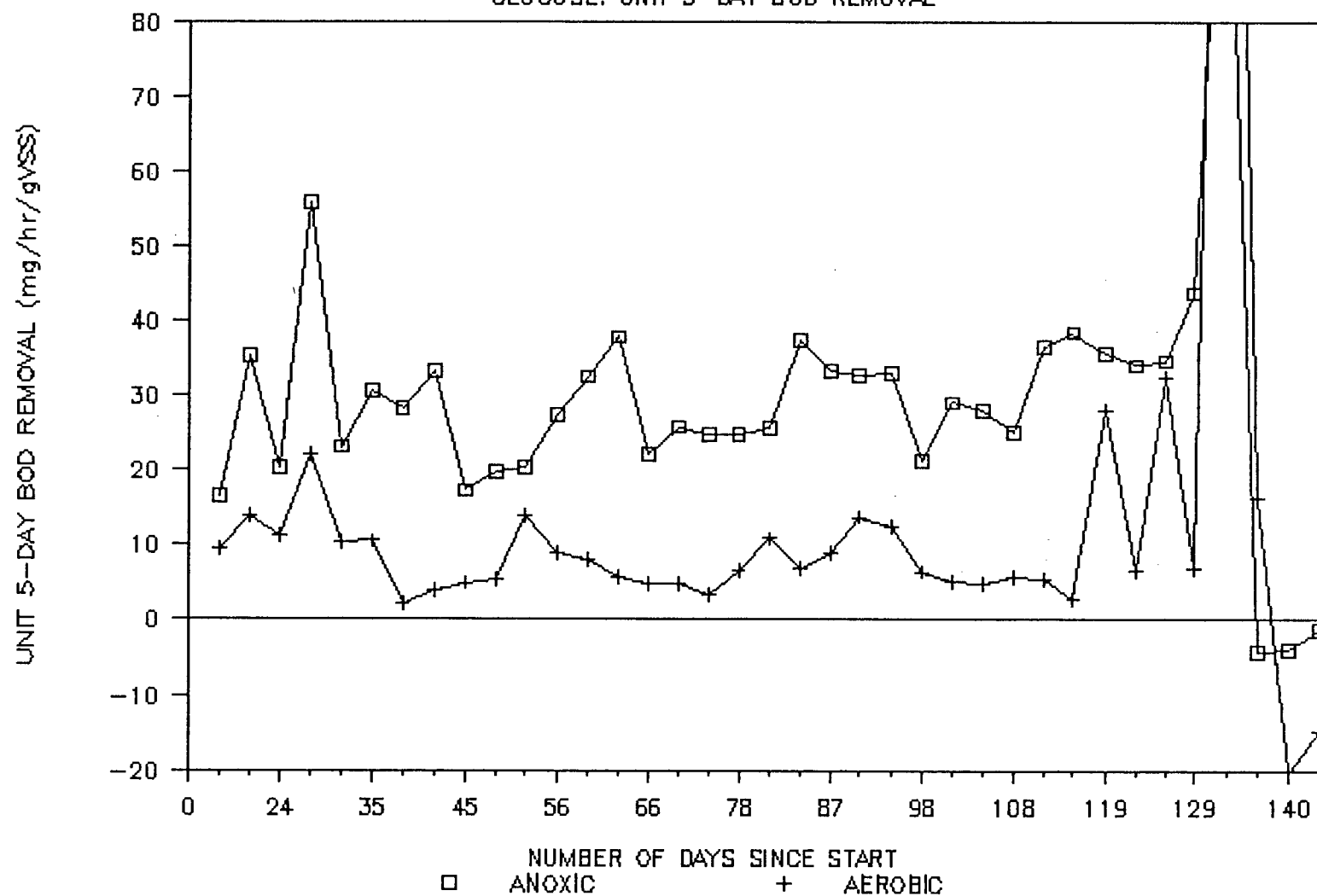
Figure 48.

ACETATE: UNIT COD REMOVAL
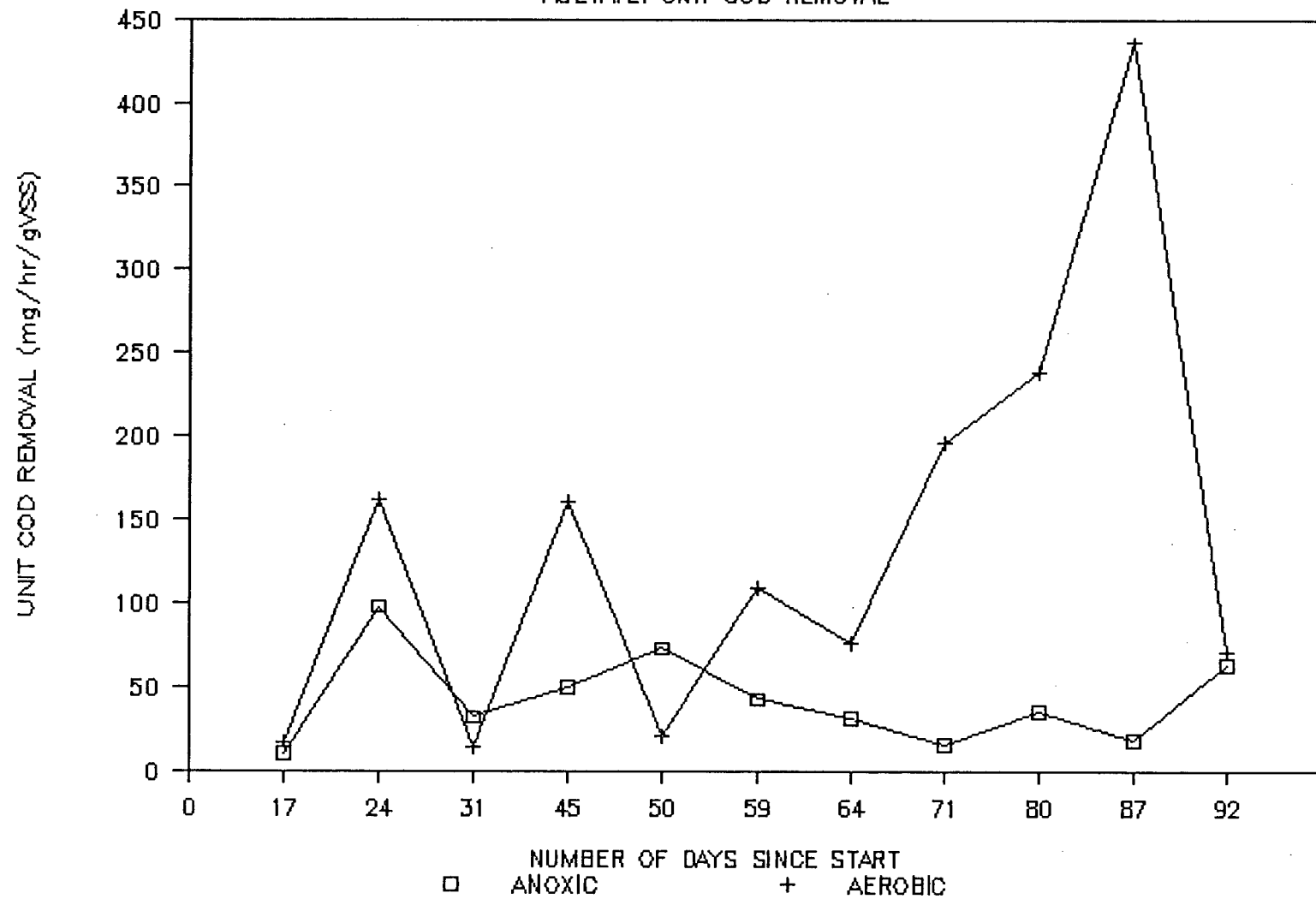
Figure 49.

ACETATE: UNIT 5-DAY BOD REMOVAL

NUMBER OF DAYS SINCE START

□   ANOXIC   +   AEROBIC
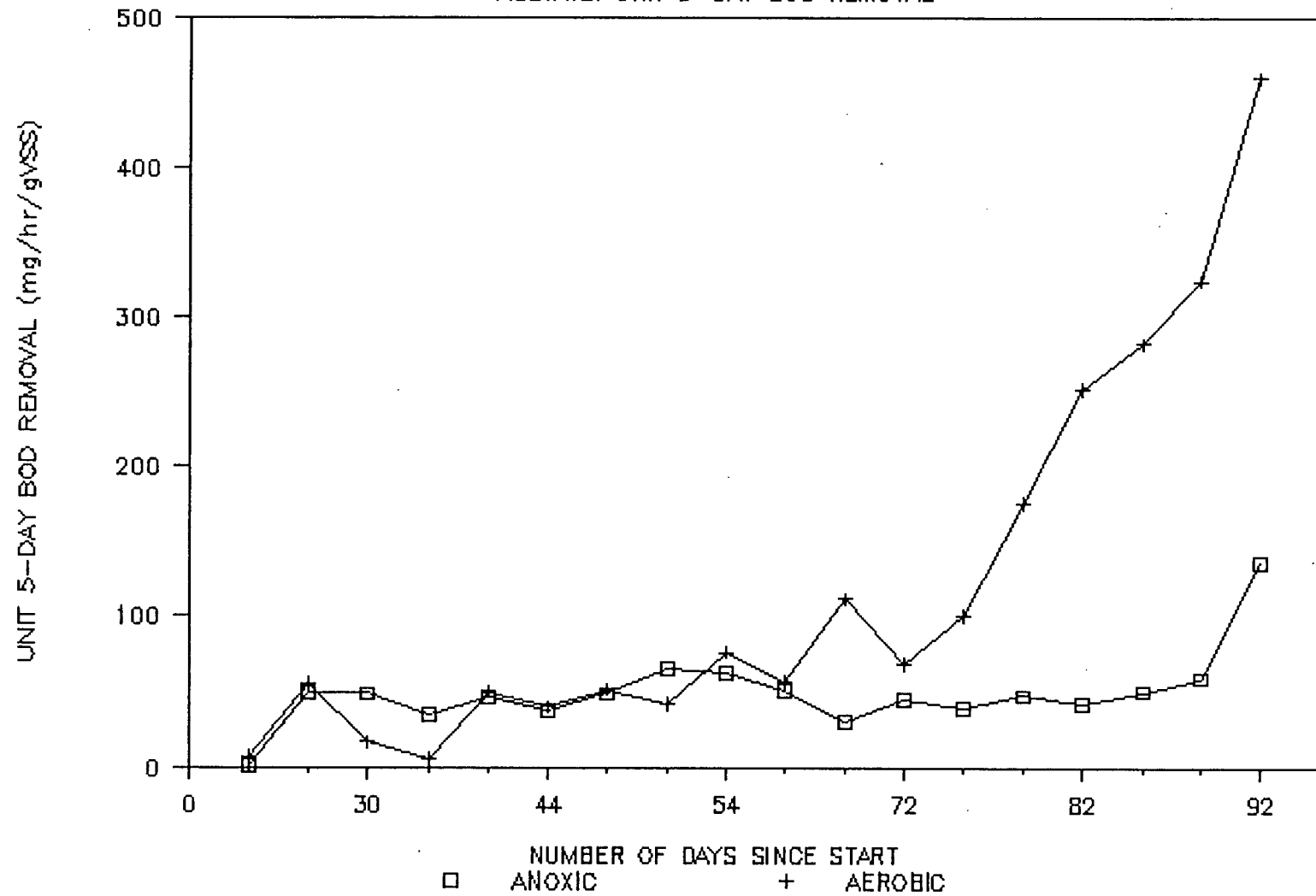
Figure 50.
YEAST WASTE: UNIT COD REMOVAL

UNIT COD REMOVAL (mg/hr/gVSS)
(Thousands)

NUMBER OF DAYS SINCE START
□ ANOXIC   + AEROBIC
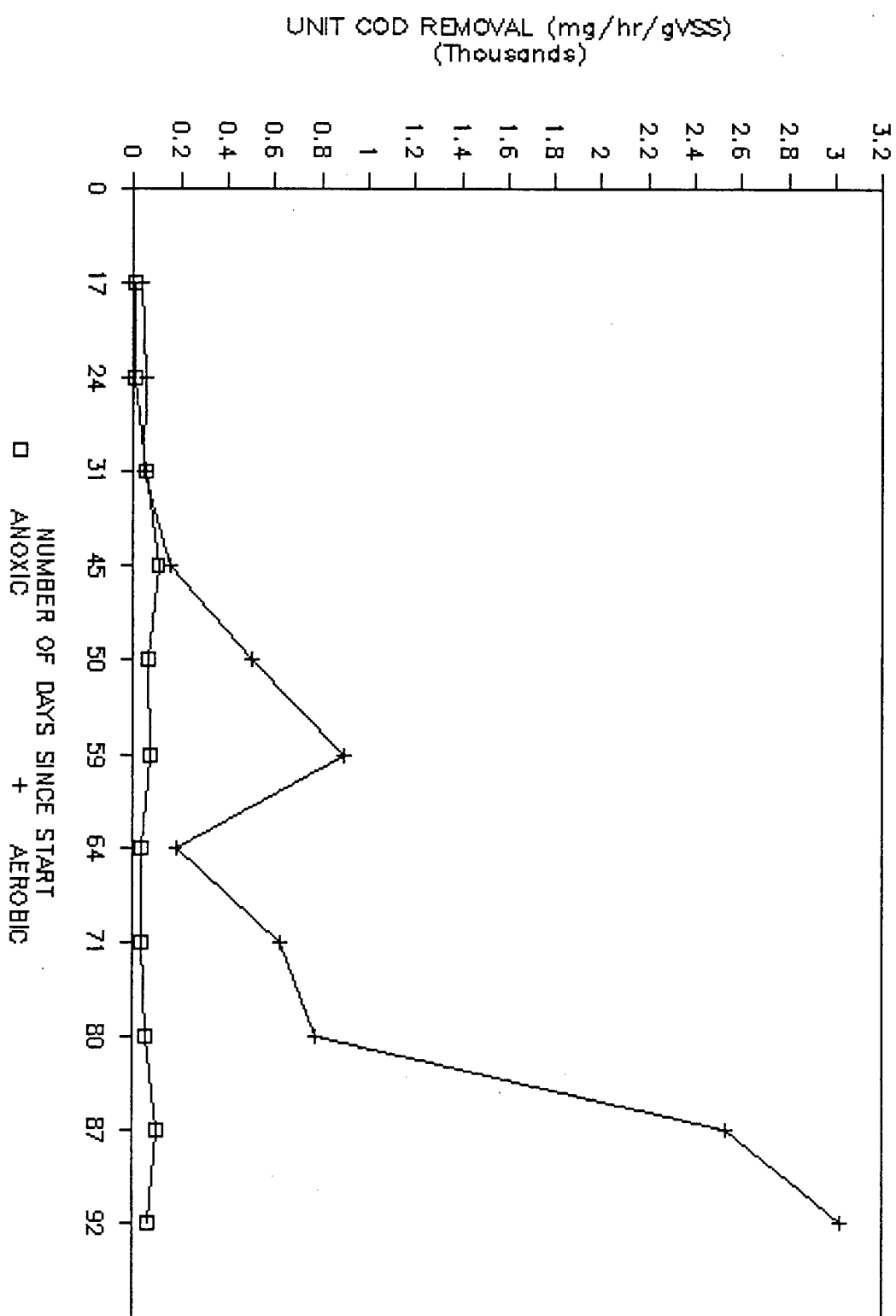
Figure 51.
YEAST WASTE: UNIT 5-DAY BOD REMOVAL
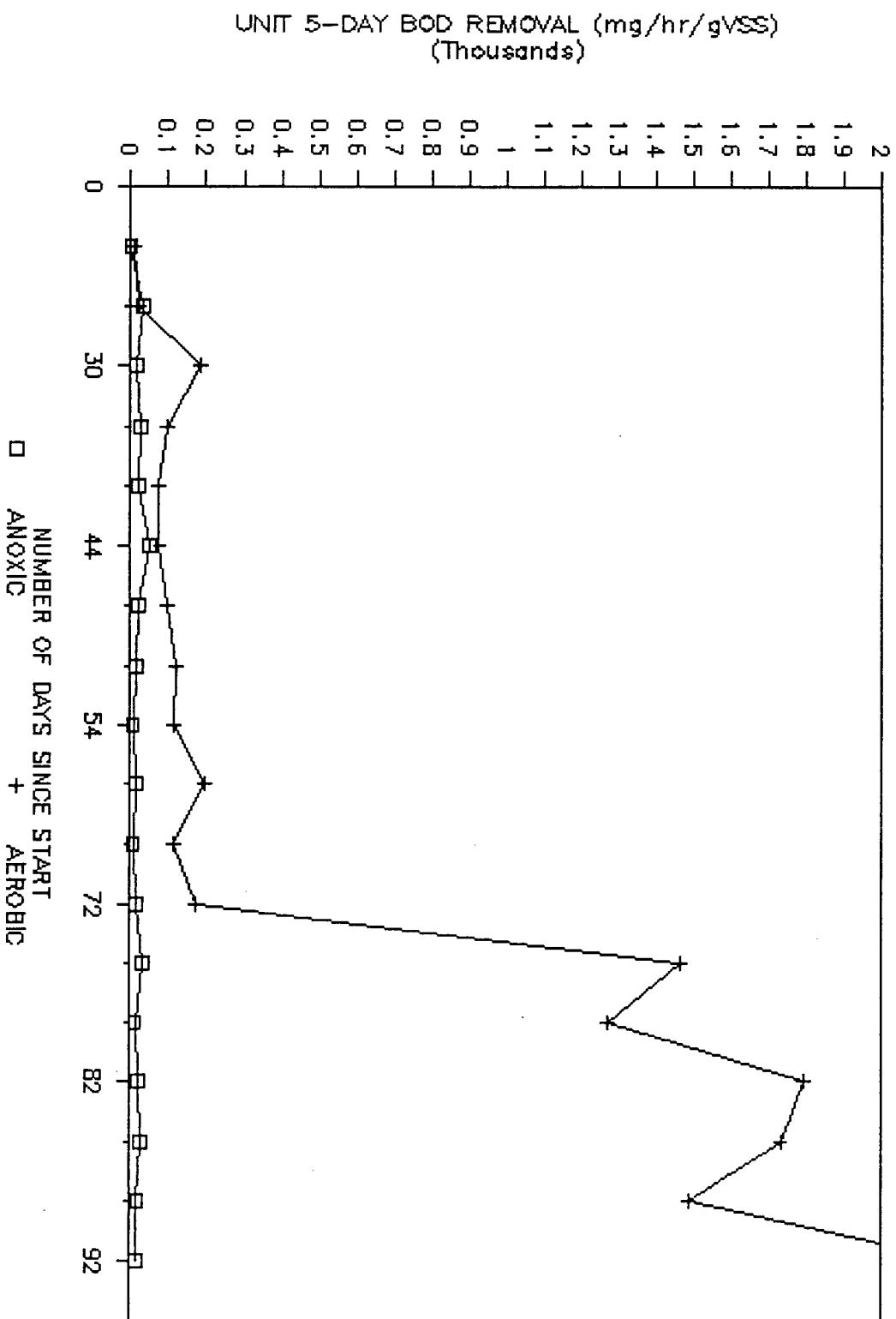
autotrophic growth. The yeast waste system exhibited a fairly constant aerobic unit FTKN removal rate, with a slight increase before decreasing at the end of the run. The range of decrease for the aerobic unit ammonia removal rates were 7 to 3 mg/hr/gVSS for methanol, 4 to 2 mg/hr/gVSS for glucose, 8 to 4 mg/hr/gVSS for acetate, and 7 to 2 mg/hr/gVSS for the yeast waste system.

The anoxic unit ammonia removal rates were low and relatively consistent over the duration of each run. The anoxic rates averaged about 0.1 mg/hr/gVSS, 0.5 mg/hr/gVSS, 0.8 mg/hr/gVSS, and 0.7 mg/hr/gVSS for methanol, glucose, acetate, and the yeast waste system respectively. The unit ammonia removal rates can be seen in Figures 52 to 55. These anoxic unit removal rates are below the values of 1.6 mg/hr/gVSS, for a zinc stressed leachate treatment system, using glucose, reported by **Dedhar** (1985), and are also lower than the values of 1.0 mg/hr/gVSS, while using methanol, 1.0-1.5 mg/hr/gVSS, with glucose, for the control side of the biological treatment system of **Mavinic and Randall** (**unpublished**). The experimental side of the **Mavinic and Randall** treatment system, that received zinc, had an anoxic removal rate of 1.0-1.5 mg/hr/gVSS, while using methanol, and 2.0-2.5 mg/hr/gVSS with glucose. The lower unit ammonia removal rates may be due to the high measured VSS, caused by the excess carbon.

Figure 52.

METHANOL UNIT AMMONIA REMOVAL

UNIT AMMONIA REMOVAL (mg/h/gVSS)

NUMBER OF DAYS SINCE START

□ ANOXIC   + AEROBIC

112
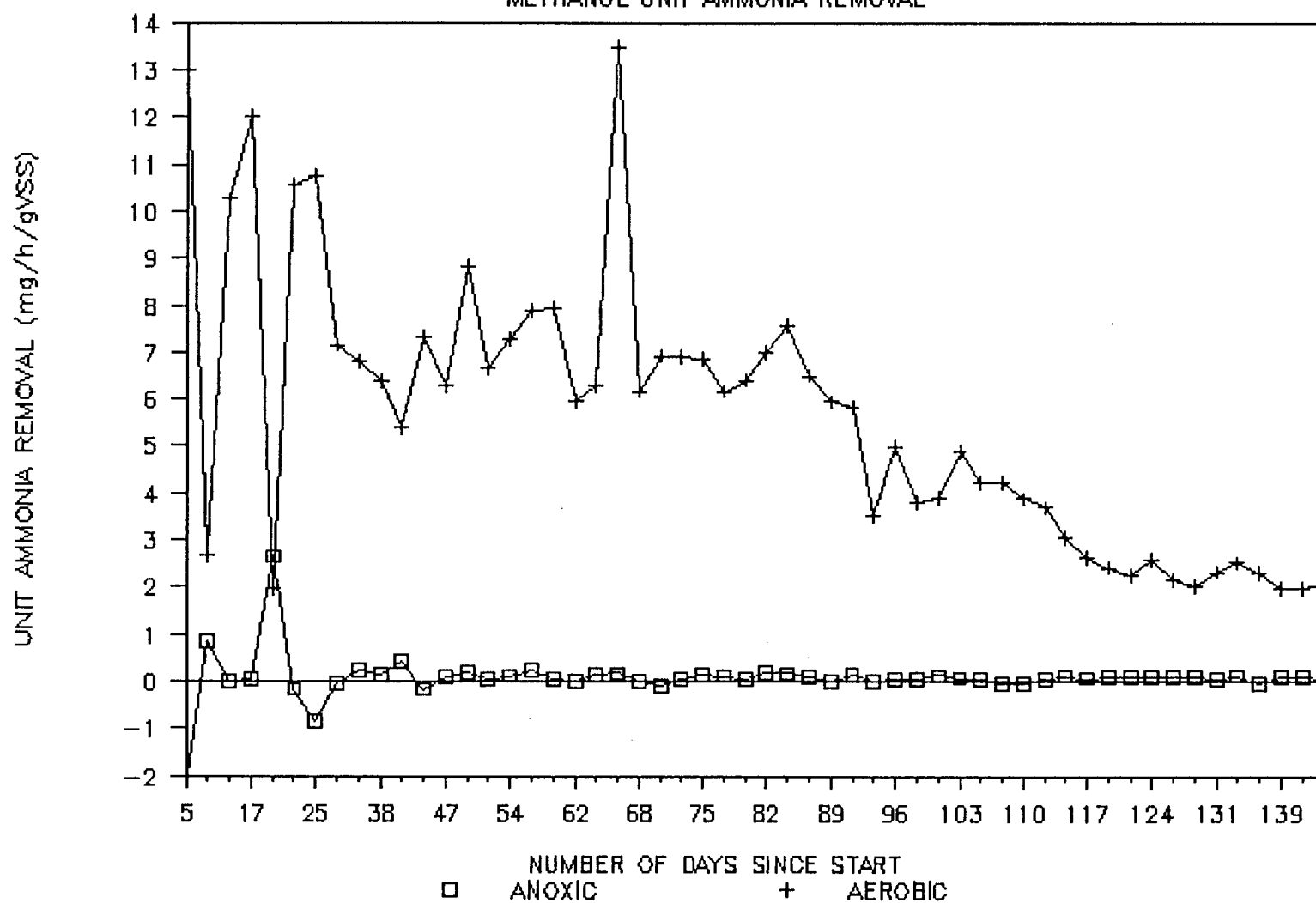
Figure 53.

GLUCOSE: UNIT AMMONIA REMOVAL

NUMBER OF DAYS SINCE START

□ ANOXIC   +   AEROBIC
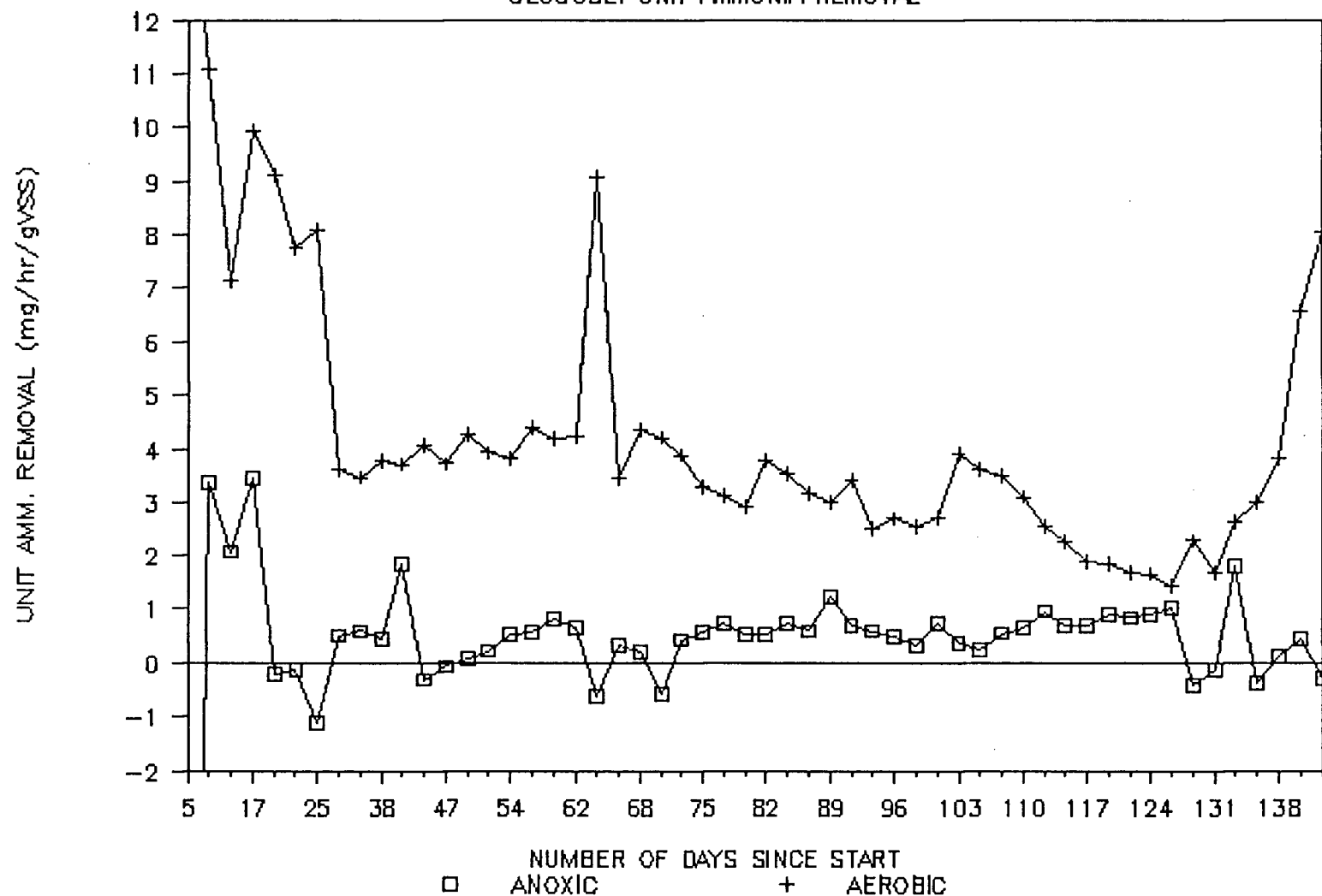
Figure 54.

ACETATE: UNIT AMMONIA REMOVAL

NUMBER OF DAYS SINCE START

□   ANOXIC   +   AEROBIC

114
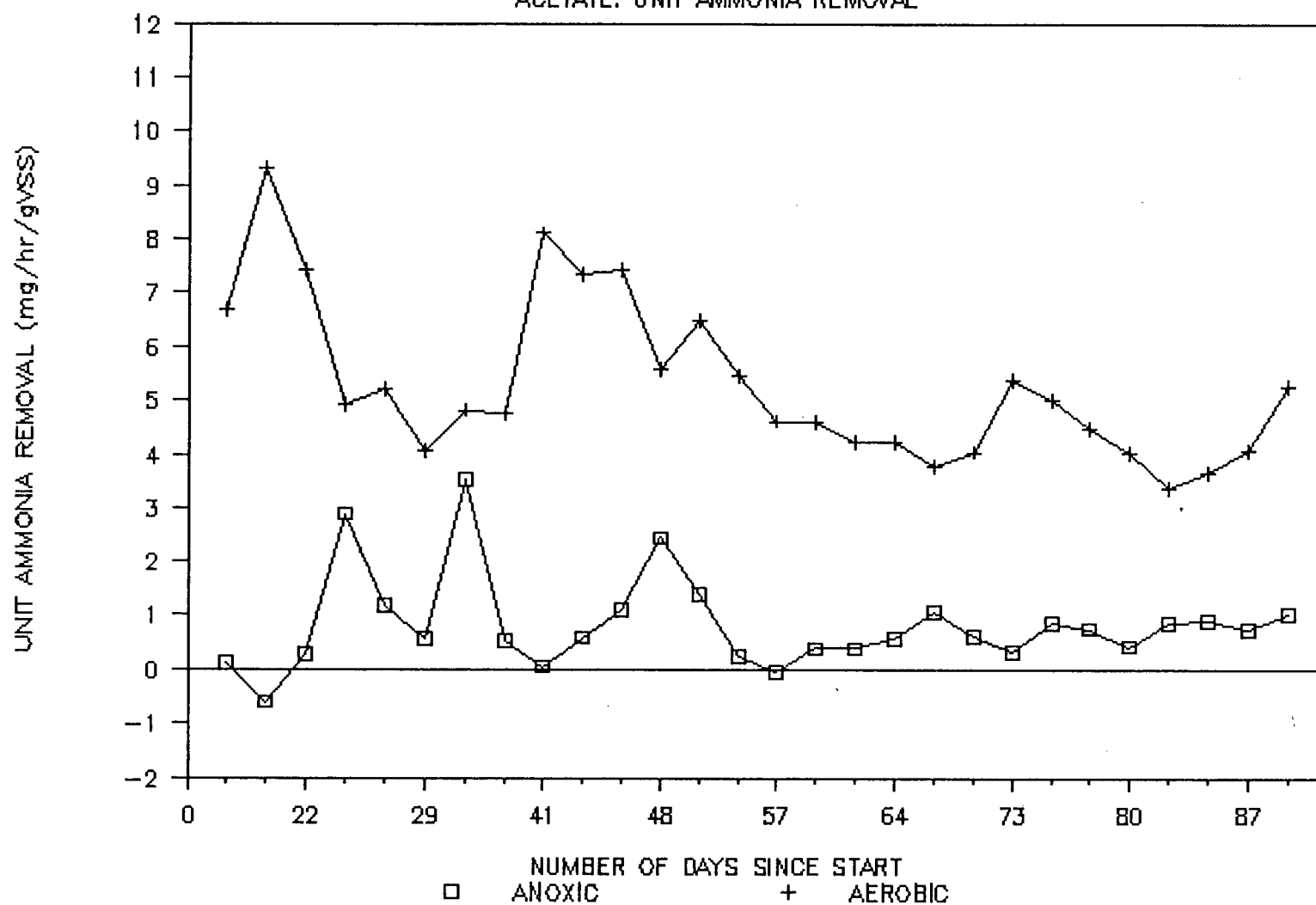
Figure 55.

YEAST WASTE: UNIT FTKN REMOVALS
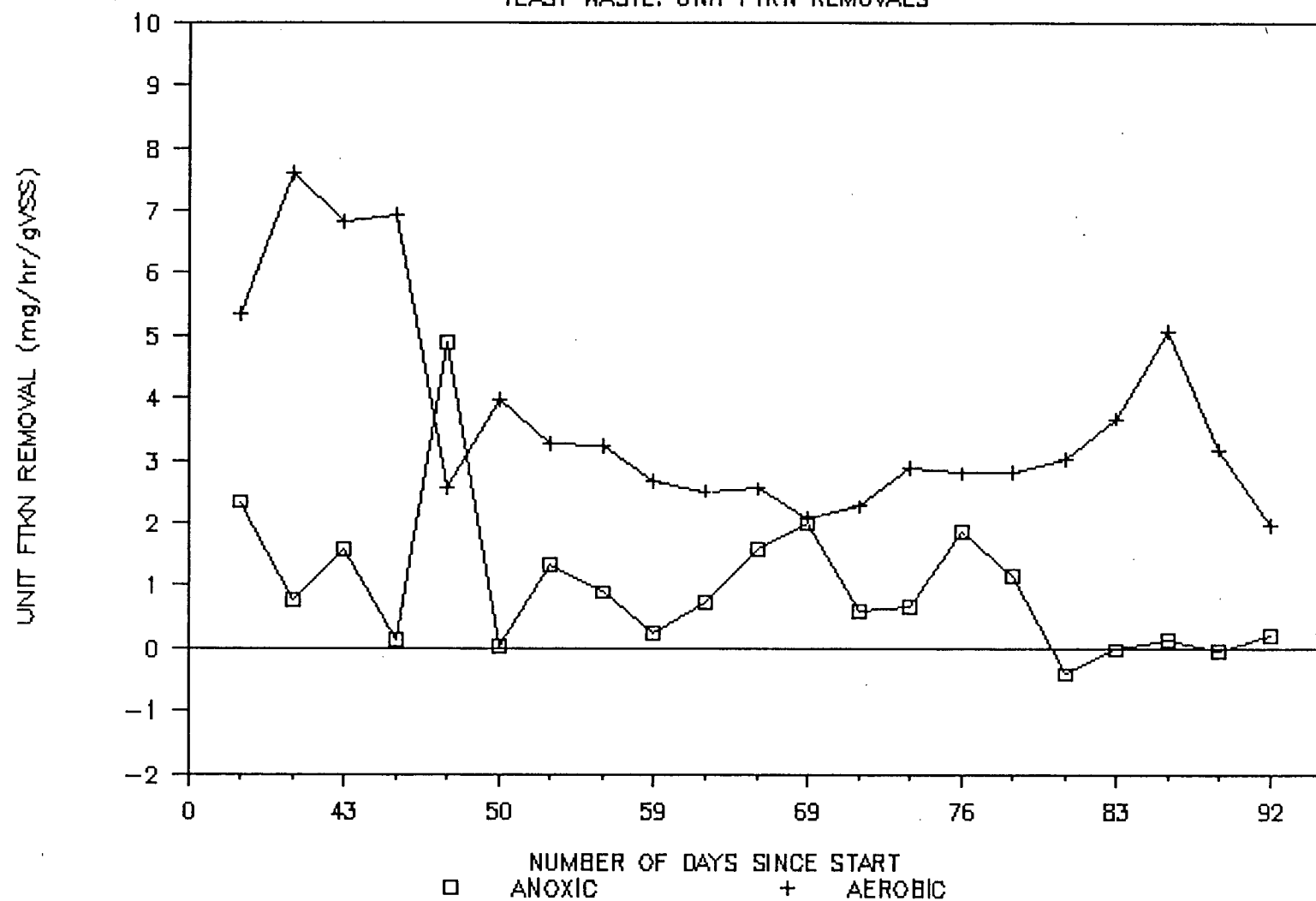
5.8.3 Nitrification

The unit nitrification rates, mg NOx produced/hr/gVSS, all decreased over each run (see **Figures** 56 to 59). The decrease can be attributed to the increase in VSS and to the increase of ammonia removal through assimilation. Although a bacterial assay was not conducted, the increase in VSS (**Figures 12, 14a, 14b**) was assumed to be due to heterotrophic growth, caused by the increasing amount of carbon available in the aerobic reactor. The increase in heterotrophs and a stable population of nitrifying autotrophs could cause an overall decrease in the percentage of nitrifiers in the biomass, and result in lower unit nitrification rates. Since the effect of the COD:NOx on nitrification was slight, the general increase in VSS due to excess carbon probably played a more important role in causing the decrease in unit nitrification rate. The decrease was 14 to 2 mg/hr/gVSS for methanol, 9 to 1.5 mg/hr/gVSS for glucose, 9 to 4 mg/hr/gVSS for acetate, and 7 to 2 mg/hr/gVSS for the yeast waste system.

Figures 56 to 59 show both the unit nitrification rate and the unit denitrification rate for the methanol, glucose, acetate, and yeast waste systems respectively.

5.8.4 Denitrification

The unit denitrification rates, mg NOx reduced/hr/gVSS, either stayed constant or showed a decline over the course or each run. The methanol system had a fairly steady decline in

Figure 56.

UNIT NITRIFICATION & DENITRIFICATION
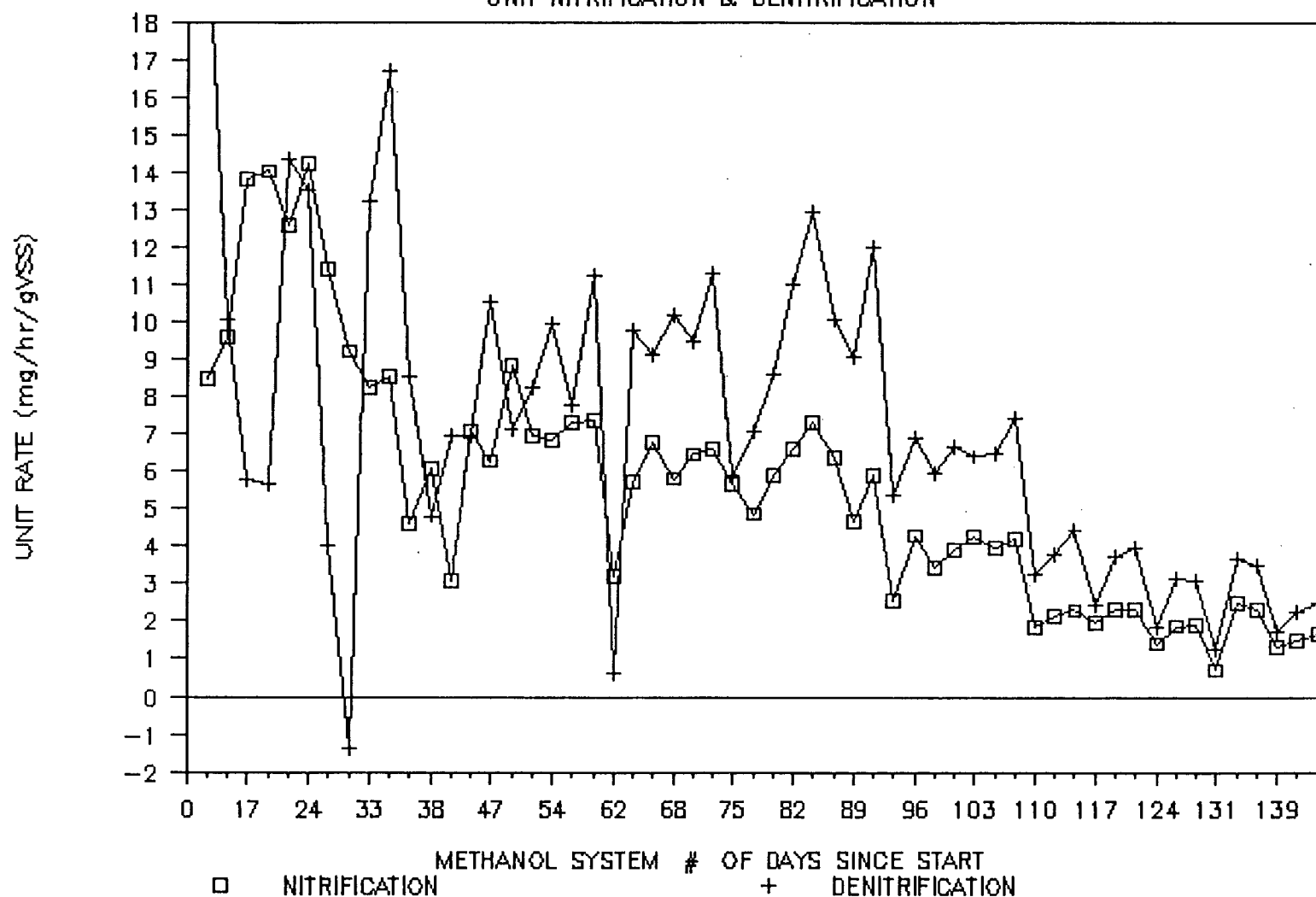
Figure 57.

UNIT NITRIFICATION & DENITRIFICATION

GLUCOSE SYSTEM # OF DAYS SINCE START

□ NITRIFICATION   +   DENITRIFICATION
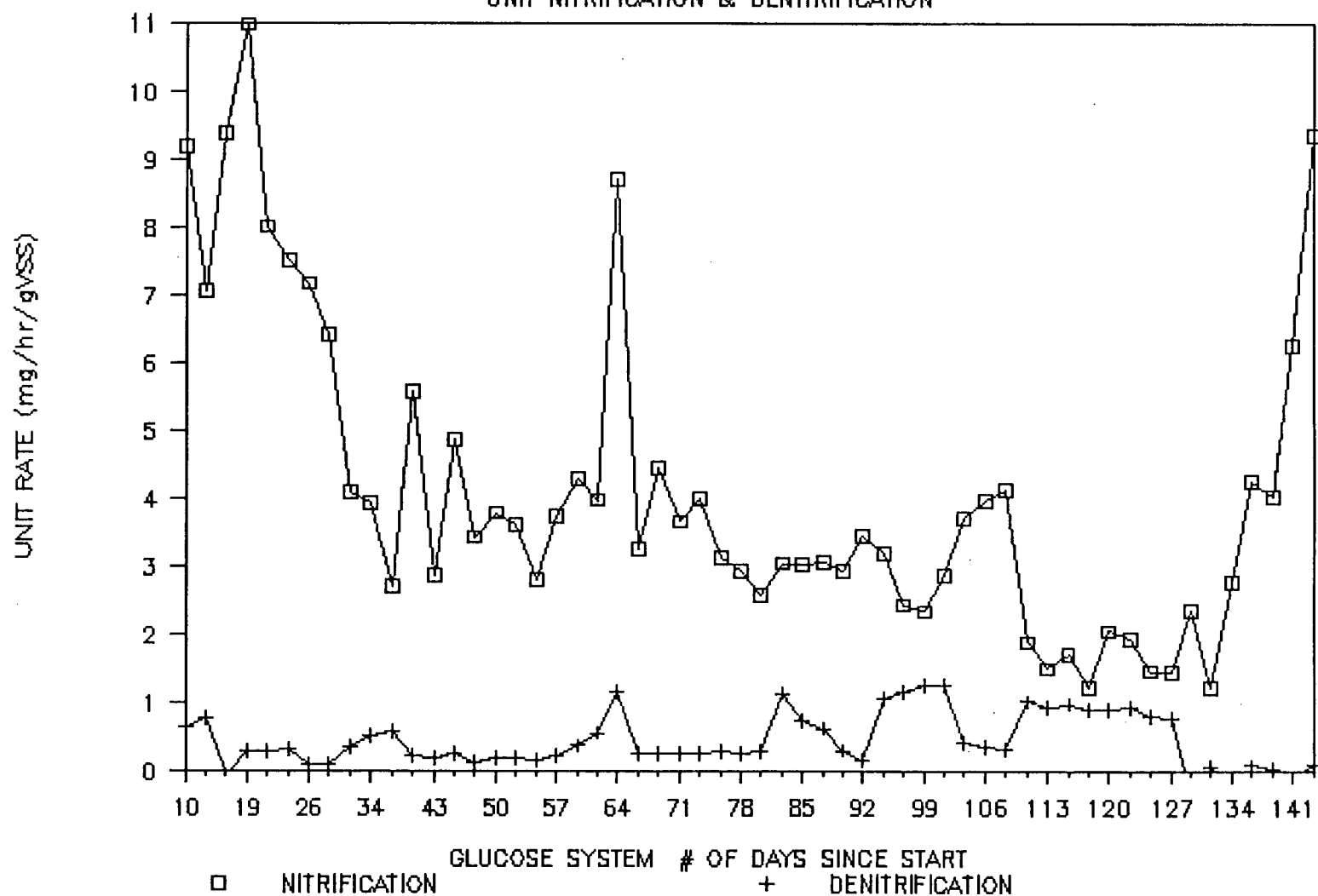
UNIT RATE (mg/hr/gVSS)

Figure 58.

UNIT NITRIFICATION & DENITRIFICATION

ACETATE SYSTEM # OF DAYS SINCE START

□   NITRIFICATION   +   DENITRIFICATION

119
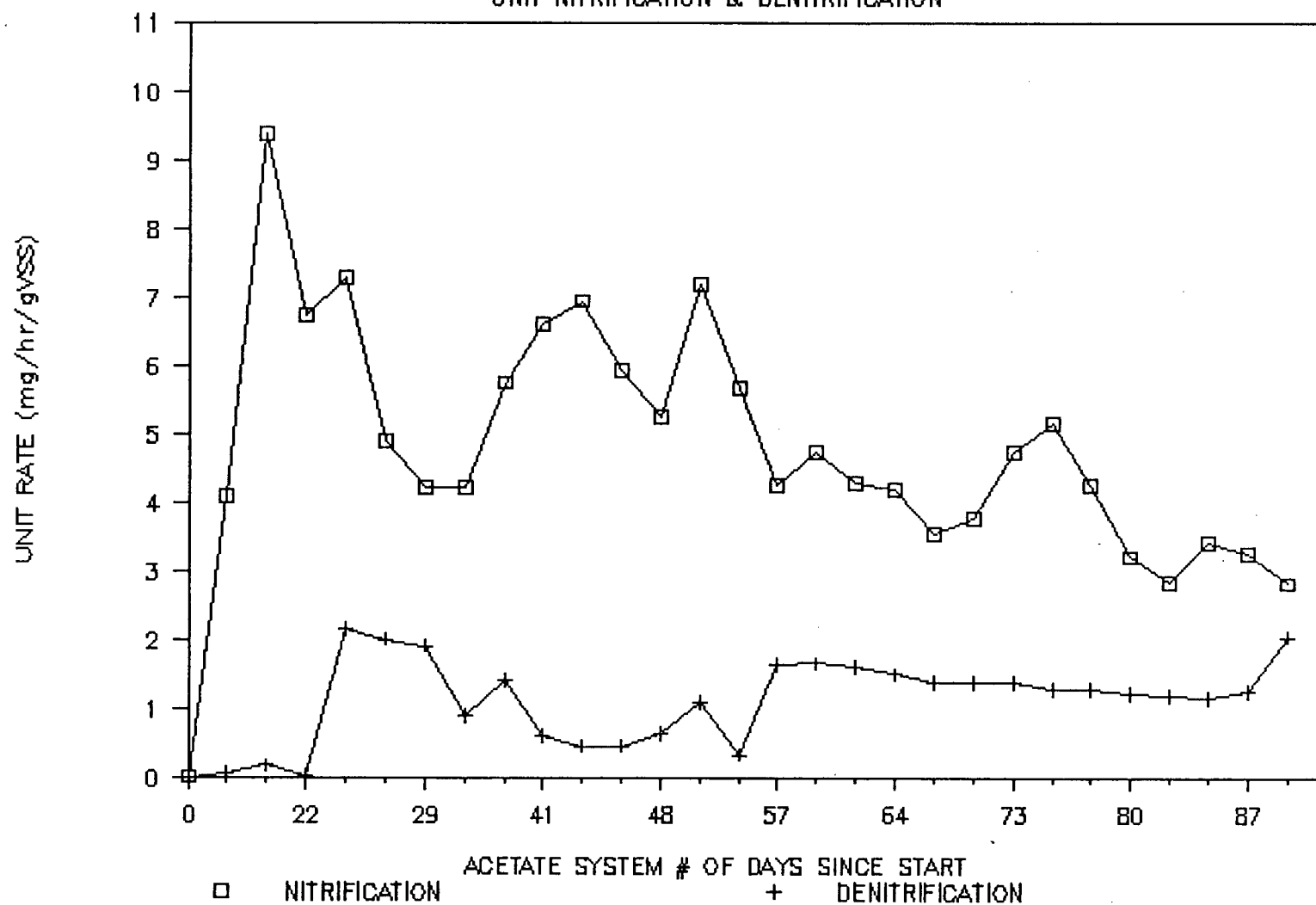
Figure 59.

UNIT NITRIFICATION & DENITRIFICATION

NUMBER OF DAYS SINCE START

□   NITRIFICATION   +   DENITRIFICATION

120
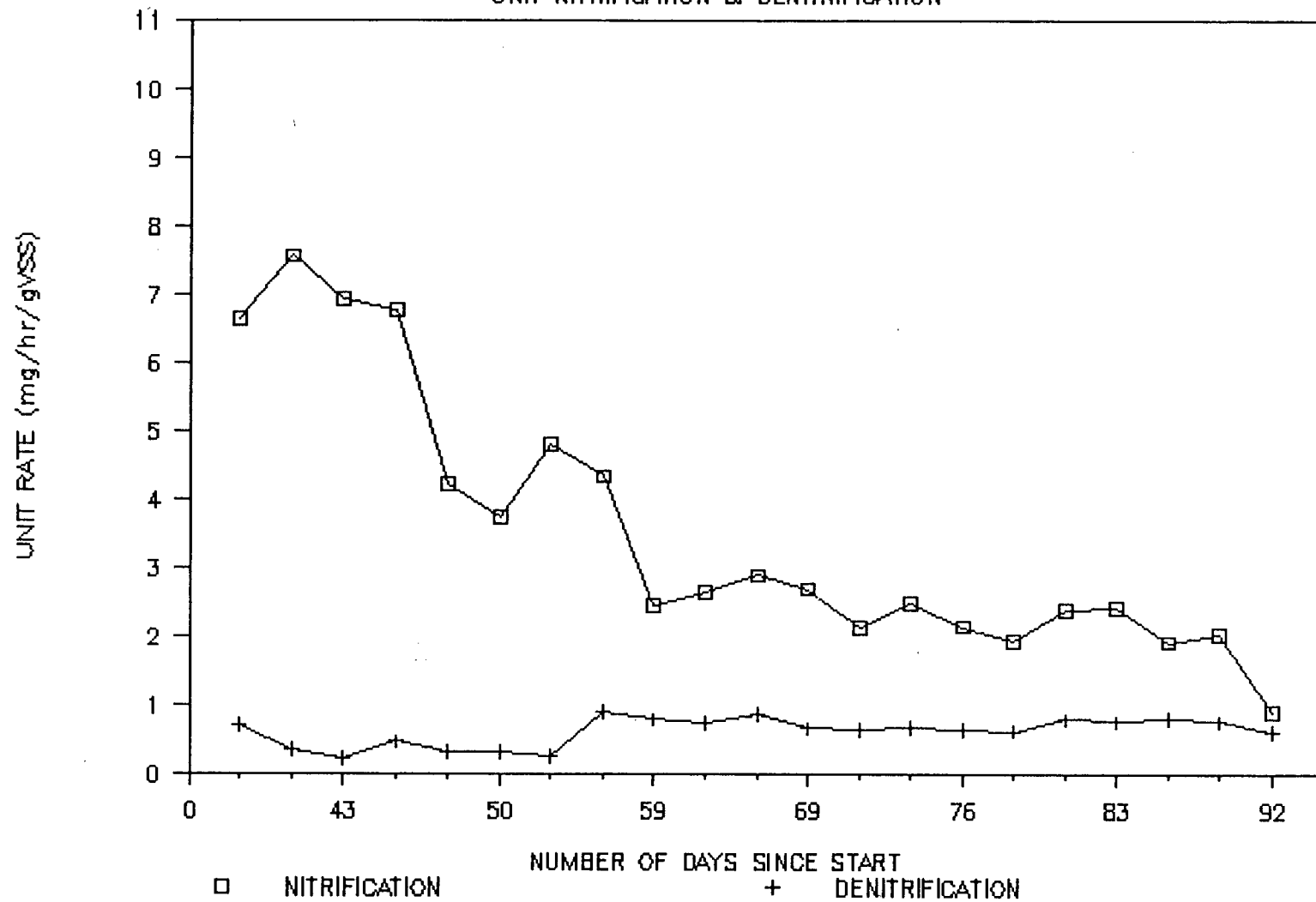
the unit denitrification rate, from 10 to 3 mg/hr/gVSS. The other three systems exhibited constant unit rates, with a slight decrease, after complete denitrification was reached. The unit denitrification rates averaged around 1 mg/hr/gVSS for glucose, 0.7 mg/hr/gVSS for acetate, and 1 mg/hr/gVSS for the yeast waste system. The unit denitrification rates for the latter three systems were well below the average unit denitrification rate of about 10 mg/hr gVSS observed by **Dedhar (1985)**. The methanol system before carbon breakthrough was around the same value, about 10 mg/hr/gVSS, as the rate reported by Dedhar. **Mavinic and Randall (unpublished)** observed average unit denitrification rates, for the control side, of 6.5 mg/hr/gVSS, when methanol was used, and 4.0 mg/hr/gVSS, for glucose. The experimental side of the system, which received zinc, had denitrification rates of 3.5 mg/hr/gVSS for methanol, and 4.0 mg/hr/gVSS for glucose. The unit denitrification rates may be lower than those observed in the other systems due to higher VSS values.

5.9 NITRITE BUILDUP

Nitrite is an intermediate byproduct of both nitrification and denitrification. A buildup of nitrite can indicate some type of inhibition or problem with one of these processes. If nitrite is observed in the aerobic reactor, then there is some problem with the conversion of nitrite to nitrate. If there is a nitrite buildup in the anoxic reactor, then denitrification is being hindered with the conversion of

nitrite to nitrogen gas. Arbitrarily, nitrite nitrogen concentrations over 10% of the total NOx nitrogen were considered a buildup. The 10% nitrite limit was chosen to exclude natural fluctuations of nitrite accumulation. Since aerobic concentrations of NOx nitrogen were about 30 mg/L, nitrite nitrogen of over 3 mg/L was considered significant. All four systems were observed to behave differently in relation to nitrite buildup.

5.9.1 Methanol

The methanol system did not display any nitrite buildup in either reactor (**Figure 60**).

5.9.2 Glucose

The glucose system showed consistently high nitrite levels in the anoxic reactor, until complete denitrification was achieved. The relationship between COD:NOx and nitrite is shown in **Figure 61**. For COD:NOx under 8:1, the anoxic nitrite nitrogen concentrations were up as high as 22 mg/L. For COD:NOx over 8:1, complete denitrification was established and nitrite did not build up. After failure, the anoxic and aerobic nitrite nitrogen levels increased dramatically, up to 85 mg/L.

The anoxic nitrite buildup, before complete denitrification was reached, is an indication of the presence of facultative anaerobic bacteria, which can only convert nitrate to

122

Figure 60.

COD:NOX vs ANOXIC & AEROBIC NITRITE

123

METHANOL SYSTEM COD:NOx

□ ANOXIC   +   AEROBIC

Figure 61.

COD:NOx vs ANOXIC & AEROBIC NITRITE

NITRITE NITROGEN CONC. (mg/L)

GLUCOSE SYSTEM COD:NOx
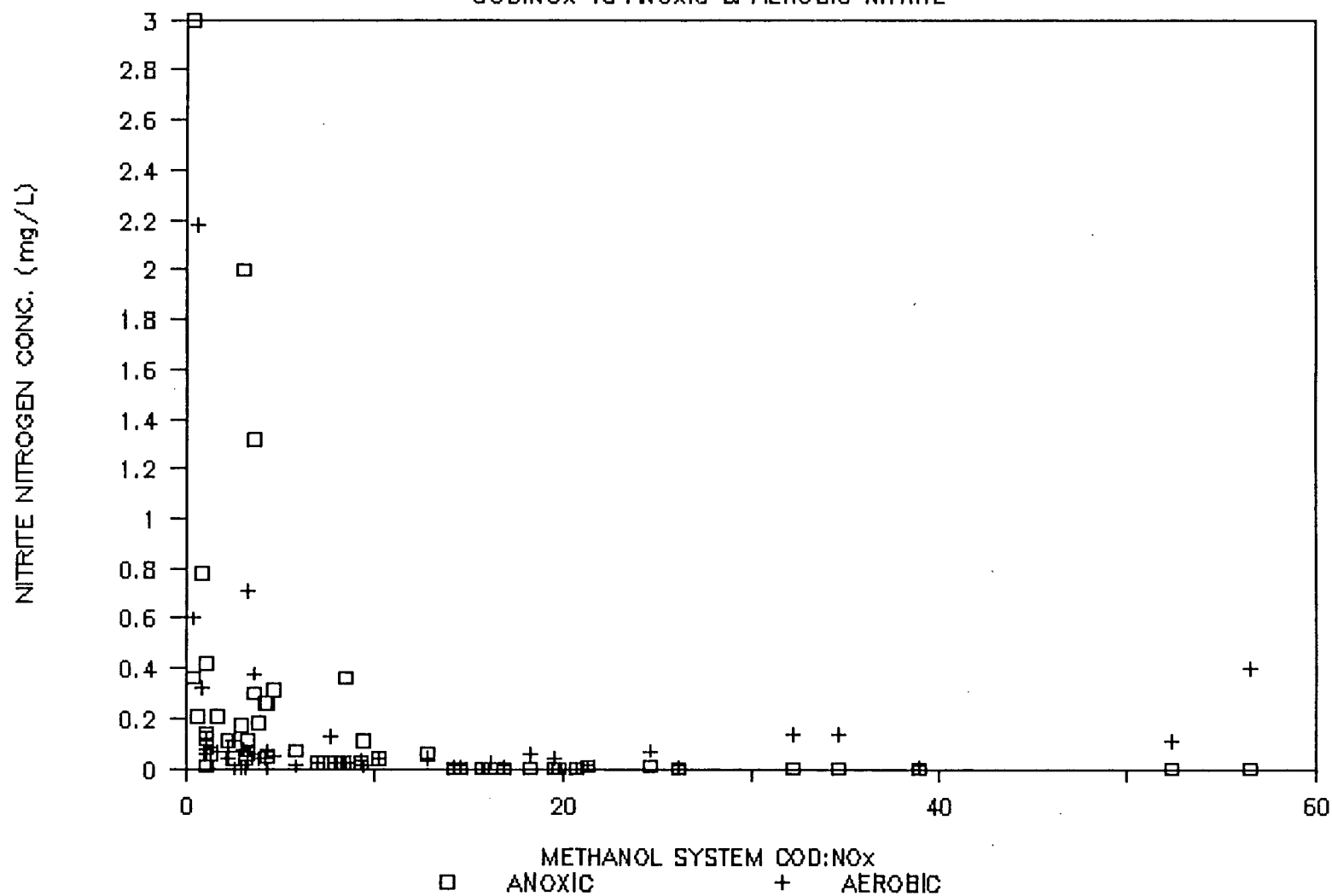
□ ANOXIC   + AEROBIC
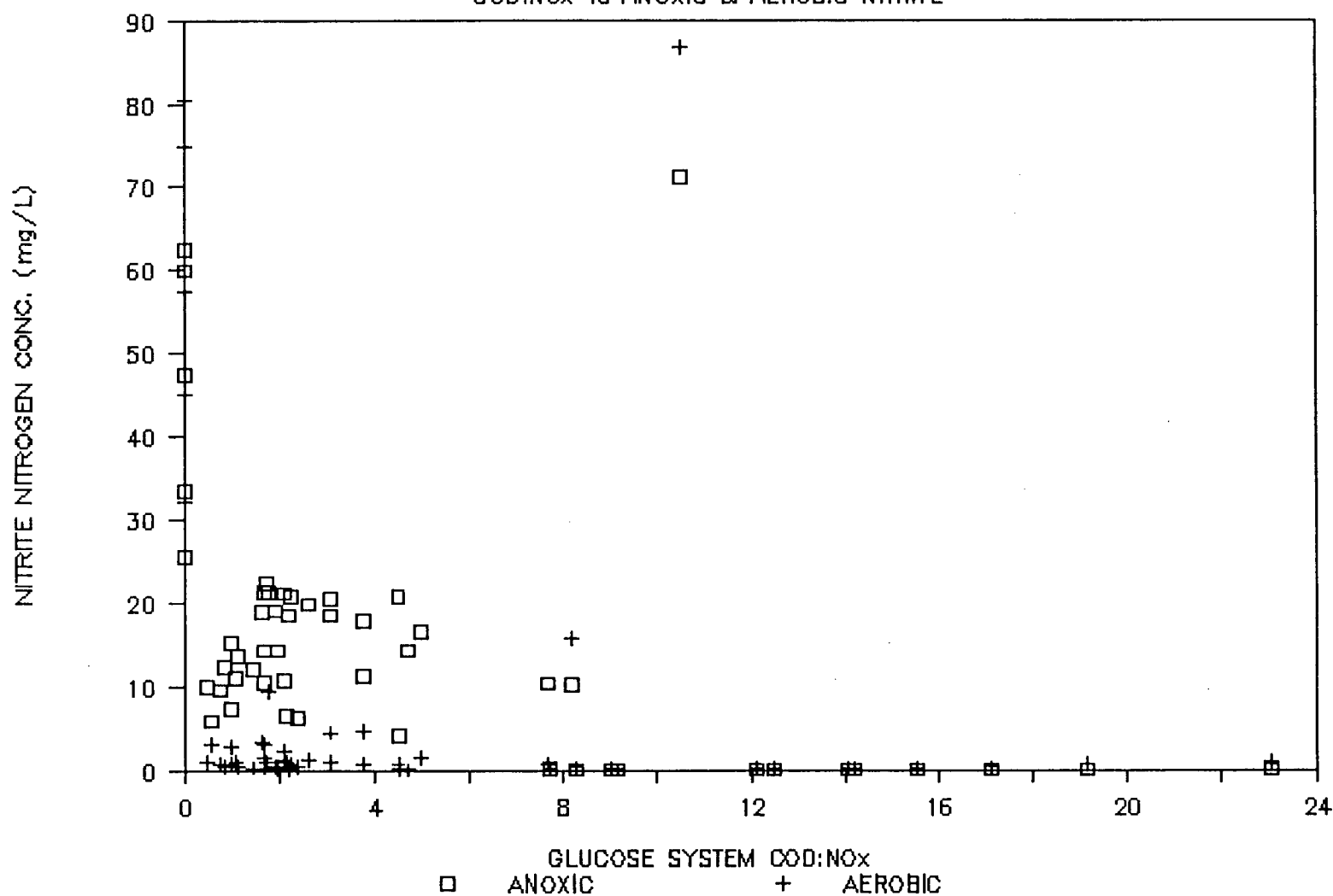
nitrite. These facultative bacteria may have been encouraged by the glucose, while the other denitrifying bacteria, especially those which convert nitrite to nitrogen gas, grew more slowly. The slower growth may have been due to acclimatization to glucose, with a slight inhibition by the lower pH due to fermentation by the facultative anaerobes. As the carbon loading increased, the facultative anaerobes used up all the nitrate and then switched to fermentation. Since fermentation processes are relatively slow, there was carbon available for nitrogen gas production by other denitrifying bacteria.

5.9.3 Acetate

The acetate system had an anoxic nitrite buildup over the period of day 38 to day 54. Day 54 was just before the start of complete denitrification. This indicates that nitrite conversion to nitrogen gas was being inhibited. The anoxic ORP was about -100 mV and the anoxic pH about 8 during this period, and were not indicative of facultative anaerobes. There is the possibility that facultative anaerobes were responsible for the nitrite buildup. Acetate is a two carbon compound, which the facultative anaerobes may have been able to ferment. A possible reason for the absence of lowered pH could be that the resulting volatile fatty acids produced by fermentation were single carbon compounds, and thus easily further utilized. The rapid removal of the acids may have prevented a drop in pH. There is no indication in the

literature of nitrite accumulation associated with acetate. The leachate, combined with the acetate, may have had some type of inhibitory effect on the true denitrifiers, or somehow encouraged the facultative anaerobes. Figure 62 shows the relationship of the nitrite buildup with COD:NOx.

5.9.4 Yeast Waste

The yeast waste system only exhibited nitrite buildup in the aerobic reactor, and only at COD:NOx above 25:1, as illustrated in **Figure 63**. These high loadings may have caused changes in the bacterial population that could hinder the nitrite to nitrate process. The probable cause of the nitrite buildup was inhibition of Nitrobacter by free (un-ionized) ammonia (**Anthonisen, et al. 1976; Turk 1986**). The higher concentration of ammonia could be caused by higher FTKN entering the anoxic reactor as the yeast waste solution strength was increased to raise the COD:NOx. The increase in ammonia concentration could lead to an increase in free ammonia, as a certain percentage of the ammonia must be free ammonia to satisfy the equilibrium constants. This increase in free ammonia could occur at the relatively low pH of about 7.4 as observed in the anoxic reactor. The dissociation constant for the ammonium ion into a proton plus free ammonia is 5.6764×10^{-10} (**Bates and Pinching, 1950**). At a pH of 7.4, and a measured total ammonia nitrogen entering the aerobic reactor of 60 mg/L, the free ammonia nitrogen concentration should be about 0.84 mg/L entering the aerobic reactor.

Figure 62.

COD:NOx vs ANOXIC & AEROBIC NITRITE
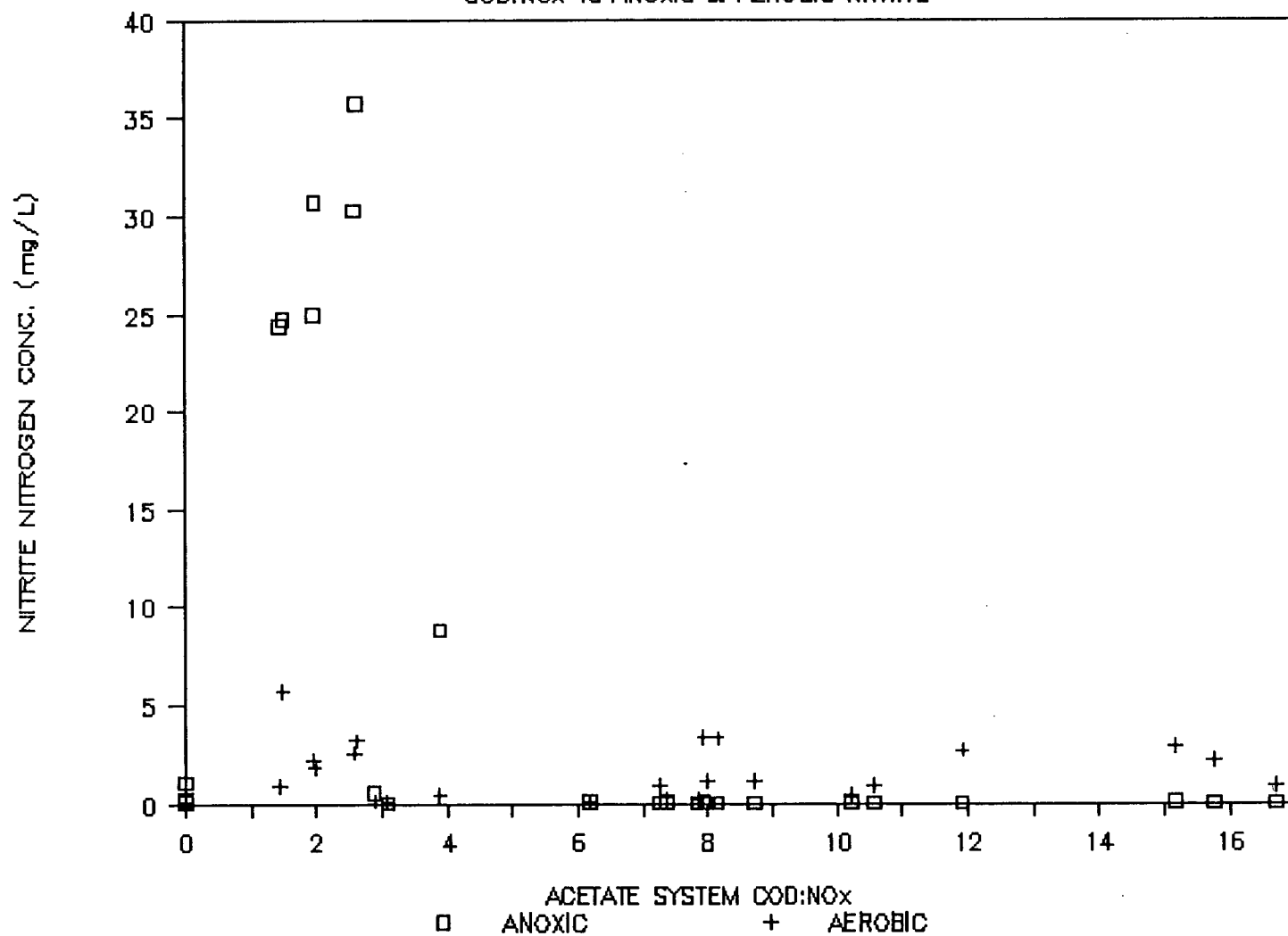
Figure 63.

COD:NOx vs ANOXIC & AEROBIC NITRITE
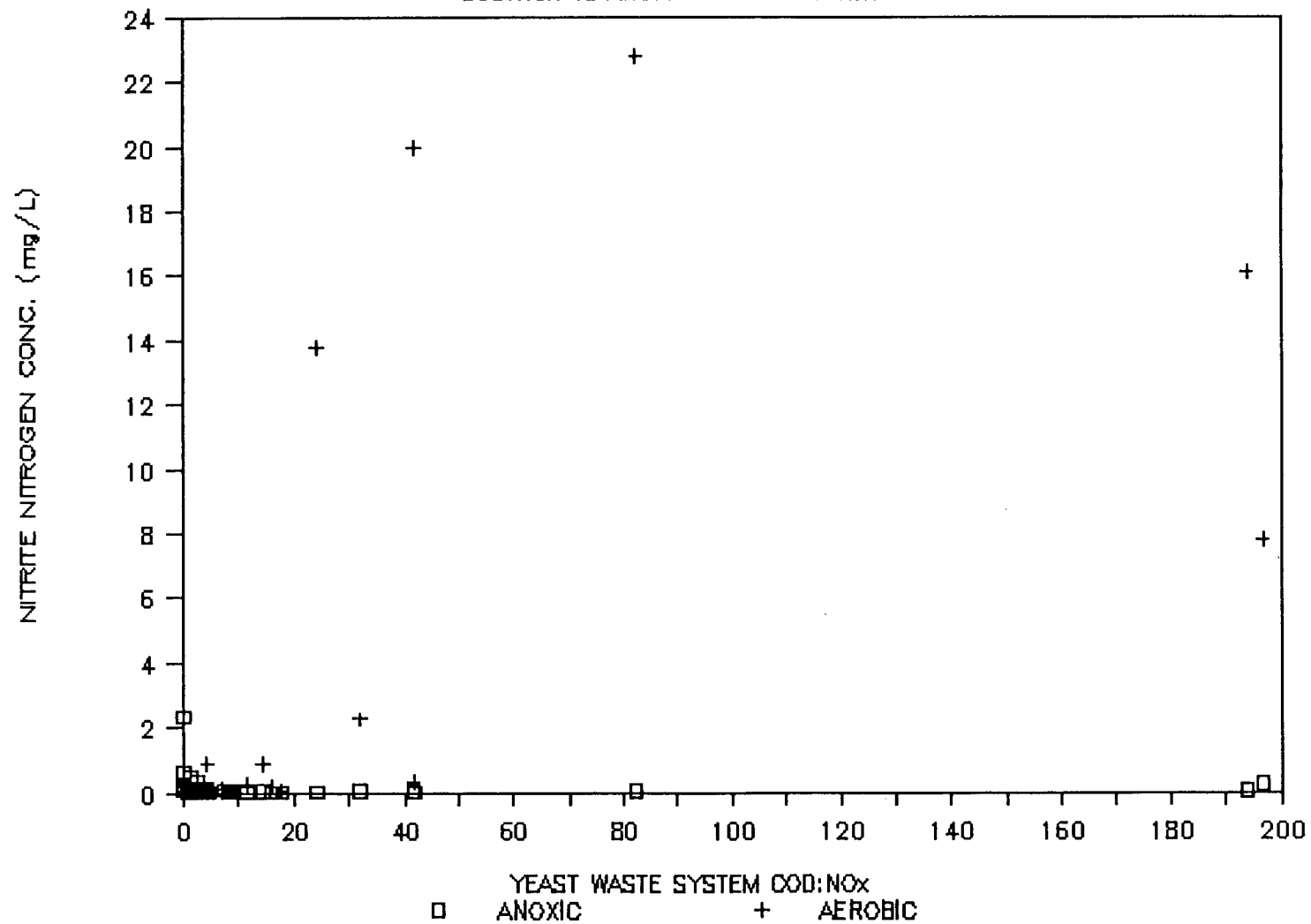
Anthonisen et al. (1976) reported inhibition to Nitrobacter at free ammonia concentrations of between 0.1 mg/L and 1.0 mg/L. This presents a good indication that free ammonia was responsible for the nitrite accumulation.

The complex nature of the yeast waste was expected to promote fermentative conditions by facultative anaerobes, and an anoxic nitrite accumulation. The yeast waste is a complicated combination of many carbon compounds, which may have provided sufficient simple organics for true denitrifiers to thrive, (along with the facultative anaerobes), so that no anoxic nitrite buildup occurred. The pH of the anoxic reactor started to decrease after COD:NOx of 10:1; this may indicate the increasing presence of facultative anaerobes after the NOx was used up.

5.10 GLUCOSE SYSTEM FAILURE

The nitrogen removal processes of the glucose system failed after an approximate 23:1 COD:NOx loading. The nitrification and denitrification processes were lost during failure, but there was no indication which process failed first or why failure occurred. The pH, immediately after failure, dropped from about 7.2 to 6.55 in both reactors, and the anoxic ORP remained low enough, approximately -230 mV, to indicate anaerobic conditions. The first possibility is that the nitrification encountered problems, thus reducing NOx production; therefore less NOx entered the anoxic reactor and

left enough carbon to fuel anaerobic fermentation. The fermentation may have produced volatile fatty acids to lower the pH, and the lowered pH could cause further inhibition of the nitrification process. The second possibility is that the COD:NOx loading was high enough for enough fermentation to take place; thus, the acid production lowered the pH to inhibit either nitrification and then denitrification as previously described, or denitrification and then nitrification. In the latter case, the denitrification could decrease, which in turn, would decrease alkalinity production and further lower the pH. Ultimately, the nitrification process would be affected.

Glucose would appear to be a poor choice as an external carbon source for denitrification purposes on the basis of the suspected growth of facultative anaerobes. The low pH, speculated to be the result of fermentation by the facultative anaerobes, is suspected of causing the failure of the nitrogen removal system.

5.11 PERFORMANCE SUMMARY

Of the four carbon sources studied, only glucose was found to be unsatisfactory as an external carbon addition for denitrification purposes. The problems associated with glucose were lowered pH and anoxic nitrite accumulation; this is suspected to be the result of facultative anaerobes

thriving on the glucose. Glucose also required the highest minimum COD:NOx, at 9:1, to just achieve complete denitrification. Acetate and methanol were found to be the most efficient carbon sources, with minimum COD:NOx values to just achieve complete denitrification of 5.9:1 and 6.2:1 respectively. The brewer's yeast waste was less efficient than methanol and acetate for the minimum amount of carbon to promote complete denitrification, at 8.5:1. The yeast waste also has a very high organic nitrogen content that may be biologically converted to ammonia; this will result in increases in the oxygen demand and reactor sizes for the nitrogen removal process. However, the increasing cost of chemicals, such as methanol and acetate, could make waste carbon sources, such as brewer's yeast waste, more attractive for such a process operation.

Table 5 summarizes the approximate performance of each carbon source for total ammonia removal, nitrification, denitrification, total BOD_5 removal, average mixed liquor VSS, effluent VSS, anoxic and aerobic pH, and effluent NOx concentration. The performance of each system is estimated for COD:NOx values of one half the minimum required for complete denitrification, the minimum required, and three times the minimum required. The glucose system failed below a COD:NOx of three times the minimum, so the maximum COD:NOx value, 23:1, is used. The values of greatest interest, with respect to COD:NOx, are nitrification, denitrification, and

thriving on the glucose. Glucose also required the highest minimum COD:NOx, at 9:1, to just achieve complete denitrification. Acetate and methanol were found to be the most efficient carbon sources, with minimum COD:NOx values to just achieve complete denitrification of 5.9:1 and 6.2:1 respectively. The brewer's yeast waste was less efficient than methanol and acetate for the minimum amount of carbon to promote complete denitrification, at 8.5:1. The yeast waste also has a very high organic nitrogen content that may be biologically converted to ammonia; this will result in increases in the oxygen demand and reactor sizes for the nitrogen removal process. However, the increasing cost of chemicals, such as methanol and acetate, could make waste carbon sources, such as brewer's yeast waste, more attractive for such a process operation.

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TABLE 5.

PERFORMANCE SUMMARY

PARAMETER		CARBON SOURCE											
		METHANOL			GLUCOSE			ACETATE			YEAST WASTE		
	COD:NOx	1 3.1:1	2 6.2:1	3 18.6:1	1 4.5:1	2 9.0:1	4 23:1	1 3.0:1	2 5.9:1	3 17.7:1	1 4.3:1	2 8.5:1	3 25.5:1
TOTAL AMMONIA REMOVAL (%)		100	100	100	100	100	100	100	100	100	100	100	100
NITRIFICATION (%)		100	98	80	92	90	88	96	95	93	96	90	80
DENITRIFICATION (%)		54	100	100	48	100	100	45	100	100	54	100	100
TOTAL BOD REMOVAL (%)		98	99	99	98	99	99	96	98	99	98	98	98
AVERAGE MIXED LIQUOR VSS (mg/L)		1500	2000	4000	4000	5000	5500	1500	2000	4000	3000	5000	6500
EFFLUENT VSS (mg/L)		10	10	60	10	10	60	15	15	300	15	15	300
ANOXIC pH		7.75	7.80	7.75	7.15	7.10	7.00	7.80	8.00	8.20	7.40	7.70	7.55
AEROBIC pH		7.45	7.50	7.55	7.25	7.30	7.40	7.50	7.60	8.20	7.00	7.40	7.40
EFFLUENT NOx (mg/L)		38	38	38	38	38	38	38	38	38	50	50	50
ANOXIC NITRITE (mg/L)		0.5	0.3	0	18	0	0	30	0	0	0	0	0
AEROBIC NITRITE (mg/L)		1.2	0	0	0	0	0	2	0	1	0	0	15
ANOXIC ORP (mV)		-80	-120	-250	+10	-150	-250	-80	-120	-300	-20	-200	-400

1. ONE HALF THE MINIMUM COD:NOx REQUIRED FOR COMPLETE DENITRIFICATION
2. MINIMUM COD:NOx REQUIRED FOR COMPLETE DENITRIFICATION
3. THREE TIMES THE MINIMUM COD:NOx REQUIRED FOR COMPLETE DENITRIFICATION
4. MAXIMUM COD:NOx ACHIEVED BY THE GLUCOSE SYSTEM

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The purpose of this study was to observe the effects of carbon addition in excess of the minimum amount necessary to just achieve complete denitrification. The nitrogen removal process was a biological single sludge pre-denitrification system with recycle. The influent was a high ammonia landfill leachate with low BOD_5; thus an external carbon source was necessary for denitrification requirements. Four carbon sources, methanol, glucose, acetate, and a brewer's yeast waste, were studied. The COD:NOx was increased gradually until the carbon loading was over three times the minimum required for complete denitrification. The following conclusions can be made from the results of this study:

1. The minimum COD:NOx required for complete denitrification was approximately 5.9:1 for acetate, 6.2:1 for methanol, 8.5:1 for the yeast waste, and 9.0:1 for glucose. One explanation for the difference between the methanol and acetate values and the glucose and yeast waste values is that the former are very simple organic compounds, while the latter are more complex and may be more difficult to utilize completely. COD:NOx reached as high as 56:1 for methanol and 23:1 for glucose. The acetate and yeast waste systems had several extreme data points which were discarded in the

analysis. The acetate system reached 16:1 with two extreme values of 62:1 and 136:1. The yeast waste system reached a COD:NOx of 42:1 with three extreme values of 82:1, 194:1, and 197:1.

2.   Carbon breakthrough, the bleeding of the carbon from the anoxic reactor into the aerobic reactor, occurred very close to the time that complete denitrification was established. This was expected, since no extra carbon was required for denitrification and the extra carbon was free to enter the aerobic basin. Some of the extra carbon would have been used to establish anaerobic growth in the anoxic basin; but, since anaerobic processes are relatively slow, most of the extra carbon would pass into the aerobic reactor. The increasing COD:NOx did not appear to affect the denitrification ability of any of the systems.

3.   The percent nitrification of all four systems was reduced as the COD:NOx increased, even though the ammonia removal remained at 100%. Ammonia assimilation is believed to have increased with the increase in biomass. Percent nitrification was based on the NOx production in comparison with the ammonia entering the aerobic reactor. Methanol was the most affected, followed by glucose, acetate, and the yeast waste. The reduction of the nitrification rate per unit increase in COD:NOx by the methanol system was double that of the glucose system, and over five times that of the acetate and yeast

waste systems.

4.   The glucose system failed completely after reaching a
COD:NOx of about 23:1. The actual failure began at about
12:1. The failure was characterized by a loss of both
nitrification and denitrification. There was no indication as
to which process failed first, but the loss of nitrification
was most likely due to a low pH (pH<6.9). This low pH was
probably caused by facultative anaerobes under fermentative
conditions in the anoxic reactor.

5.   There was evidence that facultative anaerobes were
thriving in the anoxic reactor of the glucose system.
Facultative anaerobes can only reduce nitrate to nitrite
(Blaszczyk 1983; Wilderer, et al. 1987). Glucose exhibited
nitrite accumulation in the anoxic reactor, indicating the
presence of facultative anaerobes. The anoxic pH (pH 7.1) was
lower than the aerobic pH, unlike the other three systems,
and was attributed to the production of volatile fatty acids
by the facultative anaerobes under fermentative conditions.
The anoxic pH continued to decrease as the COD:NOx increased,
indicating the presence of facultative anaerobes throughout
the study. The anoxic nitrite buildup disappeared at COD:NOx
values above 8:1.

6.   Nitrite buildup was noted in the anoxic reactor of the
acetate system for COD:NOx values under 6:1, in other words,

before complete denitrification was established. The anoxic pH was consistently higher (pH 8) than the aerobic pH, but, given that acetate is only a two carbon compound, the facultative anaerobes may have been able to ferment the acetate and then subsequently use the single carbon fatty acids produced. The removal of the fatty acids would prevent a drop in pH.

7. Nitrite buildup was noted in the aerobic reactor of the yeast waste system at over 25:1 COD:NOx. Nitrite in the aerobic reactor indicates inhibition of the conversion of nitrite to nitrate by **Nitrobacter**. The ammonia loading was higher than the other systems because of organic nitrogen in the yeast waste; this increased as the strength of the yeast waste solution was increased to raise the COD:NOx. The higher ammonia loading may suggest inhibition of **Nitrobacter** by free, or un-ionized, ammonia (**Anthonisen, et al. 1976; Suthersan and Ganczarczyk 1986; Turk 1986**)

8. The brewer's yeast waste was noted to be satisfactory as a carbon source for denitrification purposes. Denitrification was achieved with no problems. The basic characteristics of the undiluted yeast waste were about 300,000 mg/L of unfiltered COD, 115,000 mg/L of filtered COD, 150,000 mg/L of unfiltered BOD_5, 2500 mg/l of orthophosphate phosphorus, 2500 mg/L of ammonia nitrogen, 13,000 mg/L of TKN, and 7500 mg/L of FTKN. The only concern about using the yeast waste is that

the biological nature of the waste leads to a high TKN content which, when degraded, may lead to higher than expected ammonia loading. This can lead to higher NOx concentrations in the effluent. Filtered TKN was used in place of ammonia for analysis of data for the yeast waste system.

9. All four systems, but especially the acetate and yeast waste systems, exhibited rising sludge at the higher COD:NOx loadings. This led to higher solids in the clarifier effluents, and clogging of the effluent weirs.

10. The anoxic COD and BOD_5 unit removal rates held constant in the range of 30-40 mg/hr/gVSS. The aerobic unit removal rates increased after carbon breakthrough was established and greater amounts of carbon entered the aerobic reactor.

11. The aerobic unit ammonia removal rates decreased as the study progressed. This was due to an increase in heterotrophs, with the increase of available carbon in the aerobic reactor. The anoxic unit ammonia removal rate remained constant and very low since ammonia was removed only by assimilation. The overall ammonia removal for all four systems was consistently over 90% after complete nitrification was established.

12. The unit nitrification rates decreased in response to the

increase in heterotrophs and to the decrease in nitrification with the increase in the COD:NOx. The denitrification rate remained constant after denitrification was established, except for the methanol system, which exhibited a decrease over the entire study.

13. Methanol and acetate were found to be the most efficient and trouble-free carbon sources for denitrification purposes. The brewer's yeast waste performed in a satisfactory manner, and is an attractive alternative to the high priced carbon sources, such as methanol and acetate. Glucose is not recommended for denitrification purposes due to the suspected encouragement of facultative anaerobes, leading to lowered pH and anoxic nitrite accumulation.

6.2 RECOMMENDATIONS

From the results of this study, the following recommendations have been made:

1. A study to observe the effects of shock loading different carbon sources on the nitrification and denitrification system, such as the one used in this study. An investigation of this nature would examine the effect of dramatically increased carbon loading on a system that was operating at the most efficient COD:NOx. A shock load of carbon is likely to occur in an operating plant. The carbon sources of interest should be those expected to be used as external

carbon additions, as well as carbon expected to be present in the influent.

2. A study to examine the anoxic nitrite accumulation in a biological pre-denitrification leachate treatment system, when acetate is used as the external carbon source. This investigation may confirm the presence of facultative anaerobes, and explain why this has not been observed in previous literature.

3. A study to determine the hydraulically optimal recycle ratio to maximize the performance of a biological pre-denitrification system. This investigation is necessary to produce the most efficient nitrogen removal system.

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APPENDIX A
CALCULATION DEFINITION

COD REMOVAL

```
% TOTAL REMOVAL= ((INF COD*INF FLOW)+(CARBON SOLN COD*CARBON
                 SOLN FLOW)-(EFF COD*RECYC FLOW))*100/((INF
                 COD*INF FLOW)+(CARBON SOLN COD*CARBON SOLN
                 FLOW))
ANOX COD REMOVAL= (INF COD*INF FLOW)+(CARBON SOLN COD*CARBON
(mg/d)            SOLN FLOW)+(EFF COD*RECYC FLOW)-(ANOX
                  COD*(INF FLOW+RECYC FLOW)
% ANOX REMOVAL= ANOX COD REM (mg/d)*100/((INF COD*INF FLOW)
               +(CARBON SOLN COD*CARBON SOLN FLOW)+(EFF COD
               *RECYC FLOW))
             = % Carbon removed over the anoxic reactor
% AER REMOVAL = (ANOX COD-AER COD)*100/ANOX COD
              = % Carbon removed over the aerobic reactor
```

UNIT COD REMOVAL

```
UNIT COD UNIT REM= ANOX COD REM (mg/d)*1000(mg/g)/ANOX
(mg/hr/gVSS)       VSS(mg/L)/24(hr/d)/1(L)
UNIT AER COD REM= AER COD REM (mg/d)*1000(mg/g)/AER
(mg/hr/gVSS)      VSS(mg/L)/24(hr/d)/2(L)
```

BOD REMOVAL

```
% TOTAL REMOVAL= ((INF BOD*INF FLOW)+(CARBON SOLN BOD*CARBON
                 SOLN FLOW)-(EFF BOD*RECYC FLOW))*100/((INF
                 BOD*INF FLOW)+(CARBON SOLN BOD*CARBON SOLN
                 FLOW))
ANOX BOD REMOVAL= (INF BOD*INF FLOW)+(CARBON SOLN BOD*CARBON
(mg/d)            SOLN FLOW)+(EFF BOD*RECYC FLOW)-(ANOX
                  BOD*(INF FLOW+RECYC FLOW)
% ANOX REMOVAL= ANOX BOD REM (mg/d)*100/((INF BOD*INF FLOW)
               +(CARBON SOLN BOD*CARBON SOLN FLOW)+(EFF BOD
               *RECYC FLOW))
             = % Carbon removed over the anoxic reactor
% AER REMOVAL= (ANOX BOD-AER BOD)*100/ANOX BOD
             = % Carbon removed over the aerobic reactor
```

UNIT BOD REMOVAL

```
UNIT BOD UNIT REM= ANOX BOD REM (mg/d)*1000(mg/g)/ANOX
(mg/hr/gVSS)       VSS(mg/L)/24(hr/d)/1(L)
UNIT AER BOD REM= AER BOD REM (mg/d)*1000(mg/g)/AER
(mg/hr/gVSS)      VSS(mg/L)/24(hr/d)/2(L)
```

AMMONIA REMOVAL

% TOTAL REMOVAL= ((INF AMM*INF FLOW)+(CARBON SOLN AMM*CARBON
SOLN FLOW)-(EFF AMM*RECYC FLOW))*100/((INF
AMM*INF FLOW)+(CARBON SOLN AMM*CARBON SOLN
FLOW))

ANOX AMM REMOVAL= (INF AMM*INF FLOW)+(CARBON SOLN AMM*CARBON
(mg/d)   SOLN FLOW)+(EFF AMM*RECYC FLOW)-(ANOX
AMM*(INF FLOW+RECYC FLOW)

% ANOX REMOVAL= ANOX AMM REM (mg/d)*100/((INF AMM*INF FLOW)
+(CARBON SOLN AMM*CARBON SOLN FLOW)+(EFF AMM
*RECYC FLOW))
= % Ammonia removed over the anoxic reactor

% AER REMOVAL= (ANOX AMM-AER AMM)*100/ANOX AMM
= % Ammonia removed over the aerobic reactor

FTKN Removals for the Yeast Waste System were calculated by
substituting FTKN for the AMM values.

UNIT AMMONIA REMOVAL

UNIT ANOX AMM REM= ANOX AMM REM (mg/d)*1000(mg/g)/ANOX
(mg/hr/gVSS)   VSS(mg/L)/24(hr/d)/1(L)
UNIT AER AMM REM= AER AMM REM (mg/d)*1000(mg/g)/AER
(mg/hr/gVSS)   VSS(mg/L)/24(hr/d)/2(L)

Unit FTKN Removals for the Yeast Waste System were
calculated by substituting FTKN for the AMM values.

NITRIFICATION RATES

NITRIF (mg/d)= (AER NOx-ANOX NOx)*(INF FLOW+CARBON SOLN FLOW+
RECYC FLOW)
% NITRIF= NITRIF (mg/d)*100/(ANOX AMM*(INF FLOW+CARBON SOLN
FLOW+RECYC FLOW))
UNIT NITRIF RATE= NITRIF (mg/d)*1000(mg/g)/AER (mg/hr/gVSS)
VSS(mg/L)/24(hr/d)/2(L)

Nitrification rates for the Yeast Waste System were
calculated by substituting FTKN for the AMM values.

DENITRIFICATION RATES

DENITRIF (mg/L)= (INF NOx*INF FLOW)+(CARBON SOLN NOx*CARBON
SOLN FLOW)+(EFF NOx*RECYC FLOW)-(ANOX
NOx*(INF FLOW+CARBON SOLN FLOW+RECYC FLOW))
% DENITRIF= DENITRIF (mg/L)*100/((INF NOx*INF FLOW)+(CARBON
SOLN NOx*CARBON SOLN FLOW)+(EFF NOx*RECYC FLOW))

UNIT DENITRIFICATION RATE= DENITRIF(mg/d)*1000(mg/g)/ANOX VSS
(mg/L)/24((hr/d)/1L

COD:NOx

COD:NOx= (CARBON SOLN COD*CARBON SOLN FLOW)/((INF NOx*INF
FLOW)+(EFF NOx*RECYC FLOW))

APPENDIX B
RAW DATA

The raw data for this study is contained in this appendix.

AMMONIA BY THE DISTILLATION METHOD

DAY No.	DATE	INFLUENT AMMONIA (mg/L)	ACETATE EFFLUENT AMMONIA (mg/L)	YEAST WASTE EFFLUENT AMMONIA (mg/L)	DAY No.	DATE	INFLUENT AMMONIA (mg/L)	ACETATE EFFLUENT AMMONIA (mg/L)	YEAST WASTE EFFLUENT AMMONIA (mg/L)
0									
1	MAR21	253.1	15.4	15.1	47	MAY 6	225.1	0.0	0.0
2	MAR22	252.0	45.7	58.2	48	MAY 7	220.6	0.0	0.0
3	MAR23	248.6	56.0	70.0	49	MAY 8	219.5	0.0	0.0
4	MAR24	244.2	45.6	69.7	50	MAY 9	218.4	0.0	0.0
5	MAR25	237.4	35.3	63.0	51	MAY 10	228.5	0.0	0.0
6	MAR26	225.1	34.4	52.1	52	MAY 11	222.9	0.0	0.0
7	MAR27	189.3	20.7	39.2	53	MAY 12	201.6	0.0	0.0
8	MAR28	187.0	0.6	16.0	54	MAY 13	165.8	0.0	0.0
9	MAR29	187.0	0.0	4.8	55	MAY 14	237.4	0.0	0.0
10	MAR30	172.5	50.1	77.8	56	MAY 15	228.5	0.0	0.0
11	MAR31	177.0	5.0	3.6	57	MAY 16	215.0	0.0	0.0
12	APR 1	173.6	0.0	0.0	58	MAY 17	212.8	0.0	3.9
13	APR 2	171.0	0.0	0.0	59	MAY 18	211.7	0.0	0.0
14	APR 3	169.1	0.0	0.0	60	MAY 19	210.6	0.0	0.0
15	APR 4	151.2	0.0	0.0	61	MAY 20	210.6	0.0	0.0
16	APR 5	196.0	0.0	0.0	62	MAY 21	206.1	0.0	1.2
17	APR 6	192.6	0.0	1.1	63	MAY 22	201.6	0.0	0.0
18	APR 7	190.4	0.0	9.7	64	MAY 23	196.0	0.0	0.0
19	APR 8	192.6	0.0	0.0	65	MAY 24	202.7	9.1	0.0
20	APR 9	189.3	0.0	0.0	66	MAY 25	200.0	0.0	0.0
21	APR10	180.3	0.0	0.0	67	MAY 26	197.0	0.0	0.0
22	APR11	165.8	0.0	0.0	68	MAY 27	193.0	0.0	1.8
23	APR12	142.2	0.0	2.2	69	MAY 28	189.3	0.0	0.8
24	APR13	137.8	0.0	19.0	70	MAY 29	198.2	0.0	0.0
25	APR14	184.8	0.0	2.8	71	MAY 30	199.4	0.0	0.0
26	APR15	182.6	0.0	5.3	72	MAY 31	196.0	0.0	0.0
27	APR16	177.0	0.0	14.4	73	JNE 1	266.6	0.0	0.0
28	APR17	166.9	0.0	29.7	74	JNE 2	266.6	0.0	1.1
29	APR18	151.2	0.0	32.2	75	JNE 3	243.0	5.6	14.3
30	APR19	296.8	10.6	53.8	76	JNE 4	243.0	0.0	10.0
31	APR20	187.0	6.3	13.5	77	JNE 5	218.3	0.0	1.3
32	APR21	187.0	0.0	0.0	78	JNE 6	212.8	0.0	3.8
33	APR22	187.0	0.0	0.0	79	JNE 7	212.8	0.0	69.8
34	APR23	181.4	0.0	0.0	80	JNE 8	227.4	0.0	24.6
35	APR24	252.0	0.0	0.0	81	JNE 9	219.5	6.7	45.6
36	APR25	249.0	0.0	0.0	82	JNE 10	215.0	0.0	7.6
37	APR26	244.0	0.0	0.0	83	JNE 11	206.1	0.0	0.8
38	APR27	239.0	0.0	0.0	84	JNE 12	205.0	0.0	0.0
39	APR28	235.2	0.0	0.0	85	JNE 13	199.4	0.0	2.8
40	APR29	231.8	0.0	0.0	86	JNE 14	196.0	0.0	2.9
41	APR30	234.1	0.0	0.0	87	JNE 15	188.2	0.0	4.9
42	MAY 1	226.4	0.0	0.0	88	JNE 16	192.6	0.0	5.0
43	MAY 2	229.6	0.0	0.0	89	JNE 17	188.2	0.0	3.6
44	MAY 3	222.9	0.0	0.0	90	JNE 18	187.0	0.0	3.4
45	MAY 4	238.6	0.0	0.0	91	JNE 19	185.9	6.7	3.1
46	MAY 5	234.1	0.0	0.0	92	JNE 20	184.8	0.0	0.0

AMMONIA BY THE DISTILLATION METHOD

DAY No.	DATE	INFLUENT AMMONIA (mg/L)	GLUCOSE SYSTEM EFFLUENT AMMONIA (mg/L)	METHANOL SYSTEM EFFLUENT AMMONIA (mg/L)	No.	DATE	INFLUENT AMMONIA (mg/L)	GLUCOSE SYSTEM EFFLUENT AMMONIA (mg/L)	METHANOL SYSTEM EFFLUENT AMMONIA (mg/L)
62	DEC17	185.9	0.8	32.6	124	FEB 17	199.4	0.0	0.0
63	DEC18	196.0	0.8	4.7	125	FEB 18	199.4	0.0	1.9
64	DEC19	192.6	0.6	0.0	126	FEB 19	196.0	0.0	0.0
65	DEC20	193.8	1.5	0.0	127	FEB 20	194.9	0.0	0.0
66	DEC21	192.6	0.6	8.5	128	FEB 21	188.2	0.0	0.0
67	DEC22	175.8	0.5	0.3	129	FEB 22	181.4	0.7	0.0
69	DEC24	199.4	0.0	0.0	130	FEB 23	206.1	9.6	0.0
70	DEC25	185.9	0.0	0.0	131	FEB 24	206.1	15.1	0.0
71	DEC26	188.2	0.0	0.0	132	FEB 25	200.5	43.3	0.0
72	DEC27	188.2	0.0	0.0	133	FEB 26	217.3	76.2	0.0
73	DEC28	188.2	0.0	0.0	134	FEB 27	213.9	56.9	0.0
74	DEC29	180.3	0.0	0.0	135	FEB 28	213.9	42.6	0.0
75	DEC30	177.0	0.0	0.0	136	FEB 29	211.7	36.1	0.0
76	DEC31	178.1	0.0	0.0	137	MAR 1	189.3	30.8	2.6
77	JAN 1	172.5	0.0	0.0	138	MAR 2	211.7	25.8	0.0
78	JAN 2	178.1	0.0	0.0	139	MAR 3	209.4	21.8	0.0
79	JAN 3	178.1	0.0	0.0	140	MAR 4	218.4	0.8	0.0
80	JAN 4	178.1	0.0	0.0	141	MAR 5	213.9	0.0	0.0
81	JAN 5	169.1	3.9	0.0	142	MAR 6	212.8	0.2	0.0
82	JAN 6	202.7	0.0	0.0	143	MAR 7	211.7	0.0	0.0
83	JAN 7	207.2	0.0	0.0					

AMMONIA BY THE DISTILLATION METHOD

DAY No. DATE	INFLUENT AMMONIA (mg/L)	GLUCOSE SYSTEM EFFLUENT AMMONIA (mg/L)	METHANOL SYSTEM EFFLUENT AMMONIA (mg/L)	No. DATE	INFLUENT AMMONIA (mg/L)	GLUCOSE SYSTEM EFFLUENT AMMONIA (mg/L)	METHANOL SYSTEM EFFLUENT AMMONIA (mg/L)
8 OCT24	215.0	0.0	13.7	84 JAN 8	202.7	0.0	0.0
10 OCT26	202.0	24.1	19.3	85 JAN 9	210.6	0.0	0.0
16 NOV 1	219.6	31.6	0.3	86 JAN 10	207.2	0.0	0.0
17 NOV 2	217.3	8.4	0.0	87 JAN 11	206.1	0.0	0.0
18 NOV 3	218.4	0.0	0.0	88 JAN 12	210.6	0.0	0.0
20 NOV 5	212.8	0.0	0.0	89 JAN 13	202.7	0.0	0.0
21 NOV 6	203.8	0.0	0.0	90 JAN 14	210.6	0.0	0.0
22 NOV 7	187.1	0.0	0.0	91 JAN 15	208.3	0.0	0.0
23 NOV 8	233.9	8.7	0.0	92 JAN 16	207.2	0.0	0.0
24 NOV 9	227.3	7.5	0.0	93 JAN 17	164.2	0.0	0.0
25 NOV10	224.0	0.0	13.4	94 JAN 18	164.2	0.0	0.0
26 NOV11	224.0	0.0	3.9	95 JAN 19	162.4	0.0	0.0
27 NOV12	225.0	0.0	0.0	96 JAN 20	160.2	0.0	0.0
28 NOV13	223.0	0.0	24.0	97 JAN 21	144.5	0.0	0.0
29 NOV14	216.1	0.0	2.9	98 JAN 22	144.5	0.0	0.0
30 NOV15	180.3	0.0	0.0	99 JAN 23	140.0	0.0	0.0
31 NOV16	179.2	0.0	0.0	100 JAN 24	150.1	0.0	0.0
32 NOV17	174.7	0.0	0.0	101 JAN 25	152.3	0.0	0.0
34 NOV19	181.4	0.0	0.0	102 JAN 26	162.4	0.0	0.0
35 NOV20	179.2	0.0	2.0	103 JAN 27	197.1	0.0	0.0
36 NOV21	174.7	0.0	0.0	104 JAN 28	209.4	0.0	0.0
37 NOV22	172.5	0.0	0.0	105 JAN 29	205.0	0.0	0.0
38 NOV23	187.0	0.0	0.0	106 JAN 30	201.6	0.0	0.0
41 NOV26	179.2	0.0	0.0	107 JAN 31	193.8	0.0	0.0
42 NOV27	180.3	21.1	38.8	108 FEB 1	202.7	0.0	0.0
43 NOV28	181.4	7.7	57.8	109 FEB 2	207.2	0.0	0.0
44 NOV29	168.0	0.0	2.1	110 FEB 3	205.0	0.0	0.0
45 NOV30	170.0	0.0	0.0	111 FEB 4	221.8	0.0	2.0
46 DEC 1	178.1	0.0	0.0	112 FEB 5	221.8	0.0	0.0
48 DEC 3	159.0	0.0	0.0	113 FEB 6	216.2	0.0	0.0
49 DEC 4	179.2	0.0	0.0	114 FEB 7	213.9	0.0	0.0
50 DEC 5	179.2	0.0	0.0	115 FEB 8	185.9	0.0	0.0
51 DEC 6	173.6	0.0	0.0	116 FEB 9	187.0	0.0	0.0
52 DEC 7	172.5	0.0	0.0	117 FEB 10	183.7	0.0	0.0
53 DEC 8	187.0	0.0	0.0	118 FEB 11	178.1	0.0	0.0
55 DEC10	185.9	0.0	0.0	119 FEB 12	190.4	0.0	0.0
56 DEC11	192.6	0.0	0.0	120 FEB 13	189.3	0.0	0.0
57 DEC12	189.3	0.0	0.0	121 FEB 14	184.8	0.0	0.0
58 DEC13	188.2	0.0	0.0	122 FEB 15	180.3	0.0	0.0
59 DEC14	180.3	0.0	0.0	123 FEB 16	154.6	0.0	0.0

METHANOL SYSTEM

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	METHANOL SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
0									
1	OCT17	7.65	7.70	N/A	1.8	20.5	N/A	2.90	10.40
2	OCT18	7.50	7.70	N/A	1.8	19.5	N/A	2.70	11.00
3	OCT19	7.60	7.75	N/A	1.5	20.0	N/A	1.40	11.80
4	OCT20	7.25	7.40	N/A	1.8	20.5	N/A	3.70	12.30
5	OCT21	7.10	7.55	N/A	2.5	20.5	N/A	3.46	11.90
6	OCT22	7.10	7.50	N/A	6.0	20.5	N/A	2.64	10.60
7	OCT23	7.00	7.05	23	5.5	20.0	N/A	0.88	11.04
8	OCT24	7.20	7.35	-38	1.4	19.5	51	2.66	11.52
9	OCT25	7.40	7.50	-57	1.0	20.0	56	3.02	11.52
10	OCT26	7.50	7.70	-51	1.3	19.5	113	2.94	12.00
11	OCT27	7.50	7.60	-45	1.4	19.5	44	3.34	12.48
12	OCT28	7.40	7.55	-63	0.5	20.0	45	3.08	12.48
13	OCT29	7.35	7.50	-24	3.8	20.5	44	3.05	12.48
14	OCT30	7.30	7.70	-34	3.8	22.0	47	3.40	12.96
15	OCT31	7.50	7.70	-58	6.4	22.0	46	3.40	12.48
16	NOV 1	7.15	7.35	-11	3.8	20.5	34	2.49	11.52
17	NOV 2	7.00	7.50	-13	3.2	20.0	42	3.23	11.52
18	NOV 3	7.00	7.55	-16	3.5	19.5	40	3.29	12.00
19	NOV 4	6.90	7.30	-8	3.4	20.5	40	3.54	12.00
20	NOV 5	7.00	7.50	-31	2.8	19.5	53	3.42	12.00
21	NOV 6	7.10	7.60	-43	3.4	19.0	49	3.23	11.52
22	NOV 7	7.20	7.80	-52	2.4	21.0	48	3.04	12.00
23	NOV 8	7.20	7.45	-44	2.8	21.0	40	2.80	12.00
24	NOV 9	7.20	7.45	-18	3.1	20.5	46	2.90	12.00
25	NOV10	7.35	7.60	-22	1.6	22.0	26	3.05	12.00
26	NOV11	7.30	7.55	-28	3.4	22.0	30	3.09	12.00
27	NOV12	7.45	7.65	-33	3.1	20.0	79	3.08	11.04
28	NOV13	7.55	7.65	-68	0.6	20.5	85	3.05	11.04
29	NOV14	7.40	7.70	-38	3.8	19.0	41	3.03	11.04
30	NOV15	8.10	7.90	-40	2.8	19.0	48	3.04	11.04
31	NOV16	7.45	7.65	-22	4.3	18.5	56	2.81	11.76
32	NOV17	7.60	7.90	-36	4.2	19.0	61	2.93	12.00
33	NOV18	7.60	7.90	-54	3.6	19.0	58	2.92	12.00
34	NOV19	7.55	7.90	-67	3.6	19.0	64	3.23	12.00
35	NOV20	7.45	7.85	-98	2.5	20.0	67	3.16	12.00
36	NOV21	7.60	7.90	-123	3.2	19.5	69	2.71	12.00
37	NOV22	7.60	8.00	-129	4.6	19.0	54	2.58	12.75
38	NOV23	7.50	7.65	-80	4.1	18.0	60	2.69	12.00
39	NOV24	7.65	7.85	-91	6.2	19.0	57	2.71	12.48
40	NOV25	7.60	7.70	-149	4.8	19.0	0	0.00	12.00
41	NOV26	7.50	7.60	-80	3.5	18.0	15	2.73	14.40
42	NOV27	7.55	7.60	-101	3.1	19.0	38	3.48	12.00

METHANOL CONTINUED

DAY No. DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	METHANOL SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
43 NOV28	7.50	7.80	-136	0.8	19.0	140	2.94	12.00
44 NOV29	7.40	7.80	-120	4.6	19.0	117	2.71	11.52
45 NOV30	7.45	7.65	-103	4.0	19.0	130	2.79	12.00
46 DEC 1	7.35	7.60	-99	3.5	19.0	143	3.19	12.00
47 DEC 2	7.40	7.80	-94	3.4	19.0	141	2.85	12.00
48 DEC 3	7.40	7.80	-82	3.2	18.5	132	2.78	11.52
49 DEC 4	7.40	7.75	-79	0.7	18.5	135	2.79	11.76
50 DEC 5	7.50	7.75	-87	3.6	18.5	132	2.98	11.04
51 DEC 6	7.55	7.85	-91	4.2	19.0	132	2.96	11.76
52 DEC 7	7.55	7.90	-78	4.1	19.0	118	2.95	11.76
53 DEC 8	7.60	7.75	-71	4.5	19.0	130	2.89	11.52
54 DEC 9	7.45	7.70	-81	2.3	18.5	127	3.02	11.52
55 DEC10	7.50	7.80	-93	3.0	19.0	136	3.04	11.52
56 DEC11	7.50	7.70	-100	2.1	18.5	139	3.01	11.76
57 DEC12	7.45	7.70	-119	2.0	18.0	128	3.03	11.76
58 DEC13	7.45	7.75	-94	1.9	18.0	130	2.98	11.76
59 DEC14	7.45	7.90	-73	2.6	17.5	124	2.93	12.00
60 DEC15	7.45	7.80	-70	1.6	17.5	137	2.95	12.00
61 DEC16	7.40	7.75	-68	1.2	18.0	137	2.99	11.76
62 DEC17	7.40	7.70	-191	0.9	18.0	128	3.07	11.76
63 DEC18	7.20	7.60	-63	3.6	18.0	137	3.17	12.00
64 DEC19	7.10	7.60	-66	3.0	17.5	134	2.79	12.00
65 DEC20	7.20	7.70	-78	1.5	17.5	129	3.18	12.00
66 DEC21	7.10	7.70	-71	0.5	18.0	128	3.15	12.00
67 DEC22	7.00	7.80	-58	3.5	18.0	142	3.29	12.48
68 DEC23	7.30	7.60	-60	3.7	18.0	138	2.86	12.00
69 DEC24	7.30	7.70	-71	3.2	17.5	132	3.21	12.00
70 DEC25	7.50	7.75	-74	4.4	18.0	132	2.75	12.00
71 DEC26	7.50	7.80	-87	3.7	18.0	123	2.80	12.00
72 DEC27	7.50	7.85	-91	3.2	18.5	128	2.89	12.00
73 DEC28	7.50	7.80	-64	3.4	18.0	123	2.92	12.00
74 DEC29	7.45	7.70	-60	4.6	18.0	133	3.06	12.00
75 DEC30	7.45	7.70	-63	3.8	18.0	134	3.00	11.76
76 DEC31	7.45	7.70	-57	4.4	17.5	136	2.96	12.00
77 JAN 1	7.50	7.90	-97	4.2	18.0	140	2.94	12.00
78 JAN 2	7.50	7.70	-94	4.5	17.0	130	2.90	12.00
79 JAN 3	7.55	7.80	-89	4.5	17.5	132	3.05	12.00
80 JAN 4	7.45	7.80	-36	4.4	18.0	131	3.01	12.48
81 JAN 5	7.55	7.95	-30	5.2	18.0	137	2.97	12.00
82 JAN 6	7.40	7.65	-36	3.4	18.5	144	3.05	12.00
83 JAN 7	7.50	7.75	-73	4.1	19.0	145	3.04	12.00
84 JAN 8	7.50	7.80	-101	4.4	18.0	140	3.03	12.00
85 JAN 9	7.60	7.80	-113	4.2	18.0	135	3.03	12.00
86 JAN10	7.60	7.85	-122	3.8	18.0	133	3.04	12.00
87 JAN11	7.50	7.80	-84	4.2	18.0	135	3.01	12.00
88 JAN12	7.50	7.80	-150	1.1	18.0	136	2.94	12.00
89 JAN13	7.50	7.85	-115	1.8	18.0	140	3.10	12.00
90 JAN14	7.50	7.75	-176	2.8	18.5	141	3.11	12.00

METHANOL CONTINUED

DAY No. DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	METHANOL SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
95 JAN19	7.60	7.80	-180	3.1	18.0	149	2.76	12.00
96 JAN20	7.50	7.80	-168	2.0	19.0	145	3.66	12.00
97 JAN21	7.55	7.70	-186	2.9	18.5	151	3.17	12.00
98 JAN22	7.55	7.80	-190	3.5	19.0	97	2.89	12.00
99 JAN23	7.50	7.75	-186	2.6	19.0	137	3.25	12.00
100 JAN24	7.50	7.65	-141	3.4	18.0	132	3.10	12.00
101 JAN25	7.50	7.75	-181	2.8	18.0	134	3.15	12.00
102 JAN26	7.50	7.75	-189	1.6	18.5	135	3.15	12.00
103 JAN27	7.45	7.80	-182	1.9	18.5	142	3.18	12.00
104 JAN28	7.50	7.70	-188	1.3	19.0	141	2.84	12.00
105 JAN29	7.45	7.75	-211	2.0	19.5	137	2.80	12.00
106 JAN30	7.40	7.75	-214	2.7	19.0	134	2.73	12.00
107 JAN31	7.35	7.80	-186	3.6	18.0	123	3.18	12.00
108 FEB 1	7.50	7.70	-188	3.8	17.0	129	2.82	12.00
109 FEB 2	7.50	7.70	-214	3.1	17.5	138	2.82	12.00
110 FEB 3	7.55	7.80	-204	2.9	18.0	139	2.86	12.00
111 FEB 4	7.45	7.65	-172	1.8	17.5	137	3.32	12.00
112 FEB 5	7.50	7.70	-206	1.6	18.0	141	3.09	12.00
113 FEB 6	7.50	7.70	-206	2.5	19.0	133	2.95	12.00
114 FEB 7	7.45	7.80	-194	2.9	18.0	125	3.18	12.00
115 FEB 8	7.50	7.60	-207	2.9	18.5	135	3.20	12.00
116 FEB 9	7.60	7.75	-238	0.5	18.5	137	3.04	12.00
117 FEB10	7.65	7.75	-260	4.5	19.0	141	3.06	12.00
118 FEB11	7.55	7.80	-268	2.4	19.0	144	2.94	12.00
119 FEB12	7.50	7.70	-257	2.9	19.0	139	3.02	12.00
120 FEB13	7.60	7.80	-260	3.8	19.0	133	2.93	12.00
121 FEB14	7.55	7.80	-247	2.0	18.5	130	2.98	12.00
122 FEB15	7.55	7.85	-247	2.3	18.5	127	2.93	12.00
123 FEB16	7.60	7.70	-264	1.7	19.0	133	3.16	12.00
124 FEB17	7.55	7.70	-277	0.5	19.0	141	3.07	12.00
125 FEB18	7.50	7.70	-281	1.2	19.0	135	2.94	12.00
126 FEB19	7.55	7.70	-292	3.9	19.0	137	3.02	12.00
127 FEB20	7.60	7.70	-341	2.4	19.5	131	2.89	12.00
128 FEB21	7.55	7.70	-276	3.9	19.0	133	2.88	12.48
129 FEB22	7.50	7.70	-270	3.6	18.5	133	2.92	12.48
130 FEB23	7.50	7.65	-274	2.0	19.0	141	3.09	12.96
131 FEB24	7.45	7.60	-350	1.8	19.0	140	1.16	12.00
132 FEB25	7.50	7.70	-283	2.3	19.0	143	2.84	12.00
133 FEB26	7.45	7.60	-270	2.2	19.0	141	3.06	12.00
134 FEB27	7.45	7.65	-269	2.4	18.5	137	3.10	11.52
135 FEB28	7.50	7.70	-282	2.3	19.0	140	2.93	11.52
136 FEB29	7.45	7.70	-279	2.7	19.0	133	2.93	11.52
137 MAR 1	7.40	7.65	-310	0.5	19.0	147	3.18	11.52
138 MAR 2	7.50	7.65	-285	3.2	18.5	145	3.21	12.00
139 MAR 3	7.65	7.75	-301	4.4	18.5	144	2.58	12.00
140 MAR 4	7.70	7.75	-282	4.3	18.5	140	2.74	12.48
141 MAR 5	7.70	7.80	-287	4.4	18.0	137	3.05	12.00
142 MAR 6	7.70	7.85	-296	3.4	18.5	124	2.94	12.00
143 MAR 7	7.70	7.80	-296	4.3	18.0	134	2.98	11.76

GLUCOSE SYSTEM

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	GLUCOSE SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
0									
1	OCT 17	7.75	7.75	0	1.5	20.5	0	2.60	9.20
2	OCT 18	7.60	7.70	0	1.0	19.5	0	2.80	10.80
3	OCT 19	7.30	7.65	-22	2.3	20.0	0	1.80	12.10
4	OCT 20	7.10	7.35	-8	2.3	20.5	0	3.80	12.70
5	OCT 21	7.10	7.40	0	1.2	20.5	0	3.66	12.90
6	OCT 22	7.20	7.50	1	1.6	20.5	0	4.11	13.00
7	OCT 23	6.80	7.40	13	3.2	20.0	0	2.97	10.32
8	OCT 24	7.00	7.10	10	1.4	19.5	51	2.49	12.24
9	OCT 25	7.20	7.10	-51	1.2	20.0	72	2.62	13.20
10	OCT 26	7.50	7.30	-69	1.9	19.5	140	2.74	13.20
11	OCT 27	7.60	7.50	-42	1.8	19.5	51	3.04	12.48
12	OCT 28	7.50	7.30	-54	0.5	20.0	53	3.34	12.48
13	OCT 29	7.40	7.25	-21	4.5	20.5	57	3.32	12.96
14	OCT 30	7.30	7.30	-72	0.9	22.0	60	2.95	12.96
15	OCT 31	7.95	7.40	-52	8.0	22.0	57	0.50	12.48
16	NOV 1	7.40	7.30	-74	1.5	20.5	44	2.39	12.48
17	NOV 2	7.20	7.20	-32	2.7	20.0	49	2.87	12.00
18	NOV 3	7.15	7.15	-38	2.8	19.5	47	2.75	12.00
19	NOV 4	7.10	7.05	-34	2.8	20.5	51	2.88	12.00
20	NOV 5	7.15	7.00	-35	2.1	19.5	59	2.97	12.00
21	NOV 6	7.10	7.00	-35	3.5	19.0	59	2.90	11.52
22	NOV 7	7.05	7.05	-30	3.3	21.0	58	2.83	12.00
23	NOV 8	7.30	7.10	-28	0.8	21.0	46	2.79	12.00
24	NOV 9	7.20	7.05	-28	1.0	20.5	49	2.75	12.00
25	NOV 10	7.10	7.20	-8	2.0	22.0	40	2.91	12.00
26	NOV 11	7.20	7.15	8	2.4	22.0	38	2.98	11.76
27	NOV 12	7.30	7.00	21	1.0	20.0	113	2.91	11.52
28	NOV 13	7.20	7.00	22	0.8	20.5	116	2.91	12.00
29	NOV 14	7.20	7.20	16	2.1	19.0	57	2.81	12.00
30	NOV 15	7.65	7.00	28	2.3	19.0	68	2.60	11.04
31	NOV 16	7.20	7.05	33	2.6	18.5	72	2.72	11.76
32	NOV 17	7.30	7.00	11	2.4	19.0	83	2.85	12.00
33	NOV 18	7.30	7.10	22	1.9	19.0	81	2.83	12.00
34	NOV 19	7.30	7.00	27	0.9	19.0	88	2.90	12.00
35	NOV 20	7.30	7.05	21	0.7	20.0	92	2.89	12.00
36	NOV 21	7.50	7.15	9	3.0	19.5	95	2.75	12.00
37	NOV 22	7.50	7.20	-8	4.2	19.0	74	2.63	11.52
38	NOV 23	7.40	7.10	36	3.9	18.0	76	2.74	12.00
39	NOV 24	7.40	7.25	22	1.2	19.0	84	2.85	12.00
40	NOV 25	7.40	7.25	14	4.0	19.0	0	0.00	12.00
41	NOV 26	7.40	7.30	14	3.6	18.0	55	2.24	14.40
42	NOV 27	7.40	7.20	4	3.0	19.0	97	3.18	12.24

GLUCOSE SYSTEM CONTINUED

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	GLUCOSE SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
43	NOV 28	7.40	7.10	12	5.2	19.0	133	2.94	11.52
44	NOV 29	7.20	7.15	26	2.6	19.0	112	2.71	11.52
45	NOV 30	7.30	7.20	44	2.3	19.0	122	2.80	11.52
46	DEC 1	7.25	7.20	67	2.1	19.0	134	3.20	11.52
47	DEC 2	7.25	7.15	80	1.6	19.0	136	2.94	12.00
48	DEC 3	7.20	7.15	92	2.2	18.5	125	2.80	11.76
49	DEC 4	7.30	7.15	105	1.7	18.5	126	2.80	11.76
50	DEC 5	7.30	7.20	110	2.1	18.5	123	2.99	12.00
51	DEC 6	7.40	7.20	117	2.2	19.0	124	2.97	11.52
52	DEC 7	7.35	7.25	68	2.6	19.0	109	2.96	11.52
53	DEC 8	7.40	7.20	63	1.1	19.0	124	2.83	11.52
54	DEC 9	7.40	7.20	44	1.3	18.5	124	2.88	11.52
55	DEC 10	7.40	7.25	37	1.6	19.0	128	2.90	12.24
56	DEC 11	7.35	7.20	49	1.4	18.5	129	2.89	12.24
57	DEC 12	7.30	7.20	61	1.9	18.0	122	2.86	11.76
58	DEC 13	7.30	7.15	80	2.5	18.0	121	2.86	12.00
59	DEC 14	7.30	7.10	72	1.3	17.5	114	2.94	12.00
60	DEC 15	7.20	7.00	65	1.3	17.5	129	2.93	12.00
61	DEC 16	7.10	6.90	60	1.2	18.0	129	2.92	12.00
62	DEC 17	7.00	6.80	56	1.1	18.0	123	2.91	11.76
63	DEC 18	7.00	6.85	55	1.1	18.0	130	2.94	11.52
64	DEC 19	7.30	6.90	5	3.6	17.5	127	2.92	12.00
65	DEC 20	7.00	6.95	51	3.8	17.5	120	2.74	12.00
66	DEC 21	6.90	6.85	100	4.3	18.0	118	2.87	12.00
67	DEC 22	7.00	6.50	103	5.0	18.0	132	2.65	12.48
68	DEC 23	7.05	6.95	102	2.4	18.0	126	3.21	12.00
69	DEC 24	7.15	7.00	82	2.4	17.5	124	3.07	11.76
70	DEC 25	7.40	7.05	65	2.4	18.0	123	2.60	12.00
71	DEC 26	7.20	7.10	49	1.1	18.0	122	2.85	12.24
72	DEC 27	7.10	7.00	37	1.4	18.5	120	3.13	12.00
73	DEC 28	7.00	6.90	82	1.1	18.0	115	3.19	12.00
74	DEC 29	7.10	6.95	74	2.1	18.0	126	2.86	12.00
75	DEC 30	7.10	6.95	54	1.6	18.0	127	2.85	12.00
76	DEC 31	7.20	6.95	54	2.8	17.5	123	2.85	12.00
77	JAN 1	7.20	6.95	38	2.0	18.0	127	2.86	12.00
78	JAN 2	7.20	6.95	45	2.4	17.0	120	2.87	12.00
79	JAN 3	7.20	7.00	32	2.6	17.5	120	2.82	12.00
80	JAN 4	7.25	7.05	52	2.6	18.0	124	2.90	11.04
81	JAN 5	7.35	7.25	-88	1.5	18.0	127	3.05	12.00
82	JAN 6	7.30	7.10	-71	1.5	18.5	131	2.99	11.52
83	JAN 7	7.35	7.15	-81	1.0	19.0	135	2.95	11.52
84	JAN 8	7.40	7.15	-58	3.4	18.0	129	2.92	12.48
85	JAN 9	7.30	7.15	15	3.1	18.0	125	2.94	11.76
86	JAN 10	7.40	7.20	14	2.4	18.0	122	2.93	12.00
87	JAN 11	7.45	7.15	42	3.1	18.0	126	2.92	11.76
88	JAN 12	7.40	7.10	30	2.8	18.0	124	2.96	11.52
89	JAN 13	7.30	7.10	28	2.8	18.0	131	3.07	12.00

GLUCOSE SYSTEM CONTINUED

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	GLUCOSE SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
94	JAN 18	7.50	7.35	1	1.8	18.0	129	2.82	12.48
95	JAN 19	7.45	7.30	-98	1.5	18.0	136	3.34	12.00
96	JAN 20	7.40	7.30	-130	2.2	19.0	133	2.93	12.00
97	JAN 21	7.45	7.30	-152	2.4	18.5	138	3.04	12.00
98	JAN 22	7.40	7.30	-13	3.6	19.0	89	2.96	11.76
99	JAN 23	7.40	7.30	-170	2.7	19.0	127	2.99	11.52
100	JAN 24	7.40	7.20	-5	2.8	18.0	122	2.97	12.96
101	JAN 25	7.40	7.30	-26	3.8	18.0	123	3.03	11.76
102	JAN 26	7.40	7.20	30	3.8	18.5	126	3.14	11.76
103	JAN 27	7.25	7.15	32	3.2	18.5	131	3.05	11.76
104	JAN 28	7.20	7.05	37	3.2	19.0	130	3.15	11.76
105	JAN 29	7.15	7.05	58	3.1	19.5	126	3.05	12.00
106	JAN 30	7.15	7.10	77	2.0	19.0	122	3.02	12.72
107	JAN 31	7.00	6.95	89	2.7	18.0	114	2.89	12.72
108	FEB 1	7.20	7.10	88	1.7	17.0	121	3.10	12.00
109	FEB 2	7.30	6.90	-139	1.9	17.5	129	3.13	12.00
110	FEB 3	7.35	7.10	-138	1.1	18.0	127	3.17	12.00
111	FEB 4	7.30	7.10	-130	3.1	17.5	129	2.62	12.00
112	FEB 5	7.40	7.15	-133	1.7	18.0	130	2.97	12.00
113	FEB 6	7.30	7.10	-146	1.5	19.0	121	2.90	12.00
114	FEB 7	7.30	7.15	-137	1.9	18.0	117	2.87	12.00
115	FEB 8	7.30	7.10	-133	1.8	18.5	124	2.82	12.00
116	FEB 9	7.40	7.05	-141	2.6	18.5	126	2.44	12.00
117	FEB 10	7.25	6.95	-151	0.5	19.0	128	2.67	12.48
118	FEB 11	7.40	7.00	-156	2.9	19.0	132	2.68	11.52
119	FEB 12	7.30	7.00	-170	2.7	19.0	127	2.87	12.00
120	FEB 13	7.40	7.10	-181	1.8	19.0	120	2.93	12.00
121	FEB 14	7.40	7.15	-159	3.2	18.5	117	3.13	12.00
122	FEB 15	7.40	7.10	-169	2.4	18.5	116	2.75	12.00
123	FEB 16	7.30	6.95	-184	2.7	19.0	121	3.45	12.00
124	FEB 17	7.40	7.00	-213	2.1	19.0	129	2.97	12.00
125	FEB 18	7.35	7.00	-234	2.1	19.0	122	3.10	12.00
126	FEB 19	7.30	6.95	-330	1.7	19.0	124	3.02	12.00
127	FEB 20	7.35	7.00	-366	1.6	19.5	120	2.85	12.00
128	FEB 21	7.25	6.95	-249	2.7	19.0	121	2.93	12.00
129	FEB 22	7.20	7.40	-230	2.6	18.5	120	2.78	12.00
130	FEB 23	7.05	7.25	-220	2.5	19.0	128	2.97	12.00
131	FEB 24	6.85	6.60	-240	3.2	19.0	126	3.05	12.00
132	FEB 25	6.60	6.55	-245	5.4	19.0	128	3.05	12.00
133	FEB 26	7.40	7.25	-243	0.6	19.0	129	3.00	12.48
134	FEB 27	7.50	7.50	-17	5.2	18.5	129	2.89	12.00
135	FEB 28	7.15	7.40	-51	2.3	19.0	127	2.96	12.00
136	FEB 29	7.10	7.35	-79	1.8	19.0	121	2.97	12.00
137	MAR 1	6.90	7.30	-49	1.4	19.0	133	3.20	12.00
138	MAR 2	6.90	7.20	-41	2.1	18.5	130	3.16	12.00
139	MAR 3	7.10	7.30	-45	0.8	18.5	131	3.09	12.00
140	MAR 4	7.20	7.40	-23	4.2	18.5	128	2.71	12.00
141	MAR 5	7.20	7.40	-22	4.8	18.0	125	2.93	12.00
142	MAR 6	7.10	7.45	-24	5.1	18.5	111	2.89	12.00
143	MAR 7	7.00	7.35	-19	4.4	18.0	122	2.94	12.00

ACETATE SYSTEM

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	ACETATE SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
0									
1	MAR 21	7.50	7.60	70	5.90	19.0	0	2.95	12.00
2	MAR 22	7.40	7.45	69	6.40	18.5	0	3.00	12.00
3	MAR 23	7.40	7.55	68	6.20	18.0	0	2.95	12.00
4	MAR 24	7.15	7.60	65	5.50	18.0	0	2.95	12.00
5	MAR 25	7.20	7.55	55	4.30	18.0	0	2.94	12.00
6	MAR 26	7.15	7.55	52	4.20	18.5	0	2.93	12.00
7	MAR 27	7.00	7.45	48	2.90	18.0	0	2.93	12.00
8	MAR 28	6.90	7.40	43	3.80	18.0	0	2.93	12.00
9	MAR 29	7.20	7.40	54	5.70	18.5	0	2.92	12.00
10	MAR 30	7.50	7.55	15	3.50	18.0	0	2.96	12.00
11	MAR 31	6.90	7.25	29	2.90	18.0	0	2.93	11.76
12	APR 1	6.90	7.25	37	2.90	18.0	0	2.98	11.76
13	APR 2	7.00	7.30	35	3.80	18.0	0	2.95	11.52
14	APR 3	7.05	7.40	34	4.10	18.0	0	2.92	11.52
15	APR 4	6.90	7.30	35	5.40	17.5	0	2.78	11.76
16	APR 5	6.90	7.20	35	2.80	17.5	0	2.97	12.48
17	APR 6	7.05	7.40	23	3.20	17.5	0	3.31	12.84
18	APR 7	6.85	7.25	25	2.60	18.0	0	3.01	12.48
19	APR 8	6.65	7.15	24	3.40	18.0	0	2.97	12.00
20	APR 9	6.45	7.15	29	2.60	18.5	0	2.98	12.00
21	APR 10	6.50	7.15	28	3.10	19.0	0	2.98	12.00
22	APR 11	6.30	7.10	39	2.60	18.0	0	2.96	12.00
23	APR 12	6.85	7.40	9	2.80	19.5	133	3.15	12.00
24	APR 13	7.65	8.15	-69	3.10	21.0	145	3.27	12.00
25	APR 14	7.50	8.15	-144	3.40	20.5	81	2.98	12.00
26	APR 15	7.45	8.15	-193	2.10	20.5	104	2.97	12.00
27	APR 16	7.40	8.10	-229	1.90	21.0	106	3.02	12.00
28	APR 17	7.30	8.10	-288	2.20	19.0	101	2.92	12.00
29	APR 18	7.40	8.15	-343	3.20	18.5	94	2.80	11.76
30	APR 19	7.50	8.10	-428	1.60	19.0	100	2.90	12.00
31	APR 20	7.35	7.90	-171	2.50	20.0	111	3.02	12.00
32	APR 21	7.30	7.95	-110	1.70	20.5	119	3.04	12.00
33	APR 22	7.35	8.00	-68	2.00	20.0	120	2.98	11.52
34	APR 23	7.20	7.90	-46	2.30	19.0	108	2.91	11.52
35	APR 24	7.30	7.80	-34	0.90	19.5	106	2.90	11.28
36	APR 25	7.30	7.85	-31	2.80	20.0	110	2.95	11.28
37	APR 26	7.35	7.90	-37	2.80	20.0	116	2.97	11.28
38	APR 27	7.40	8.00	-49	2.70	20.0	116	3.02	11.28
39	APR 28	7.60	8.10	-61	2.80	21.0	117	3.04	11.28
40	APR 29	7.45	8.00	-44	3.20	19.0	117	3.06	11.28
41	APR 30	7.50	7.80	-39	3.30	18.0	107	2.95	9.60
42	MAY 1	7.40	7.75	-34	3.90	18.5	98	2.95	15.36
43	MAY 2	7.40	7.85	-42	4.00	18.0	104	2.99	12.00

ACETATE SYSTEM CONTINUED

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC D.O. (mg/L)	AEROBIC TEMP (CELCIUS)	ACETATE SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
44	MAY 3	7.45	7.90	-49	3.30	18.0	109	2.96	12.00
45	MAY 4	7.50	7.85	-56	3.10	18.5	109	2.99	12.72
46	MAY 5	7.60	7.90	-55	3.50	19.0	104	2.98	12.72
47	MAY 6	7.60	7.80	-76	1.40	20.0	113	2.99	12.00
48	MAY 7	7.75	8.00	-88	3.20	21.0	114	2.99	12.00
49	MAY 8	7.60	7.90	-89	2.20	20.5	116	2.95	12.00
50	MAY 9	7.65	8.00	-99	2.80	21.0	120	2.99	12.00
51	MAY 10	7.75	8.00	-35	1.80	22.0	123	3.12	12.24
52	MAY 11	7.80	8.20	-251	2.20	22.0	126	3.07	12.24
53	MAY 12	7.80	8.20	-263	2.20	22.0	127	3.06	12.24
54	MAY 13	7.90	8.30	-286	2.00	22.5	138	3.05	12.00
55	MAY 14	7.70	7.80	-99	0.80	21.0	40	2.93	12.00
56	MAY 15	7.60	7.75	-88	2.40	21.0	56	2.87	12.00
57	MAY 16	7.85	8.10	-253	0.60	21.0	219	2.83	12.00
58	MAY 17	8.00	8.25	-241	4.20	20.0	114	2.85	12.00
59	MAY 18	8.00	8.30	-233	5.40	19.0	102	2.89	12.24
60	MAY 19	8.00	8.25	-254	2.00	19.0	102	1.96	12.24
61	MAY 20	8.00	8.20	-284	1.80	21.0	107	2.07	12.24
62	MAY 21	8.00	8.25	-308	1.00	22.0	104	2.64	11.52
63	MAY 22	7.95	8.25	-374	2.00	20.5	115	2.87	13.20
64	MAY 23	7.85	8.25	-430	0.70	19.5	96	3.09	12.00
65	MAY 24	7.80	8.00	-263	0.50	19.5	105	3.30	12.00
66	MAY 25	7.80	8.00	-262	1.50	20.0	108	3.30	12.00
67	MAY 26	7.85	8.10	-274	1.30	20.0	110	3.30	12.00
68	MAY 27	7.90	8.20	-281	1.10	20.0	112	3.29	12.00
69	MAY 28	7.95	8.30	-290	0.90	21.5	116	3.28	12.00
70	MAY 29	7.85	8.10	-267	2.40	19.5	103	3.21	12.00
71	MAY 30	7.90	8.20	-359	0.60	21.0	100	3.29	12.00
72	MAY 31	7.90	8.20	-286	3.20	21.0	111	3.37	12.00
73	JNE 1	7.95	8.25	-283	1.70	20.5	112	3.06	12.00
74	JNE 2	7.90	8.25	-279	2.70	19.0	99	2.98	12.00
75	JNE 3	7.90	8.25	-287	0.60	20.0	102	3.70	12.00
76	JNE 4	7.90	8.30	-293	4.10	21.0	105	3.24	12.00
77	JNE 5	8.00	8.30	-283	3.90	20.0	103	3.19	12.00
78	JNE 6	8.00	8.30	-292	1.00	20.0	129	3.38	12.00
79	JNE 7	8.05	8.30	-307	4.10	21.0	134	3.28	12.00
80	JNE 8	8.00	8.30	-306	2.30	20.5	136	2.97	12.00
81	JNE 9	8.00	8.20	-308	0.50	21.0	139	3.36	12.00
82	JNE 10	8.20	8.35	-312	4.40	21.5	132	2.92	12.00
83	JNE 11	8.20	8.20	-312	4.30	22.0	121	2.88	12.00
84	JNE 12	8.25	8.25	-316	3.90	22.0	121	2.79	12.00
85	JNE 13	8.10	8.10	-322	2.10	22.0	131	3.39	12.00
86	JNE 14	8.10	8.30	-432	3.10	23.0	138	3.24	12.00
87	JNE 15	8.10	8.20	-509	0.70	23.0	144	3.40	12.00
88	JNE 16	8.20	8.25	-524	0.70	23.0	138	3.31	12.00
89	JNE 17	8.20	8.40	-313	0.50	23.0	77	3.38	12.00
90	JNE 18	8.30	8.30	-330	2.10	22.0	120	3.09	12.00
91	JNE 19	8.40	8.30	-348	0.00	22.0	125	3.07	12.00
92	JNE 20	8.50	8.45	-387	5.00	22.0	127	2.94	12.00

YEAST WASTE SYSTEM

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC TEMP (CELCIUS)	AEROBIC D.O. (mg/L)	YEAST WASTE SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
0									
1	MAR 21	7.55	7.60	38	19.0	6.10	0	3.35	11.52
2	MAR 22	7.55	7.55	41	18.5	6.50	0	3.30	11.52
3	MAR 23	7.60	7.65	40	18.0	6.50	0	3.18	12.00
4	MAR 24	7.30	7.65	37	18.0	3.00	0	2.93	11.76
5	MAR 25	7.30	7.60	29	18.0	2.70	0	2.93	11.76
6	MAR 26	7.25	7.60	25	18.5	3.40	0	2.93	11.76
7	MAR 27	7.15	7.45	23	18.0	2.00	0	2.93	11.76
8	MAR 28	7.00	7.25	15	18.0	2.20	0	2.92	12.48
9	MAR 29	6.85	7.30	-4	18.5	2.00	0	2.92	11.76
10	MAR 30	6.40	7.10	42	18.0	2.10	0	2.94	12.00
11	MAR 31	6.95	7.30	3	18.0	2.90	0	2.94	11.76
12	APR 1	6.95	7.25	10	18.0	2.80	0	2.97	11.52
13	APR 2	7.00	7.30	15	18.0	3.70	0	2.93	11.52
14	APR 3	7.05	7.40	20	18.0	3.90	0	2.88	11.52
15	APR 4	7.10	7.30	22	17.5	4.60	0	2.78	11.52
16	APR 5	7.00	7.30	6	17.5	5.40	0	2.89	11.52
17	APR 6	7.00	7.40	-5	17.5	5.90	0	3.31	12.00
18	APR 7	7.05	7.35	18	18.0	0.60	0	2.94	11.76
19	APR 8	6.70	7.15	21	18.0	5.40	0	2.89	11.76
20	APR 9	6.55	7.10	42	18.5	6.30	0	2.90	12.00
21	APR 10	6.45	7.10	63	19.0	5.80	0	2.90	12.00
22	APR 11	6.30	7.05	88	18.0	6.40	0	2.83	12.00
23	APR 12	5.95	6.60	106	19.5	3.60	0	3.46	12.00
24	APR 13	6.80	7.40	-164	21.0	0.40	1038	3.40	12.00
25	APR 14	5.70	6.70	-86	20.5	5.40	701	3.39	12.00
26	APR 15	5.10	6.35	-30	20.5	5.60	949	2.96	12.00
27	APR 16	5.10	6.75	-133	21.0	5.50	1116	2.85	12.00
28	APR 17	4.85	6.40	-32	19.0	6.00	1010	2.75	12.00
29	APR 18	5.10	6.60	49	18.5	3.80	959	2.68	11.76
30	APR 19	7.50	8.20	-343	19.0	0.90	1054	2.74	11.76
31	APR 20	7.20	7.60	-26	20.0	5.60	1017	2.82	11.76
32	APR 21	6.85	7.35	32	20.5	5.30	933	2.96	11.76
33	APR 22	6.05	6.90	73	20.0	5.80	814	2.76	11.76
34	APR 23	7.00	7.85	28	19.0	5.70	837	2.65	11.76
35	APR 24	7.05	7.40	58	19.5	4.70	843	2.82	11.76
36	APR 25	6.95	7.35	60	20.0	4.10	874	2.95	11.76
37	APR 26	6.80	7.30	55	20.0	3.50	874	3.01	11.76
38	APR 27	6.60	7.20	63	20.0	3.10	874	3.02	11.76
39	APR 28	6.40	7.15	80	21.0	2.50	874	3.04	11.76
40	APR 29	6.20	7.30	74	19.0	4.10	893	3.01	11.76
41	APR 30	6.50	7.05	85	18.0	4.10	971	2.68	11.76
42	MAY 1	6.70	7.30	75	18.5	4.10	883	2.72	10.56
43	MAY 2	6.55	7.30	-54	18.0	3.40	872	2.99	11.00

YEAST WASTE SYSTEM CONTINUED

DAY No.	DATE	AEROBIC pH	ANOXIC pH	ANOXIC ORP (mV)	AEROBIC TEMP (CELCIUS)	AEROBIC D.O. (mg/L)	YEAST WASTE SOLUTION FLOW (mL/d)	INFLUENT FLOW (L/d)	RECYCLE FLOW (L/d)
44	MAY 3	6.30	7.25	-39	18.0	3.20	996	3.03	11.00
45	MAY 4	6.90	7.45	-30	18.5	3.10	657	3.08	11.00
46	MAY 5	7.00	7.50	-58	19.0	4.50	713	3.13	10.66
47	MAY 6	6.95	7.30	-106	20.0	2.50	1483	3.19	10.66
48	MAY 7	6.55	7.40	-26	21.0	2.20	0	2.70	10.66
49	MAY 8	6.60	7.35	-189	20.5	2.30	662	2.85	10.32
50	MAY 9	6.50	7.15	-82	21.0	1.40	1091	3.12	10.56
51	MAY 10	7.00	7.30	-107	22.0	4.80	1167	3.09	10.56
52	MAY 11	7.20	7.40	-58	22.0	4.90	604	3.13	10.56
53	MAY 12	7.00	7.40	20	22.0	5.20	330	3.10	11.00
54	MAY 13	6.90	7.30	53	22.5	4.30	655	3.38	10.56
55	MAY 14	7.00	7.35	27	21.0	2.90	700	2.83	10.32
56	MAY 15	6.85	7.30	75	21.0	3.80	0	2.97	10.32
57	MAY 16	7.10	7.45	-227	21.0	1.90	1908	2.98	11.00
58	MAY 17	7.00	7.45	-258	20.0	0.80	1246	2.99	10.56
59	MAY 18	7.25	7.65	-293	19.0	4.70	1454	2.55	10.56
60	MAY 19	7.35	7.60	-291	19.0	5.60	1235	2.09	10.56
61	MAY 20	7.30	7.40	-192	21.0	6.40	0	2.66	10.32
62	MAY 21	7.40	7.70	-327	22.0	4.90	1029	2.95	10.80
63	MAY 22	7.40	7.75	-313	20.5	5.40	761	3.03	11.00
64	MAY 23	7.40	7.70	-267	19.5	4.50	872	2.76	11.00
65	MAY 24	7.40	7.60	-238	19.5	3.30	694	3.09	11.00
66	MAY 25	7.40	7.70	-317	20.0	3.20	1200	3.08	11.00
67	MAY 26	7.45	7.75	-336	20.0	3.30	1400	3.06	11.00
68	MAY 27	7.40	7.70	-268	20.0	3.90	300	3.05	11.00
69	MAY 28	7.50	7.95	-343	21.5	4.00	1600	3.04	10.80
70	MAY 29	7.50	7.70	-353	19.5	5.30	861	2.78	11.00
71	MAY 30	7.45	7.70	-367	21.0	3.80	1000	3.06	11.00
72	MAY 31	7.40	7.75	-349	21.0	3.20	919	3.17	11.00
73	JNE 1	7.40	7.70	-353	20.5	1.20	837	2.73	10.80
74	JNE 2	7.45	7.75	-357	19.0	3.30	720	2.50	10.80
75	JNE 3	7.50	7.20	-337	20.0	1.00	1695	2.90	10.80
76	JNE 4	7.30	7.30	-363	21.0	2.90	1250	2.70	10.80
77	JNE 5	7.30	7.40	-394	20.0	2.70	1003	2.69	10.80
78	JNE 6	7.35	7.30	-415	20.0	1.00	1066	3.21	10.32
79	JNE 7	7.85	7.00	-435	21.0	0.00	918	3.39	10.80
80	JNE 8	7.40	7.60	-410	20.5	7.10	1103	2.26	10.80
81	JNE 9	7.50	6.90	-398	21.0	0.60	1275	2.78	12.72
82	JNE 10	7.35	7.15	-391	21.5	4.00	1101	3.22	10.56
83	JNE 11	7.30	7.30	-434	22.0	4.90	1345	2.69	11.00
84	JNE 12	7.35	7.20	-448	22.0	5.80	2039	1.95	11.00
85	JNE 13	7.25	6.90	-444	22.0	4.20	1257	3.54	11.00
86	JNE 14	7.25	7.10	-447	23.0	5.30	1230	3.16	11.00
87	JNE 15	7.20	6.90	-458	23.0	3.90	1297	3.05	11.00
88	JNE 16	7.40	7.00	-479	23.0	4.70	1212	2.93	11.00
89	JNE 17	7.45	7.00	-340	23.0	5.80	1054	3.40	11.00
90	JNE 18	7.40	6.95	-360	22.0	4.80	1143	2.91	11.00
91	JNE 19	7.40	6.90	-389	22.0	4.50	904	2.89	11.00
92	JNE 20	7.30	6.70	-391	22.0	1.40	1133	2.77	11.00

GLUCOSE AND METHANOL SYSTEMS

DAY No.	DATE	INFLUENT TSS (mg/L)	GLUC. ANOXIC TSS (mg/L)	GLUC. AEROBIC TSS (mg/L)	GLUC. EFFLUENT TSS (mg/L)	MeOH ANOXIC TSS (mg/L)	MeOH AEROBIC TSS (mg/L)	MeOH EFFLUENT TSS (mg/L)
	OCT 3	132	1580	1600	148	1625	1685	30
1	OCT 17	55	1910	1970	52	2200	2410	28
3	OCT 19	98	1940	1950	47	2390	2530	95
5	OCT 21	92	1850	1900	53	2150	2430	66
7	OCT 23	316	1620	1580	34	1850	2230	38
9	OCT 25	75	1640	1570	30	1970	2180	39
12	OCT 28	110	1880	1710	15	1800	1830	36
16	NOV 1	59	1640	1540	11	1600	1650	13
18	NOV 3	100	1890	1630	26	1760	1620	12
22	NOV 7	68	1811	1708	17	1470	1480	15
25	NOV 10	147	2400	2220	16	1440	1630	15
27	NOV 12	94	2520	2460	15	1640	1710	15
32	NOV 17	73	2990	2960	12	1770	1910	21
34	NOV 19	45	3620	3190	7	1750	2080	15
36	NOV 21	41	3710	3270	7	1800	1840	12
39	NOV 24	43	3460	3270	7	2190	2150	12
41	NOV 26	34	3650	3550	18	2030	2340	10
43	NOV 28	58	3820	3580	31	2330	2540	22
46	DEC 1	53	3830	3490	12	1990	2200	11
48	DEC 3	212	3930	3630	16	2020	2220	18
50	DEC 5	142	3550	3360	11	1660	1740	12
53	DEC 8	47	3720	3480	7	2910	2300	9
55	DEC 10	153	3700	3470	8	1980	2190	14
57	DEC 12	67	3530	3290	8	2120	2100	13
64	DEC 19	141	9400	1510	6	2220	2480	11
67	DEC 22	244	4420	4200	10	2510	2550	17
69	DEC 24	59	4200	3890	6	2510	2760	16
71	DEC 26	47	3960	3620	6	2060	2350	17
75	DEC 30	78	4200	3060	4	2140	2240	11
78	JAN 2	105	4350	4080	5	2200	2390	13
81	JAN 5	245	4090	4380	6	2090	2380	18
83	JAN 7	53	4670	4290	6	2130	2520	11
85	JAN 9	59	4400	4040	6	1940	2150	5
88	JAN 12	58	4840	4550	6	2150	2570	6
90	JAN 14	43	4820	4540	6	2510	2930	6
92	JAN 16	68	4430	4310	9	2170	2860	6
95	JAN 19	98	4390	4360	7	2580	3260	5
97	JAN 21	59	4150	4300	6	2830	3100	8
99	JAN 23	84	4430	4110	8	2890	3190	8
102	JAN 26	104	4550	4110	6	3220	3170	5
104	JAN 28	71	4390	4130	8	3420	3480	7
106	JAN 30	79	4700	4530	7	3510	3500	5
109	FEB 2	41	5000	4290	7	3420	3600	18
111	FEB 4	38	5330	4970	12	3910	4060	8
113	FEB 6	58	5460	5410	23	4010	4330	8
116	FEB 9	135	5170	5170	22	4140	4450	10
118	FEB 11	269	5530	5530	33	4800	4900	27

GLUCOSE AND METHANOL SYSTEMS

DAY No.	DATE	INFLUENT TSS (mg/L)	GLUC. ANOXIC TSS (mg/L)	GLUC. AEROBIC TSS (mg/L)	GLUC. EFFLUENT TSS (mg/L)	MeOH ANOXIC TSS (mg/L)	MeOH AEROBIC TSS (mg/L)	MeOH EFFLUENT TSS (mg/L)
120	FEB 13	194	5600	5590	21	4790	4820	38
123	FEB 16	252	5890	5360	15	4750	4740	14
125	FEB 18	521	8170	6210	10	4970	5040	19
127	FEB 20	203	6270	6460	16	4970	5300	16
130	FEB 23	184	5770	5500	16	5470	5350	17
132	FEB 25	295	7030	6880	75	5530	5560	14
134	FEB 27	137	4870	4300	68	5290	5420	15
137	MAR 1	504	4430	4330	49	5800	5970	30
139	MAR 3	51	3750	3670	32	6170	7060	27
141	MAR 5	43	2490	2470	72	6830	6610	32
143	MAR 7	95	2230	1940	37	6310	6300	13

GLUCOSE AND METHANOL SYSTEMS

DAY No.	DATE	INFLUENT VSS (mg/L)	GLUC. ANOXIC VSS (mg/L)	GLUC. AEROBIC VSS (mg/L)	GLUC. EFFLUENT VSS (mg/L)	MeOH ANOXIC VSS (mg/L)	MeOH AEROBIC VSS (mg/L)	MeOH EFFLUENT VSS (mg/L)
	OCT 3	42	1110	1060	76	1150	1185	22
1	OCT 17	29	1200	1230	31	1470	1630	16
3	OCT 19	35	1260	1260	25	1590	1670	32
5	OCT 21	37	1160	1230	27	1430	1590	31
7	OCT 23	74	1070	1080	22	1260	1500	17
9	OCT 25	33	1180	1160	21	1380	1520	21
12	OCT 28	32	1400	1270	11	1300	1330	19
16	NOV 1	28	1270	1240	9	1220	1240	10
18	NOV 3	16	1410	1270	8	1240	1200	9
22	NOV 7	29	1489	1427	14	1150	1170	11
25	NOV 10	46	1860	1760	11	1050	1220	10
27	NOV 12	27	2010	1970	12	1190	1320	10
32	NOV 17	27	1500	2440	10	1300	1410	13
34	NOV 19	12	3030	2690	6	1320	1540	11
36	NOV 21	17	3130	2740	6	1350	1390	9
39	NOV 24	31	2910	2750	6	1640	1590	9
41	NOV 26	20	3030	2940	14	1740	1670	7
43	NOV 28	28	3160	2950	16	1680	1810	16
46	DEC 1	26	3160	2880	10	1430	1610	8
48	DEC 3	83	3230	3000	13	1520	1650	10
50	DEC 5	52	2840	2690	8	1170	1240	6
53	DEC 8	22	2990	2760	5	2040	1630	6
55	DEC 10	51	3050	2840	7	1500	1620	10
57	DEC 12	31	2870	2690	7	1560	1540	9
64	DEC 19	56	7810	1320	6	1680	1890	9
67	DEC 22	75	3660	3440	8	1910	1930	12
69	DEC 24	30	3530	3290	5	1980	2130	12
71	DEC 26	21	3260	2990	5	1520	1790	12
75	DEC 30	36	3510	3320	4	1670	1730	9
78	JAN 2	42	3640	3390	3	1710	1850	10
81	JAN 5	79	3510	3720	5	2050	1860	14
83	JAN 7	29	4030	3680	5	1690	1990	10
85	JAN 9	35	3825	3530	5	1590	1770	5
88	JAN 12	32	4160	3930	5	1750	2090	5
90	JAN 14	20	4090	3880	5	2070	2420	5
92	JAN 16	34	3810	3780	7	1810	2350	4
95	JAN 19	49	3650	3610	4	2080	2680	3
97	JAN 21	35	3500	3590	6	2310	2550	7
99	JAN 23	48	3640	3370	6	2350	2590	7
102	JAN 26	46	3630	3310	5	2450	2540	4
104	JAN 28	32	3600	3360	6	2780	2810	6
106	JAN 30	37	3780	3610	6	2840	2840	4
109	FEB 2	19	4140	3510	6	2810	2950	16
111	FEB 4	23	4420	4110	9	3280	3380	7
113	FEB 6	34	4650	4540	12	3410	3650	7
116	FEB 9	44	4330	4300	8	3530	3790	7
118	FEB 11	59	4730	4620	8	4120	4230	14

GLUCOSE AND METHANOL SYSTEMS

DAY No.	DATE	INFLUENT VSS (mg/L)	GLUC. ANOXIC VSS (mg/L)	GLUC. AEROBIC VSS (mg/L)	GLUC. EFFLUENT VSS (mg/L)	MeOH ANOXIC VSS (mg/L)	MeOH AEROBIC VSS (mg/L)	MeOH EFFLUENT VSS (mg/L)
120	FEB 13	57	4780	4730	4	4120	4190	17
123	FEB 16	73	5050	4540	9	4090	4150	13
125	FEB 18	134	6950	5220	7	4300	4360	14
127	FEB 20	65	5360	5460	7	4340	4600	14
130	FEB 23	63	4800	4600	13	4720	4630	15
132	FEB 25	97	6140	6010	63	4740	4810	12
134	FEB 27	52	4080	3560	50	4600	4710	14
137	MAR 1	139	3580	3500	39	5060	5210	27
139	MAR 3	30	2980	2900	23	5390	6170	24
141	MAR 5	26	1930	1890	48	5890	5780	27
143	MAR 7	37	1650	1530	25	5540	5580	10

ACETATE SYSTEM

DAY No.	DATE		INFLUENT TSS (mg/L)	ACETATE ANOXIC TSS (mg/L)	ACETATE AEROBIC TSS (mg/L)	ACETATE EFFLUENT TSS (mg/L)	YEAST WASTE ANOXIC TSS (mg/L)	YEAST WASTE AEROBIC TSS (mg/L)	YEAST WASTE EFFLUENT TSS (mg/L)
0									
2	MAR	22	20	790	790	26	860	950	34
4	MAR	24	38	730	680	27	850	910	48
11	MAR	31	45	3140	3130	51	3000	3150	72
17	APR	6	134	2500	2610	56	2710	2750	57
20	APR	9	145	1630	1760	23	1990	2160	66
22	APR	11	222	1710	1990	31	2030	2160	67
24	APR	13	156	1940	1960	52	2120	2140	69
27	APR	16	92	2660	2630	6	2640	2590	40
29	APR	18	171	2880	2740	4	2760	2640	67
31	APR	20	51	3040	2990	5	2490	2550	47
34	APR	23	104	2740	2710	6	2100	2150	37
41	APR	30	179	2090	2040	11	2160	2120	38
43	MAY	2	229	2380	2300	16	2660	2670	21
45	MAY	4	158	2340	2320	11	3460	3060	15
48	MAY	7	202	2380	2390	29	6660	5820	15
50	MAY	9	295	2100	2070	24	4610	4610	24
55	MAY	14	47	3190	3130	34	5620	5910	25
57	MAY	16	60	3380	3300	39	7740	7180	35
59	MAY	18	56	3070	3260	30	6940	7380	29
62	MAY	21	90	3350	3280	22	7570	7700	89
64	MAY	23	121	3580	3490	19	6650	6600	27
69	MAY	28	70	3710	3620	19	8370	8060	20
71	MAY	30	98	3640	3710	24	8030	8190	24
73	JNE	1	101	3870	3660	32	7630	7540	522
76	JNE	4	160	4060	3930	19	7930	7650	280
78	JNE	6	92	4090	3960	18	7750	7770	656
80	JNE	8	53	4150	4190	16	5830	6230	1848
83	JNE	11	127	4260	4270	23	6380	6230	184
85	JNE	13	100	4070	4070	17	5980	5950	640
87	JNE	15	87	3680	4050	30	6130	6100	2290
92	JNE	20	41	1710	2420	860	7030	7340	1090

ACETATE SYSTEM

DAY No.	DATE	INFLUENT VSS (mg/L)	ACETATE ANOXIC VSS (mg/L)	ACETATE AEROBIC VSS (mg/L)	ACETATE EFFLUENT VSS (mg/L)	YEAST WASTE ANOXIC VSS (mg/L)	YEAST WASTE AEROBIC VSS (mg/L)	YEAST WASTE EFFLUENT VSS (mg/L)
0								
2	MAR 22	6	580	590	15	630	710	20
4	MAR 24	16	600	560	19	700	740	34
11	MAR 31	20	2440	2430	40	2350	2440	53
17	APR 6	43	1850	1980	18	2020	2050	30
20	APR 9	57	1250	1330	15	1490	1640	42
22	APR 11	87	1250	1480	17	1440	1600	43
24	APR 13	60	1480	1530	38	1680	1710	55
27	APR 16	43	2110	2080	5	2130	2160	34
29	APR 18	70	2290	2190	3	2350	2250	60
31	APR 20	31	2430	2360	5	2090	2150	41
34	APR 23	32	2200	2170	5	1800	1810	35
41	APR 30	43	1700	1700	10	1820	1780	28
43	MAY 2	48	1920	1800	11	2040	2060	17
45	MAY 4	34	1900	1880	8	2470	2200	12
48	MAY 7	49	1850	1870	20	4360	3910	11
50	MAY 9	72	1660	1640	15	3210	3220	18
55	MAY 14	26	2510	2420	22	3700	3860	20
57	MAY 16	31	2650	2540	24	5100	4690	27
59	MAY 18	31	2420	2520	19	5130	5340	22
62	MAY 21	42	2680	2600	13	5560	5690	67
64	MAY 23	54	2840	2800	13	4930	4920	22
69	MAY 28	39	3050	3000	15	6640	6430	18
71	MAY 30	43	3040	3030	16	6460	6570	16
73	JNE 1	69	3230	3020	23	6230	6160	426
76	JNE 4	87	3370	3250	16	6800	6590	242
78	JNE 6	51	3360	3280	14	6740	6770	548
80	JNE 8	30	3430	3460	11	5060	5340	1556
83	JNE 11	52	3550	3490	15	5690	5550	140
85	JNE 13	40	3470	3610	12	5420	5320	568
87	JNE 15	34	3100	3350	23	5600	5520	2070
92	JNE 20	22	1440	2020	720	6510	6800	1020

DAY No.	DATE	INFLUENT AMMONIA (mg/L)	ANOXIC AMMONIA (mg/L)	AEROBIC AMMONIA (mg/L)	EFFLUENT AMMONIA (mg/L)	DAY No.	DATE	INFLUENT AMMONIA (mg/L)	ANOXIC AMMONIA (mg/L)	AEROBIC AMMONIA (mg/L)	EFFLUENT AMMONIA (mg/L)
5	OCT 21	166	66.3	1.60	0.20	127	FEB 20	178	31.8	0.07	0.10
7	OCT 23	209	16.5	0.40	7.10	129	FEB 22	175	29.5	0.12	0.15
12	OCT 28	218	64.3	22.20	26.30	131	FEB 24	199	37.0	0.90	0.20
17	NOV 2	219	47.5	0.50	0.10	134	FEB 27	209	39.0	0.14	0.16
19	NOV 4	217	10.4	3.10	0.01	136	FEB 29	186	39.8	0.07	0.22
22	NOV 7	187	39.5	0.01	0.01	139	MAR 2	203	38.8	0.31	0.23
25	NOV 10	223	69.0	27.10	14.80	141	MAR 5	211	36.8	0.18	0.07
33	NOV 18	178	35.5	0.05	0.01	143	MAR 7	198	37.3	0.17	0.29
36	NOV 21	182	31.0	0.08	0.07						
38	NOV 23	194	33.5	0.27	0.05						
43	NOV 28	192	71.0	39.50	59.00						
45	NOV 30	193	38.5	0.13	0.08						
47	DEC 2	181	33.5	0.06	0.04						
50	DEC 5	187	37.5	0.09	0.07						
52	DEC 7	181	35.5	0.09	0.07						
54	DEC 9	195	39.0	-0.05	0.10						
57	DEC 12	212	39.5	0.12	0.15						
59	DEC 14	204	39.5	0.17	0.05						
62	DEC 17	204	69.5	39.80	34.80						
64	DEC 19	216	38.5	0.07	0.07						
66	DEC 21	209	47.0	2.95	9.40						
68	DEC 23	220	42.5	0.05	0.03						
71	DEC 26	206	40.3	0.07	0.06						
73	DEC 28	206	39.8	0.06	0.02						
75	DEC 30	201	38.8	0.12	0.01						
78	JAN 2	198	36.8	0.04	0.04						
80	JAN 4	194	37.0	0.09	0.06						
82	JAN 6	238	44.5	0.02	0.02						
85	JAN 9	227	42.8	0.02	0.01						
87	JAN 11	226	43.5	0.04	0.04						
89	JAN 13	221	45.8	0.03	0.92						
92	JAN 16	224	43.3	0.02	0.02						
94	JAN 18	171	31.0	0.01	0.01						
96	JAN 20	172	39.3	0.24	0.04						
99	JAN 23	148	31.0	0.04	0.01						
101	JAN 25	163	31.5	0.01	0.00						
103	JAN 27	217	43.5	0.00	0.00						
106	JAN 30	215	39.0	0.02	0.02						
108	FEB 1	207	40.3	0.00	0.00						
110	FEB 3	215	42.3	0.00	0.00						
113	FEB 6	228	43.3	0.05	0.07						
115	FEB 8	191	36.5	0.06	0.02						
117	FEB 10	186	35.3	0.02	0.02						
120	FEB 13	179	32.5	0.04	0.04						
122	FEB 15	169	30.3	0.15	0.10						
124	FEB 17	191	36.5	0.91	2.67						

GLUCOSE SYSTEM

DAY No.	DATE	INFLUENT AMMONIA (mg/L)	ANOXIC AMMONIA (mg/L)	AEROBIC AMMONIA (mg/L)	EFFLUENT AMMONIA (mg/L)	DAY No.	DATE	INFLUENT AMMONIA (mg/L)	ANOXIC AMMONIA (mg/L)	AEROBIC AMMONIA (mg/L)	EFFLUENT AMMONIA (mg/L)
0											
5	OCT 21	166	67.2	9.80	2.80	127	FEB 20	178	25.5	0.11	0.23
7	OCT 23	209	45.3	2.10	6.60	129	FEB 22	175	37.0	3.01	0.99
12	OCT 28	218	87.0	59.50	57.50	131	FEB 24	199	55.5	23.40	17.40
17	NOV 2	219	41.5	0.75	8.75	134	FEB 27	209	72.5	42.30	54.30
19	NOV 4	217	42.5	0.50	0.01	136	FEB 29	186	65.5	32.00	33.00
22	NOV 7	187	36.0	0.12	0.01	138	MAR 2	203	61.0	26.00	24.30
25	NOV 10	223	47.0	1.10	0.12	141	MAR 5	211	40.3	0.47	0.36
33	NOV 18	178	31.5	0.14	0.04	143	MAR 7	198	40.0	0.47	0.31
36	NOV 21	182	31.0	0.11	0.11						
38	NOV 23	194	34.0	0.07	0.05						
43	NOV 28	192	36.5	0.20	9.00						
45	NOV 30	193	39.5	0.26	0.13						
47	DEC 2	181	36.0	0.14	0.06						
50	DEC 5	187	37.0	0.18	0.09						
52	DEC 7	181	36.0	0.14	0.11						
54	DEC 9	195	36.5	0.24	0.20						
57	DEC 12	212	39.0	0.15	0.19						
59	DEC 14	204	36.5	0.21	0.15						
62	DEC 17	204	37.5	0.31	0.18						
64	DEC 19	216	50.5	12.00	0.39						
66	DEC 21	209	38.5	0.09	0.11						
68	DEC 23	220	45.5	0.18	0.17						
71	DEC 26	206	42.0	2.29	0.20						
73	DEC 28	206	41.0	0.38	0.12						
75	DEC 30	201	35.5	0.20	0.12						
78	JAN 2	198	34.0	0.03	0.09						
80	JAN 4	194	37.3	0.16	0.11						
82	JAN 6	238	46.0	0.12	0.70						
85	JAN 9	227	41.0	0.10	0.17						
87	JAN 11	226	41.0	0.17	0.15						
89	JAN 13	221	37.3	0.09	0.27						
92	JAN 16	224	40.3	0.17	0.38						
94	JAN 18	171	28.3	0.02	0.16						
96	JAN 20	172	31.0	0.02	0.10						
99	JAN 23	148	28.5	0.04	0.03						
101	JAN 25	163	29.0	0.02	0.01						
103	JAN 27	217	42.5	0.01	0.02						
106	JAN 30	215	40.0	0.10	0.16						
108	FEB 1	207	39.0	0.14	0.16						
110	FEB 3	215	40.3	0.07	0.07						
113	FEB 6	228	37.3	0.12	0.10						
115	FEB 8	191	31.5	0.09	0.15						
117	FEB 10	186	27.5	0.00	0.00						
120	FEB 13	179	28.3	0.11	0.11						
122	FEB 15	169	24.8	0.14	0.20						
124	FEB 17	191	28.0	0.25	0.20						

ACETATE SYSTEM

DAY No.	DATE	INFLUENT AMMONIA (mg/L)	ANOXIC AMMONIA (mg/L)	AEROBIC AMMONIA (mg/L)	EFFLUENT AMMONIA (mg/L)
17	APR 6	194	39.5	0.13	0.10
20	APR 9	194	39.8	0.13	0.00
22	APR 11	182	35.5	0.18	0.04
24	APR 13	142	23.8	0.13	0.14
27	APR 16	193	34.8	0.06	0.06
29	APR 18	164	29.5	0.10	0.10
31	APR 20	188	36.5	0.18	15.60
34	APR 23	180	34.5	0.03	0.11
41	APR 30	228	53.5	0.73	0.09
43	MAY 2	222	42.5	0.07	0.03
45	MAY 4	241	42.8	0.16	0.18
48	MAY 7	215	35.8	2.44	0.18
50	MAY 9	191	34.5	0.34	0.15
55	MAY 14	223	43.0	0.41	0.31
57	MAY 16	204	39.3	1.37	0.25
59	MAY 18	202	37.3	0.49	0.25
62	MAY 21	210	37.5	0.30	0.14
64	MAY 23	199	38.3	0.62	0.12
69	MAY 28	190	35.8	0.33	0.11
71	MAY 30	194	38.8	0.40	0.00
73	JNE 1	265	52.3	0.40	0.11
76	JNE 4	264	51.8	0.34	0.31
78	JNE 6	228	46.3	0.39	0.20
80	JNE 8	240	45.3	0.58	0.00
83	JNE 11	223	38.3	0.26	0.10
85	JNE 13	209	41.5	0.34	0.36
87	JNE 15	209	43.3	0.86	0.86
92	JNE 20	188	35.8	1.63	1.50

YEAST WASTE SYSTEM

DAY No.	DATE	YEAST WASTE SOLUTION FTKN (mg/L)	INFLUENT FTKN (mg/L)	ANOXIC FTKN (mg/L)	AEROBIC FTKN (mg/L)	EFFLUENT FTKN (mg/L)
0						
34	APR 23	91.6	190	40.2	5.00	4.90
41	APR 30	60.0	252	56.8	9.30	7.00
43	MAY 2	77.2	241	56.4	8.10	7.10
45	MAY 4	36.6	253	62.2	10.20	7.30
48	MAY 7	30.0	244	44.6	8.60	42.00
50	MAY 9	39.8	197	54.3	9.30	8.30
55	MAY 14	84.5	249	55.8	9.90	8.60
57	MAY 16	105.0	223	61.6	9.60	9.60
59	MAY 18	114.0	224	59.7	7.70	7.20
62	MAY 21	154.0	214	58.2	8.40	10.00
64	MAY 23	272.0	211	52.7	8.90	8.30
69	MAY 28	210.0	212	56.7	10.20	11.30
71	MAY 30	213.0	201	58.9	8.00	8.30
73	JNE 1	256.0	280	72.4	9.30	9.40
76	JNE 4	292.0	272	75.9	10.40	21.00
78	JNE 6	262.0	254	78.2	10.80	14.60
80	JNE 8	146.0	266	73.1	13.80	13.20
83	JNE 11	274.0	244	83.8	12.40	10.80
85	JNE 13	482.0	226	105.0	16.10	12.60
87	JNE 15	96.3	223	69.9	10.00	15.50
92	JNE 20	78.5	211	57.0	10.60	13.00

METHANOL SYSTEM

DAY No.	DATE	TOTAL AMMONIA REMOVAL %	ANOXIC AMMONIA REMOVAL (mg/d)	ANOXIC AMMONIA REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC AMMONIA REMOVAL (mg/d)	AEROBIC AMMONIA REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
5	OCT 21	99.88	-441.63	-76.57	-2.23	993.79	97.59	13.02
7	OCT 23	96.60	65.62	25.02	0.83	191.91	97.58	2.67
12	OCT 28	87.94	-0.84	-0.08	0.00	655.08	65.47	10.26
17	NOV 2	99.95	7.90	1.11	0.04	693.25	98.95	12.04
19	NOV 4	100.00	606.68	78.96	2.65	113.44	70.19	1.97
22	NOV 7	99.99	-25.48	-4.48	-0.16	593.93	99.97	10.58
25	NOV 10	93.36	-180.70	-21.07	-0.84	630.60	60.72	10.77
33	NOV 18	99.99	-9.78	-1.88	-0.06	528.91	99.86	7.16
36	NOV 21	99.96	38.05	7.70	0.24	454.83	99.74	6.82
38	NOV 23	99.97	30.34	5.81	0.15	488.15	99.19	6.40
43	NOV 28	69.27	211.74	16.64	0.41	470.61	44.37	5.42
45	NOV 30	99.96	-29.99	-5.56	-0.16	567.49	99.66	7.34
47	DEC 2	99.98	18.86	3.65	0.10	496.58	99.82	6.27
50	DEC 5	99.96	32.28	5.79	0.21	524.49	99.76	8.81
52	DEC 7	99.96	12.57	2.35	0.05	520.88	99.75	6.66
54	DEC 9	99.95	22.99	3.90	0.11	566.33	99.87	7.28
57	DEC 12	99.93	59.92	9.30	0.25	582.43	99.70	7.88
59	DEC 14	99.98	8.59	1.43	0.04	587.20	99.57	7.94
62	DEC 17	82.94	4.84	0.47	0.01	440.45	42.73	5.96
64	DEC 19	99.97	34.07	5.64	0.14	568.38	99.82	6.27
66	DEC 21	95.50	59.10	7.66	0.17	667.36	93.72	13.50
68	DEC 23	99.99	-1.99	-0.32	-0.01	630.81	99.88	6.17
71	DEC 26	99.97	-18.92	-3.28	-0.09	595.40	99.83	6.93
73	DEC 28	99.99	7.94	1.32	0.04	592.92	99.85	6.90
75	DEC 30	100.00	30.43	5.05	0.13	570.92	99.69	6.88
78	JAN 2	99.98	26.36	4.59	0.11	547.72	99.89	6.17
80	JAN 4	99.97	11.56	1.98	0.04	571.74	99.76	6.40
82	JAN 6	99.99	56.41	7.77	0.19	669.42	99.96	7.01
85	JAN 9	100.00	44.65	6.49	0.17	642.98	99.95	7.57
87	JAN 11	99.98	27.80	4.08	0.10	652.33	99.91	6.50
89	JAN 13	99.58	4.56	0.66	0.01	691.13	99.93	5.95
92	JAN 16	99.99	48.04	6.83	0.16	655.26	99.95	5.81
94	JAN 18	99.99	-2.28	-0.50	-0.01	453.69	99.97	3.53
96	JAN 20	99.98	14.56	2.31	0.04	611.68	99.39	5.00
99	JAN 23	99.99	8.37	1.74	0.03	472.14	99.87	3.80
101	JAN 25	100.00	36.22	7.06	0.12	477.07	99.97	3.91
103	JAN 27	100.00	29.73	4.31	0.06	660.33	100.00	4.90
106	JAN 30	99.99	12.72	2.17	0.03	574.18	99.95	4.21
108	FEB 1	100.00	-13.51	-2.31	-0.03	597.25	100.00	4.22
110	FEB 3	100.00	-13.68	-2.22	-0.03	628.58	100.00	3.87
113	FEB 6	99.97	26.11	3.88	0.05	646.59	99.88	3.69
115	FEB 8	99.99	56.64	9.26	0.11	553.89	99.84	3.04
117	FEB 10	99.99	37.78	6.64	0.07	531.32	99.94	2.62
120	FEB 13	99.98	39.73	7.57	0.08	484.63	99.88	2.41
122	FEB 15	99.94	43.99	8.86	0.09	450.14	99.50	2.26
124	FEB 17	98.60	68.35	11.05	0.11	536.34	97.51	2.56

METHANOL SYSTEM

DAY No.	DATE	TOTAL AMMONIA REMOVAL %	ANOXIC AMMONIA REMOVAL (mg/d)	ANOXIC AMMONIA REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC AMMONIA REMOVAL (mg/d)	AEROBIC AMMONIA REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
127	FEB 20	99.94	42.12	8.17	0.08	472.46	99.78	2.14
129	FEB 22	99.91	58.57	11.42	0.10	452.45	99.59	2.04
131	FEB 24	99.90	24.96	4.34	0.04	537.17	97.57	2.33
134	FEB 27	99.92	79.56	12.25	0.11	568.13	99.64	2.51
136	FEB 29	99.88	-27.60	-5.04	-0.04	574.10	99.82	2.30
139	MAR 2	99.89	64.24	9.82	0.08	585.43	99.20	1.98
141	MAR 5	99.97	90.55	14.05	0.10	551.13	99.51	1.99
143	MAR 7	99.85	43.65	7.36	0.06	547.30	99.54	2.04

GLUCOSE SYSTEM

DAY No.	DATE	AMMONIA REMOVAL %	AMMONIA REMOVAL (mg/d)	AMMONIA REMOVAL %	ANOXIC REMOVAL (mg/hr/gVSS)	AMMONIA REMOVAL (mg/d)	AMMONIA REMOVAL %	AEROBIC REMOVAL (mg/hr/gVSS)
0								
5	OCT 21	98.31	-469.15	0.00	-16.85	950.54	85.42	16.10
7	OCT 23	96.84	86.81	12.60	3.38	574.13	95.36	11.08
12	OCT 28	73.62	69.38	4.80	2.06	435.05	31.61	7.14
17	NOV 2	96.00	116.43	15.87	3.44	605.95	98.19	9.94
19	NOV 4	100.00	-7.32	-1.17	-0.20	624.96	98.82	9.12
22	NOV 7	99.99	-4.55	-0.86	-0.13	532.10	99.67	7.77
25	NOV 10	99.95	-50.40	-7.75	-1.13	684.37	97.66	8.10
33	NOV 18	99.98	37.08	7.35	0.51	465.07	99.56	3.60
36	NOV 21	99.94	44.57	8.88	0.59	455.63	99.65	3.46
38	NOV 23	99.97	31.00	5.83	0.44	500.13	99.79	3.79
43	NOV 28	95.31	140.37	21.01	1.85	524.90	99.45	3.71
45	NOV 30	99.93	-23.74	-4.38	-0.31	561.92	99.34	4.06
47	DEC 2	99.97	-4.98	-0.93	-0.06	535.75	99.61	3.72
50	DEC 5	99.95	5.58	1.00	0.08	551.93	99.51	4.27
52	DEC 7	99.94	15.75	2.93	0.22	519.25	99.61	3.92
54	DEC 9	99.90	38.30	6.79	0.52	522.14	99.34	3.83
57	DEC 12	99.91	38.37	6.31	0.56	567.99	99.62	4.40
59	DEC 14	99.93	56.25	9.35	0.82	542.17	99.42	4.20
62	DEC 17	99.91	45.63	7.66	0.66	545.58	99.17	4.23
64	DEC 19	99.82	-118.06	-18.58	-0.63	574.42	76.24	9.07
66	DEC 21	99.95	28.66	4.77	0.33	571.16	99.77	3.46
68	DEC 23	99.92	16.18	2.29	0.19	689.32	99.60	4.36
71	DEC 26	99.90	-44.23	-7.50	-0.57	599.22	94.55	4.20
73	DEC 28	99.94	35.79	5.43	0.42	617.02	99.07	3.87
75	DEC 30	99.94	47.12	8.20	0.56	524.21	99.44	3.29
78	JAN 2	99.95	63.76	11.20	0.73	505.13	99.91	3.10
80	JAN 4	99.94	43.85	7.78	0.52	517.73	99.57	2.90
82	JAN 6	99.71	52.22	7.26	0.54	665.72	99.74	3.77
85	JAN 9	99.93	66.68	9.96	0.72	601.23	99.76	3.55
87	JAN 11	99.93	59.80	9.04	0.60	599.38	99.59	3.18
89	JAN 13	99.88	119.60	17.54	1.22	560.75	99.76	3.01
92	JAN 16	99.83	62.88	9.45	0.69	599.94	99.58	3.40
94	JAN 18	99.91	51.23	10.58	0.58	432.68	99.93	2.50
96	JAN 20	99.94	42.33	8.38	0.50	462.53	99.94	2.68
99	JAN 23	99.98	29.33	6.62	0.34	412.95	99.86	2.55
101	JAN 25	99.99	65.10	13.18	0.75	428.61	99.93	2.70
103	JAN 27	99.99	32.66	4.93	0.38	629.28	99.98	3.90
106	JAN 30	99.93	21.74	3.34	0.24	628.03	99.75	3.62
108	FEB 1	99.92	54.72	8.50	0.55	586.79	99.64	3.48
110	FEB 3	99.97	71.04	10.41	0.67	610.29	99.83	3.09
113	FEB 6	99.96	106.63	16.10	0.96	553.98	99.68	2.54
115	FEB 8	99.92	73.59	13.62	0.71	465.50	99.71	2.26
117	FEB 10	100.00	79.99	16.11	0.70	416.63	100.00	1.88
120	FEB 13	99.94	103.27	19.64	0.90	420.88	99.61	1.85
122	FEB 15	99.88	101.35	21.70	0.84	363.74	99.44	1.67
124	FEB 17	99.90	150.51	26.42	0.90	415.42	99.11	1.66
127	FEB 20	99.87	131.39	25.76	1.02	377.04	99.57	1.44

GLUCOSE SYSTEM

DAY No.	DATE	AMMONIA REMOVAL %	AMMONIA REMOVAL (mg/d)	AMMONIA REMOVAL %	ANOXIC REMOVAL (mg/hr/gVSS)	AMMONIA REMOVAL (mg/d)	AMMONIA REMOVAL %	AEROBIC REMOVAL (mg/hr/gVSS)
129	FEB 22	99.43	-48.48	-9.73	-0.42	502.37	91.86	2.28
131	FEB 24	91.26	-19.53	-2.39	-0.13	483.11	57.84	1.67
134	FEB 27	74.02	176.09	14.02	1.80	449.68	41.66	2.63
136	FEB 29	82.26	-32.11	-3.39	-0.37	501.50	51.15	2.99
138	MAR 2	88.03	8.32	0.89	0.12	530.60	57.38	3.81
141	MAR 5	99.83	20.87	3.35	0.45	594.66	98.83	6.55
143	MAR 7	99.84	-11.76	-2.01	-0.30	590.58	98.83	8.04

ACETATE SYSTEM

DAY No.	DATE	TOTAL AMMONIA REMOVAL %	ANOXIC AMMONIA REMOVAL (mg/d)	ANOXIC AMMONIA REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC AMMONIA REMOVAL (mg/d)	AEROBIC AMMONIA REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
17	APR 6	99.95	5.50	0.85	0.12	635.83	99.67	6.69
20	APR 9	100.00	-18.08	-3.13	-0.60	594.26	99.67	9.31
22	APR 11	99.98	8.12	1.51	0.27	528.39	99.49	7.44
24	APR 13	99.90	102.59	22.01	2.89	361.44	99.45	4.92
27	APR 16	99.97	60.88	10.43	1.20	521.79	99.83	5.23
29	APR 18	99.94	30.86	6.70	0.56	428.06	99.66	4.07
31	APR 20	91.70	206.73	27.38	3.54	545.53	99.51	4.82
34	APR 23	99.94	27.23	5.19	0.52	497.40	99.91	4.78
41	APR 30	99.96	2.04	0.30	0.05	662.26	98.64	8.12
43	MAY 2	99.99	27.07	4.08	0.59	636.03	99.84	7.36
45	MAY 4	99.93	50.49	6.98	1.11	669.87	99.63	7.42
48	MAY 7	99.92	108.37	16.80	2.44	500.07	93.18	5.57
50	MAY 9	99.92	55.74	9.73	1.40	512.06	99.01	6.50
55	MAY 14	99.86	15.12	2.30	0.25	635.87	99.05	5.47
57	MAY 16	99.88	-2.50	-0.43	-0.04	562.50	96.51	4.61
59	MAY 18	99.88	22.49	3.83	0.39	556.94	98.69	4.60
62	MAY 21	99.93	25.01	4.50	0.39	526.75	99.20	4.22
64	MAY 23	99.94	38.40	6.23	0.56	568.59	98.38	4.23
69	MAY 28	99.94	77.50	12.41	1.06	541.98	99.08	3.76
71	MAY 30	100.00	45.01	7.05	0.62	587.14	98.97	4.04
73	JNE 1	99.96	24.58	3.03	0.32	781.61	99.24	5.39
76	JNE 4	99.88	69.65	8.11	0.87	784.25	99.34	5.03
78	JNE 6	99.91	60.95	7.88	0.76	706.10	99.16	4.48
80	JNE 8	100.00	34.66	4.86	0.42	669.46	98.72	4.03
83	JNE 11	99.96	73.54	11.43	0.86	566.04	99.32	3.38
85	JNE 13	99.83	74.15	10.40	0.89	633.45	99.18	3.66
87	JNE 15	99.59	54.10	7.50	0.73	653.58	98.01	4.06
92	JNE 20	99.20	35.87	6.28	1.04	510.50	95.45	5.27

YEAST WASTE SYSTEM

DAY No.	DATE	TOTAL FILT.TKN REMOVAL %	ANOXIC FILT.TKN REMOVAL (mg/d)	ANOXIC FILT.TKN REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC FILT.TKN REMOVAL (mg/d)	AEROBIC FILT.TKN REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
34	APR 23	99.98	100.87	15.96	2.33	464.99	87.56	5.35
41	APR 30	99.97	33.60	4.14	0.77	649.80	83.63	7.61
43	MAY 2	99.97	76.97	8.89	1.57	675.72	85.64	6.83
45	MAY 4	99.91	7.81	0.88	0.13	732.16	83.60	6.93
48	MAY 7	82.79	510.66	46.15	4.88	480.96	80.72	2.56
50	MAY 9	99.94	2.89	0.39	0.04	615.60	82.87	3.98
55	MAY 14	99.96	118.80	13.93	1.34	603.58	82.26	3.26
57	MAY 16	99.99	109.31	11.26	0.89	726.96	84.42	3.23
59	MAY 18	99.99	30.32	3.73	0.25	681.72	87.10	2.66
62	MAY 21	99.98	97.52	10.86	0.73	684.75	85.57	2.51
64	MAY 23	99.99	185.69	20.39	1.57	602.69	83.11	2.55
69	MAY 28	99.99	317.79	28.82	1.99	643.56	82.01	2.09
71	MAY 30	99.99	91.23	9.92	0.59	715.65	86.42	2.27
73	JNE 1	99.99	100.62	9.32	0.67	853.74	87.15	2.89
76	JNE 4	99.98	301.55	22.74	1.85	884.25	86.30	2.80
78	JNE 6	99.98	187.26	15.04	1.16	911.92	86.19	2.81
80	JNE 8	99.98	-49.93	-5.52	-0.41	774.46	81.12	3.02
83	JNE 11	99.99	-3.53	-0.31	-0.03	977.47	85.20	3.67
85	JNE 13	99.99	17.81	1.15	0.14	1292.61	84.67	5.06
87	JNE 15	99.96	-6.54	-0.67	-0.05	841.60	85.69	3.18
92	JNE 20	99.96	31.52	3.86	0.20	638.93	81.40	1.96

METHANOL SYSTEM

DAY No.	DATE	COD CONC. (g/L)	INFLUENT NOx (mg/L)	ANOXIC NOx (mg/L)	AEROBIC NOx (mg/L)	EFFLUENT NOx (mg/L)	INFLUENT NITRITE (mg/L)	ANOXIC NITRITE (mg/L)	AEROBIC NITRITE (mg/L)	EFFLUENT NITRITE (mg/L)
10	OCT 26	12.77	3.97	69.60	111.0	144.0				
12	OCT 28	12.77	1.51	69.10	108.5	111.0	0.68	3.00	11.60	12.50
17	NOV 2	28.02	4.80	112.00	166.0	157.0	2.02	0.21	2.18	0.26
19	NOV 4	28.02	4.80	130.00	182.0	181.0				
22	NOV 7	28.02	28.90	92.00	139.0	141.0				
24	NOV 9	28.02	6.10	108.00	164.0	161.0				
26	NOV 11	28.02	7.60	118.00	166.0	156.0	3.48	0.36	0.60	2.40
29	NOV 14	25.64	12.60	85.50	127.0	102.0	6.25	0.78	0.32	1.40
33	NOV 18	40.60	6.50	23.50	61.0	62.0	0.90	2.00	0.08	0.00
34	NOV 19	37.51	7.00	8.50	50.0	53.0		1.32	0.06	0.02
36	NOV 21	37.51	10.80	2.00	23.0	23.0	1.16	0.36	0.02	0.00
38	NOV 23	35.38	10.90	27.50	59.0	47.0	0.56	0.30	0.38	0.00
43	NOV 28	25.64	13.60	0.00	18.0	20.0	2.28	0.06	0.04	0.30
45	NOV 30	9.26	15.10	63.00	100.0	94.0	2.60	0.01	0.08	0.01
47	DEC 2	9.26	24.10	59.50	93.0	100.0	8.35	0.12	0.06	0.02
50	DEC 5	9.26	18.60	64.50	102.0	95.0	3.75	0.14	0.12	0.03
52	DEC 7	14.48	22.20	45.00	82.0	85.0	4.85	0.21	0.07	0.02
54	DEC 9	14.48	6.20	26.50	63.0	63.0	8.05	0.04	0.11	0.00
57	DEC 12	14.48	6.30	36.50	73.0	69.0	0.45	0.11	0.04	0.09
59	DEC 14	7.36	10.20	28.50	65.0	68.0	1.55	0.42	0.11	0.04
62	DEC 17	7.36	6.70	1.00	17.0	1.5	2.40	0.01	0.07	0.20
64	DEC 19	7.36	4.20	22.00	57.0	59.0	3.65	0.06	0.03	0.01
66	DEC 21	14.96	5.10	11.50	53.0	48.0	2.40	0.11	0.71	0.26
68	DEC 23	14.96	0.90	12.00	52.0	55.0	1.05	0.04	0.00	0.00
71	DEC 26	14.96	1.40	25.50	63.0	60.0	0.85	0.09	0.00	0.00
73	DEC 28	15.55	1.90	17.00	55.0	55.0	0.75	0.17	0.00	0.00
75	DEC 30	15.55	4.00	27.00	59.0	53.0	0.45	0.07	0.03	0.00
78	JAN 2	15.55	4.30	12.00	41.0	38.0	0.70	0.05	0.00	0.00
80	JAN 4	15.55	7.00	7.00	41.0	41.0	2.20	0.18	0.04	0.00
82	JAN 6	19.71	4.80	15.50	57.5	55.5	0.30	0.26	0.04	0.01
85	JAN 9	19.71	4.50	5.60	47.0	47.0	0.45	0.31	0.05	0.01
87	JAN 11	19.71	5.80	13.00	55.5	50.0	1.35	0.26	0.07	0.01
89	JAN 13	30.27	10.60	0.10	36.0	35.0	5.20	0.11	0.01	0.19
92	JAN 16	30.27	9.90	0.10	44.0	41.0	4.80	0.07	0.01	0.05
94	JAN 18	30.27	0.10	0.10	22.5	22.5	0.00	0.00	0.00	0.00
96	JAN 20	20.42	0.00	0.03	33.5	32.0	0.11	0.02	0.13	0.08
99	JAN 23	20.42	0.00	0.01	28.0	28.0	0.03	0.02	0.02	0.02
101	JAN 25	20.42	2.70	0.01	31.5	32.0	0.34	0.02	0.02	0.02
103	JAN 27	30.63	4.28	0.00	37.8	34.5	1.54	0.04	0.04	0.05
106	JAN 30	30.63	5.66	0.00	36.5	35.5	2.32	0.02	0.03	0.03
108	FEB 1	30.63	3.70	0.05	40.3	40.8	1.60	0.02	0.02	0.02
110	FEB 3	39.29	4.98	0.06	20.3	20.3	1.97	0.01	0.01	0.00
113	FEB 6	39.29	1.42	0.00	25.0	25.5	0.75	0.00	0.01	0.03
115	FEB 8	39.29	0.88	0.00	27.5	31.0	0.43	0.00	0.01	0.01
117	FEB 10	44.40	1.92	0.00	26.3	19.5	1.51	0.00	0.01	0.06
120	FEB 13	44.40	2.50	0.00	31.0	30.0	1.90	0.00	0.02	0.02
122	FEB 15	44.40	9.60	0.00	31.0	30.0	6.05	0.00	0.01	0.02
124	FEB 17	51.88	0.50	0.00	19.5	15.5	0.64	0.00	0.01	0.11

METHANOL SYSTEM

DAY No.	DATE	COD CONC. (g/L)	INFLUENT NOx (mg/L)	ANOXIC NOx (mg/L)	AEROBIC NOx (mg/L)	EFFLUENT NOx (mg/L)	INFLUENT NITRITE (mg/L)	ANOXIC NITRITE (mg/L)	AEROBIC NITRITE (mg/L)	EFFLUENT NITRITE (mg/L)
127	FEB 20	51.88	0.20	0.00	27.8	27.3	0.35	0.00	0.00	0.00
129	FEB 22	51.88	8.55	0.00	27.3	26.0	6.15	0.00	0.00	0.01
131	FEB 24	57.69	3.75	0.00	11.0	11.0	2.08	0.00	0.40	0.06
134	FEB 27	57.69	1.10	0.00	38.5	34.8	0.47	0.00	0.04	0.07
136	FEB 29	57.69	6.10	0.00	39.8	35.0	3.64	0.00	0.06	0.12
139	MAR 2	80.61	2.95	0.00	25.5	17.8	1.26	0.00	0.11	0.11
141	MAR 5	80.61	4.80	0.00	27.5	25.3	2.31	0.00	0.14	0.02
143	MAR 7	80.61	12.40	0.00	30.3	25.3	7.05	0.00	0.14	0.09

GLUCOSE SYSTEM

DAY No. DATE	INFLUENT NOx (mg/L)	ANOXIC NOx (mg/L)	AEROBIC NOx (mg/L)	EFFLUENT NOx (mg/L)	INFLUENT NITRITE (mg/L)	ANOXIC NITRITE (mg/L)	AEROBIC NITRITE (mg/L)	EFFLUENT NITRITE (mg/L)
10 OCT 26	3.97	71.90	104.0	104.0	---	---	---	---
12 OCT 28	1.51	54.30	81.5	88.9	0.68	5.85	3.10	3.24
17 NOV 2	4.80	88.50	127.0	106.0	2.02	7.35	2.88	6.95
19 NOV 4	4.80	114.00	159.0	153.0	---	---	---	---
22 NOV 7	28.90	120.00	157.0	157.0	---	---	---	---
24 NOV 9	6.10	107.00	150.0	150.0	---	---	---	---
26 NOV 11	7.60	127.00	173.0	164.0	3.48	9.90	0.85	1.05
29 NOV 14	12.60	108.00	149.0	135.0	6.25	9.55	0.80	0.80
33 NOV 18	6.50	64.50	100.0	101.0	0.90	19.00	0.50	0.15
34 NOV 19	7.00	50.00	84.0	90.0	---	20.80	0.75	0.10
36 NOV 21	10.80	24.00	48.0	45.0	1.16	14.30	0.05	0.05
38 NOV 23	10.90	62.00	112.0	86.0	0.56	14.30	0.15	0.05
43 NOV 28	13.60	36.00	64.0	48.0	2.38	20.80	0.80	1.48
45 NOV 30	15.10	76.00	123.0	111.0	2.60	11.00	0.86	0.20
47 DEC 2	24.10	95.00	128.0	124.0	8.35	15.20	0.71	0.18
50 DEC 5	18.60	96.50	129.0	132.0	3.75	12.40	0.34	0.26
52 DEC 7	22.20	92.00	125.0	125.0	4.85	13.70	0.33	0.26
54 DEC 9	6.20	72.50	99.0	99.0	8.05	10.50	1.36	0.18
57 DEC 12	6.30	77.00	110.0	109.0	0.45	12.00	0.26	0.63
59 DEC 14	10.20	72.00	109.0	114.0	1.55	22.40	0.89	0.63
62 DEC 17	6.70	37.00	72.0	70.0	2.40	18.50	0.94	0.46
64 DEC 19	4.20	37.00	74.0	71.0	3.65	20.60	4.49	1.81
66 DEC 21	5.10	66.00	102.0	100.0	2.40	14.30	0.23	0.23
68 DEC 23	0.90	65.00	111.0	103.0	1.05	21.30	9.45	4.70
71 DEC 26	1.40	69.50	104.0	104.0	0.85	18.90	3.30	0.93
73 DEC 28	1.90	70.50	108.0	108.0	0.75	21.30	3.10	0.62
75 DEC 30	4.00	60.50	94.0	96.0	0.45	21.20	1.11	0.45
78 JAN 2	4.30	57.00	89.0	87.0	0.70	18.50	0.04	0.33
80 JAN 4	7.00	49.00	82.0	81.0	2.20	19.80	1.25	0.35
82 JAN 6	4.80	0.09	37.0	37.0	0.30	0.06	0.32	0.71
85 JAN 9	4.50	11.80	46.5	37.5	0.45	10.30	0.63	0.13
87 JAN 11	5.80	20.30	59.5	58.5	1.35	16.60	1.53	0.83
89 JAN 13	10.60	40.30	76.5	66.5	5.20	17.80	4.56	2.61
92 JAN 16	9.90	61.50	102.0	85.5	4.80	10.70	2.32	4.36
94 JAN 18	0.10	4.00	40.0	54.5	0.00	4.20	0.11	0.38
96 JAN 20	0.00	0.05	28.0	26.5	0.11	0.02	0.14	0.18
99 JAN 23	0.00	0.01	26.0	26.0	0.03	0.02	0.04	0.10
101 JAN 25	2.70	0.17	31.0	28.5	0.34	0.16	0.05	0.11
103 JAN 27	4.28	33.50	73.8	60.8	1.54	11.30	0.60	0.72
106 JAN 30	5.66	47.50	91.0	83.0	2.32	6.20	0.40	0.50
108 FEB 1	3.70	57.00	103.0	97.0	1.60	6.50	0.85	1.00
110 FEB 3	4.98	0.06	24.5	18.8	1.97	0.02	0.28	0.23
113 FEB 6	1.42	0.00	21.8	23.0	0.75	0.00	0.21	0.11
115 FEB 8	0.88	0.00	23.5	23.5	0.43	0.00	0.15	0.11
117 FEB 10	1.92	0.00	18.3	25.3	1.51	0.00	0.11	0.02
120 FEB 13	2.50	0.00	31.0	30.3	1.90	0.00	0.26	0.18
122 FEB 15	9.60	0.00	28.3	26.8	6.05	0.00	0.16	0.20
124 FEB 17	0.50	0.00	24.3	20.3	0.64	0.00	0.86	0.42

GLUCOSE SYSTEM

DAY No. DATE	INFLUENT NOx (mg/L)	ANOXIC NOx (mg/L)	AEROBIC NOx (mg/L)	EFFLUENT NOx (mg/L)	INFLUENT NITRITE (mg/L)	ANOXIC NITRITE (mg/L)	AEROBIC NITRITE (mg/L)	EFFLUENT NITRITE (mg/L)
127 FEB 20	0.20	0.00	25.5	22.8	0.35	0.00	0.60	0.75
129 FEB 22	8.55	61.50	96.5	51.5	6.15	10.10	15.80	7.15
131 FEB 24	3.75	78.30	101.5	106.0	2.08	71.30	86.80	89.50
134 FEB 27	1.10	56.80	88.5	37.5	0.47	33.50	45.00	19.30
136 FEB 29	6.10	109.80	157.5	143.5	3.64	60.00	74.80	71.80
138 MAR 2	2.95	134.00	171.0	172.0	1.26	62.50	80.50	79.00
141 MAR 5	4.80	172.00	210.0	207.0	2.31	47.50	57.50	66.50
143 MAR 7	12.40	173.00	219.0	220.0	7.05	25.50	32.00	27.50

ACETATE SYSTEM

DAY No. DATE	INFLUENT NOx (mg/L)	ANOXIC NOx (mg/L)	AEROBIC NOx (mg/L)	EFFLUENT NOx (mg/L)	INFLUENT NITRITE (mg/L)	ANOXIC NITRITE (mg/L)	AEROBIC NITRITE (mg/L)	EFFLUENT NITRITE (mg/L)
0								
17 APR 6	2.80	115.00	139.0	147.0	1.07	0.09	0.44	0.03
20 APR 9	5.75	142.00	182.0	186.0	3.60	0.16	0.11	0.01
22 APR 11	17.10	152.00	184.0	187.0	11.35	1.07	0.11	0.03
24 APR 13	11.70	16.00	51.0	91.5	6.30	8.80	0.40	2.68
27 APR 16	16.10	0.02	32.5	32.5	10.50	0.04	0.25	0.04
29 APR 18	37.60	0.03	30.5	30.5	25.80	0.06	0.08	0.02
31 APR 20	7.80	18.60	50.5	45.0	2.50	0.03	0.08	0.61
34 APR 23	11.80	11.00	52.5	48.0	4.60	0.51	0.13	0.00
41 APR 30	7.00	64.00	107.0	109.0	2.00	25.00	2.15	0.04
43 MAY 2	11.40	76.00	116.0	115.0	2.60	24.40	0.93	0.04
45 MAY 4	4.70	65.80	99.8	101.0	1.31	30.70	1.86	0.06
48 MAY 7	3.40	49.80	81.3	85.8	1.06	30.30	2.59	0.05
50 MAY 9	19.70	41.30	79.0	85.0	7.40	35.80	3.18	0.09
55 MAY 14	5.60	85.80	130.0	72.0	0.80	24.70	5.70	0.42
57 MAY 16	4.00	0.00	35.0	73.5	2.03	0.03	1.11	0.42
59 MAY 18	4.50	0.02	37.8	38.5	2.87	0.00	0.21	0.00
62 MAY 21	5.60	0.02	37.7	31.6	3.08	0.00	0.43	0.01
64 MAY 23	14.80	0.02	37.2	37.2	7.38	0.00	0.92	0.00
69 MAY 28	15.80	0.04	33.3	34.0	1.79	0.00	0.85	0.00
71 MAY 30	8.30	0.05	35.8	37.8	0.27	0.00	1.15	0.00
73 JNE 1	0.80	0.03	45.5	47.8	0.30	0.03	3.31	0.37
76 JNE 4	6.00	0.05	52.8	54.8	2.10	0.05	3.40	2.31
78 JNE 6	3.00	0.03	43.5	45.3	1.20	0.03	2.69	0.11
80 JNE 8	3.00	0.01	35.5	36.0	1.70	0.00	2.18	0.06
83 JNE 11	5.10	0.01	31.8	34.8	2.66	0.00	0.88	0.04
85 JNE 13	11.20	0.05	38.3	39.8	5.40	0.04	2.88	1.12
87 JNE 15	6.80	0.03	34.0	13.0	2.30	0.05	1.69	1.05
92 JNE 20	13.10	0.07	18.3	2.8	6.20	0.12	2.26	0.82

YEAST WASTE SYSTEM

DAY No. DATE	INFLUENT NOx (mg/L)	ANOXIC NOx (mg/L)	AEROBIC NOx (mg/L)	EFFLUENT NOx (mg/L)	INFLUENT NITRITE (mg/L)	ANOXIC NITRITE (mg/L)	AEROBIC NITRITE (mg/L)	EFFLUENT NITRITE (mg/L)
0								
34 APR 23	11.80	62.30	106.0	109.0	4.60	0.49	0.06	0.04
41 APR 30	7.00	98.80	146.0	142.0	2.00	0.04	0.14	0.01
43 MAY 2	11.40	101.00	150.0	140.0	2.60	0.04	0.22	0.01
45 MAY 4	4.70	83.30	134.0	139.0	1.31	0.13	0.91	0.04
48 MAY 7	3.40	74.80	134.0	131.0	1.06	2.33	0.21	0.07
50 MAY 9	19.70	71.80	114.0	117.0	7.40	0.07	0.11	0.07
55 MAY 14	5.60	96.30	164.0	158.0	0.80	0.30	0.30	0.10
57 MAY 16	4.00	0.09	69.8	120.0	2.03	0.07	0.13	0.30
59 MAY 18	4.50	0.05	47.8	51.8	2.87	0.00	0.03	0.01
62 MAY 21	5.60	0.47	52.8	55.9	3.08	0.03	0.06	0.25
64 MAY 23	14.80	0.17	49.6	51.8	7.38	0.01	0.03	0.00
69 MAY 28	15.80	0.00	59.8	105.0	1.79	0.00	0.23	0.20
71 MAY 30	8.30	0.05	47.8	46.5	0.27	0.00	0.16	0.11
73 JNE 1	0.80	0.05	54.3	54.3	0.30	0.03	0.86	0.36
76 JNE 4	6.00	0.08	50.0	31.8	2.10	0.04	0.30	0.28
78 JNE 6	3.00	0.05	46.0	30.8	1.20	0.03	2.27	0.38
80 JNE 8	3.00	0.03	46.5	30.5	1.70	0.02	13.80	16.00
83 JNE 11	5.10	0.02	47.0	31.5	2.66	0.01	20.00	12.90
85 JNE 13	11.20	0.04	33.5	183.0	5.40	0.04	22.80	10.60
87 JNE 15	6.80	0.08	38.3	7.8	3.25	0.05	16.10	5.20
92 JNE 20	13.10	0.06	21.0	6.3	7.85	0.25	7.80	4.30

METHANOL SYSTEM

DAY No.	DATE	NITIF. (mg/d)	NITRIF. %	UNIT NITRIF (mg/hr/gVSS)	DENITRF. (mg/d)	DENITRF. %	UNIT DENITRIF. (mg/hr/gVSS)	COD:NOx
10	OCT 26	618.52	82.80	8.48	699.85	40.23	21.13	0.83
12	OCT 28	613.06	61.28	9.60	314.73	22.64	10.09	0.41
17	NOV 2	796.50	113.68	13.83	172.14	9.44	5.78	0.65
19	NOV 4	808.08	500.00	14.03	168.79	7.71	5.67	0.51
22	NOV 7	706.88	118.99	12.59	396.18	22.26	14.35	0.76
24	NOV 9	834.40	81.16	14.25	340.49	17.46	13.51	0.66
26	NOV 11	724.32	96.00	11.43	114.86	6.06	4.02	0.44
29	NOV 14	583.91	92.22	9.22	-38.73	-3.33	-1.36	0.90
33	NOV 18	559.50	105.63	8.27	412.36	54.05	13.22	3.09
34	NOV 19	632.05	133.87	8.55	529.16	80.34	16.70	3.65
36	NOV 21	308.91	67.74	4.63	275.85	90.36	8.51	8.48
38	NOV 23	462.74	94.03	6.06	189.35	31.91	4.81	3.58
43	NOV 28	268.92	25.35	3.10	279.98	100.00	6.94	12.82
45	NOV 30	547.23	96.10	7.08	238.36	20.37	6.95	1.03
47	DEC 2	497.48	100.00	6.28	385.11	30.36	10.56	1.03
50	DEC 5	525.75	100.00	8.83	199.94	18.11	7.12	1.11
52	DEC 7	544.27	104.23	6.96	403.14	37.85	8.23	1.60
54	DEC 9	530.71	93.59	6.82	359.17	48.24	9.98	2.47
57	DEC 12	539.84	92.41	7.30	290.69	35.00	7.76	2.23
59	DEC 14	544.95	92.41	7.37	420.38	49.70	11.23	1.08
62	DEC 17	237.28	23.02	3.21	23.38	61.19	0.62	24.66
64	DEC 19	517.65	90.91	5.71	394.34	54.79	9.78	1.37
66	DEC 21	628.73	88.30	6.79	417.84	70.57	9.12	3.23
68	DEC 23	594.40	94.12	5.81	484.25	73.09	10.19	3.12
71	DEC 26	555.00	93.05	6.46	346.52	47.87	9.50	2.54
73	DEC 28	566.96	95.48	6.60	411.91	61.89	11.29	2.87
75	DEC 30	472.32	82.47	5.69	236.76	37.27	5.91	3.28
78	JAN 2	432.10	78.80	4.87	289.67	61.83	7.06	4.32
80	JAN 4	526.66	91.89	5.90	424.32	79.65	8.62	3.82
82	JAN 6	632.10	94.38	6.62	447.37	65.73	11.03	4.17
85	JAN 9	622.24	96.73	7.32	493.47	85.43	12.93	4.61
87	JAN 11	637.93	97.70	6.36	422.33	68.40	10.06	4.31
89	JAN 13	542.09	78.38	-4.67	451.35	99.67	9.09	9.36
92	JAN 16	664.65	101.39	5.89	521.57	99.71	12.01	5.84
94	JAN 18	327.94	72.26	2.55	268.80	99.46	5.38	15.68
96	JAN 20	524.14	85.17	4.28	383.53	99.88	6.92	7.71
99	JAN 23	426.85	90.29	3.43	335.85	99.95	5.95	8.33
101	JAN 25	477.07	99.97	3.91	392.35	99.96	6.67	6.97
103	JAN 27	573.80	86.90	4.25	427.61	100.00	6.41	10.17
106	JAN 30	537.65	93.59	3.94	441.45	100.00	6.48	9.30
108	FEB 1	596.51	99.88	4.21	499.29	99.85	7.40	7.90
110	FEB 3	300.77	47.85	1.85	256.95	99.65	3.26	21.18
113	FEB 6	373.75	57.74	2.13	310.19	100.00	3.79	16.85
115	FEB 8	418.00	75.34	2.30	374.82	100.00	4.42	14.15
117	FEB 10	396.08	74.50	1.95	239.88	100.00	2.43	26.10
120	FEB 13	462.83	95.38	2.30	367.33	100.00	3.71	16.08
122	FEB 15	462.83	102.31	2.32	388.13	100.00	3.95	14.53
124	FEB 17	293.87	53.42	1.40	187.54	100.00	1.82	39.01

METHANOL SYSTEM

DAY No.	DATE	NITIF. (mg/d)	NITRIF. %	UNIT NITRIF (mg/hr/gVSS)	DENITRF. (mg/d)	DENITRF. %	UNIT DENITRIF. (mg/hr/gVSS)	COD:NOx
127	FEB 20	413.94	87.42	1.87	328.18	100.00	3.15	20.71
129	FEB 22	420.42	92.54	1.89	349.45	100.00	3.08	19.75
131	FEB 24	163.68	29.73	0.71	142.80	100.00	1.26	56.56
134	FEB 27	562.87	98.72	2.49	404.31	100.00	3.66	19.55
136	FEB 29	575.11	100.00	2.30	421.07	100.00	3.47	18.22
139	MAR 2	387.86	65.72	1.31	223.07	100.00	1.72	52.40
141	MAR 5	413.88	74.73	1.49	318.24	100.00	2.25	34.70
143	MAR 7	446.62	81.23	1.67	334.48	100.00	2.52	32.29

GLUCOSE SYSTEM

DAY No.	DATE	NITRIF. (mg/d)	NITRIF. %	UNIT NITRIF. (mg/hr/gVSS)	DENITR. (mg/d)	DENITR. %	UNIT DENITR. (mg/hr/gVSS)	COD:NOx
10	OCT 26	511.7	70.86	9.19	237.59	17.17	0.62	1.22
12	OCT 28	430.3	31.26	7.06	255.49	22.92	0.75	0.57
17	NOV 2	572.5	92.77	9.39	-30.22	-2.35	-0.08	0.98
19	NOV 4	669.6	105.88	10.98	153.50	8.30	0.27	0.71
22	NOV 7	548.7	102.78	8.01	186.19	9.47	0.28	0.76
24	NOV 9	634.3	91.49	7.51	238.53	13.13	0.31	0.70
26	NOV 11	678.0	97.87	7.17	79.31	4.06	0.09	0.50
29	NOV 14	607.2	117.14	6.42	55.93	3.38	0.07	0.77
33	NOV 18	526.5	112.70	4.08	273.86	22.26	0.34	1.90
34	NOV 19	506.6	109.68	3.92	355.30	32.29	0.50	2.25
36	NOV 21	354.0	77.42	2.69	215.70	37.86	0.58	4.69
38	NOV 23	737.0	147.06	5.58	147.99	13.94	0.21	1.98
43	NOV 28	404.9	76.71	2.86	72.38	12.21	0.17	4.49
45	NOV 30	673.0	118.99	4.87	232.68	17.61	0.25	1.07
47	DEC 2	493.0	91.67	3.42	139.55	8.95	0.12	1.01
50	DEC 5	487.2	87.84	3.77	193.08	11.78	0.18	0.87
52	DEC 7	477.8	91.67	3.61	173.55	11.53	0.17	1.13
54	DEC 9	381.6	72.60	2.80	114.34	9.87	0.14	1.67
57	DEC 12	482.5	84.62	3.74	174.12	13.40	0.21	1.47
59	DEC 14	552.8	101.37	4.28	322.31	23.06	0.36	1.71
62	DEC 17	513.5	93.33	3.98	299.91	35.59	0.55	3.06
64	DEC 19	552.0	73.27	8.71	312.22	36.13	1.14	3.08
66	DEC 21	535.3	93.51	3.24	233.22	19.20	0.23	1.68
68	DEC 23	699.7	101.10	4.43	250.24	20.20	0.26	1.76
71	DEC 26	520.6	82.14	3.65	228.20	17.87	0.25	1.66
73	DEC 28	569.6	91.46	4.00	231.17	17.75	0.25	1.69
75	DEC 30	497.5	94.37	3.12	264.98	22.78	0.29	2.09
78	JAN 2	475.8	94.12	2.92	208.75	19.76	0.24	2.18
80	JAN 4	460.0	88.47	2.58	231.48	25.31	0.28	2.60
82	JAN 6	535.6	80.24	3.03	439.29	99.70	1.13	8.27
85	JAN 9	510.1	84.63	3.01	280.77	61.81	0.73	7.66
87	JAN 11	575.5	95.61	3.05	406.89	57.72	0.61	4.97
89	JAN 13	545.5	97.05	2.93	223.22	26.88	0.29	3.75
92	JAN 16	605.5	100.50	3.43	135.78	12.87	0.15	2.12
94	JAN 18	550.8	127.21	3.18	619.24	91.01	1.05	4.50
96	JAN 20	417.3	90.16	2.42	317.25	99.77	1.16	9.00
99	JAN 23	377.1	91.19	2.33	299.37	99.95	1.24	9.12
101	JAN 25	456.0	106.31	2.87	340.83	99.27	1.25	7.71
103	JAN 27	596.8	94.82	3.70	231.93	31.86	0.40	3.76
106	JAN 30	684.7	108.75	3.95	325.20	30.31	0.35	2.37
108	FEB 1	694.6	117.95	4.12	314.77	26.78	0.32	2.15
110	FEB 3	370.8	60.65	1.88	240.48	99.62	1.01	17.11
113	FEB 6	324.8	58.45	1.49	280.12	100.00	0.92	14.05
115	FEB 8	348.3	74.60	1.69	284.48	100.00	0.97	14.18
117	FEB 10	268.5	66.55	1.21	308.73	100.00	0.90	15.53
120	FEB 13	462.8	109.54	2.04	370.93	100.00	0.88	12.12
122	FEB 15	417.4	114.11	1.92	348.00	100.00	0.92	12.48
124	FEB 17	363.8	86.79	1.45	245.09	100.00	0.80	23.03

GLUCOSE SYSTEM

DAY No. DATE	NITRIF. (mg/d)	NITRIF. %	UNIT NITRIF. (mg/hr/gVSS)	DENITR. (mg/d)	DENITR. %	UNIT DENITR. (mg/hr/gVSS)	COD:NOx
127 FEB 20	378.7	100.00	1.44	274.17	100.00	0.76	19.15
129 FEB 22	517.3	94.59	2.34	-267.20	-41.64	-0.38	8.18
131 FEB 24	349.2	41.80	1.21	105.02	8.18	0.06	10.50
134 FEB 27	472.0	43.72	2.76	-392.57	-86.63	-1.01	0.00
136 FEB 29	714.1	72.82	4.25	96.41	5.54	0.07	0.00
138 MAR 2	560.9	60.66	4.03	41.88	2.02	0.03	0.00
141 MAR 5	567.3	94.29	6.25	-69.90	-2.80	-0.06	0.00
143 MAR 7	687.2	115.00	9.36	91.84	3.43	0.09	0.00

ACETATE SYSTEM

DAY No. DATE	NITRIF. (mg/d)	NITRIF. %	UNIT NITRIF. (mg/hr/gVSS)	DENITR. (mg/d)	DENITR. %	UNIT DENITR. (mg/hr/gVSS)	COD:NOx
0							
17 APR 6	387.6	60.76	4.08	39.50	2.08	0.04	0.00
20 APR 9	599.2	100.50	9.39	121.98	5.42	0.17	0.00
22 APR 11	478.7	90.14	6.74	20.70	0.90	0.03	0.00
24 APR 13	534.5	147.06	7.28	891.94	78.50	2.14	3.88
27 APR 16	487.8	93.33	4.89	438.32	99.93	2.00	7.35
29 APR 18	443.6	103.29	4.22	463.52	99.91	1.90	6.16
31 APR 20	479.1	87.40	4.23	284.18	50.43	0.89	3.08
34 APR 23	598.8	120.29	5.75	428.57	72.97	1.40	2.87
41 APR 30	539.7	80.37	6.61	263.85	24.73	0.61	1.96
43 MAY 2	599.6	94.12	6.94	274.85	19.44	0.45	1.44
45 MAY 4	534.1	79.44	5.92	265.06	20.41	0.45	1.97
48 MAY 7	472.2	87.99	5.26	293.26	28.20	0.63	2.58
50 MAY 9	565.1	109.28	7.18	459.82	42.62	1.08	2.61
55 MAY 14	659.9	102.79	5.68	295.41	18.74	0.32	3.33
57 MAY 16	519.1	89.06	4.26	893.32	100.00	1.64	7.98
59 MAY 18	571.6	101.29	4.73	483.94	99.94	1.65	7.83
62 MAY 21	533.5	100.48	4.28	378.53	99.93	1.60	10.21
64 MAY 23	561.0	97.08	4.17	491.83	99.94	1.49	7.25
69 MAY 28	508.2	92.91	3.53	459.21	99.87	1.39	10.57
71 MAY 30	546.6	92.14	3.76	480.14	99.84	1.37	8.71
73 JNE 1	684.8	86.94	4.72	575.60	99.92	1.38	8.14
76 JNE 4	803.9	101.83	5.15	676.28	99.89	1.28	7.93
78 JNE 6	668.6	93.89	4.25	553.28	99.92	1.27	11.91
80 JNE 8	531.3	78.34	3.20	440.76	99.97	1.20	15.77
83 JNE 11	473.0	83.00	2.82	432.14	99.97	1.19	16.70
85 JNE 13	588.7	92.17	3.40	514.80	99.85	1.15	15.16
87 JNE 15	523.1	78.27	3.25	178.66	99.74	1.24	61.72
92 JNE 20	272.4	50.92	2.81	70.47	98.54	2.03	136.33

YEAST WASTE SYSTEM

DAY No. DATE	NITRIF. (mg/d)	NITRIF. %	UNIT NITRIF. (mg/hr/gVSS)	DENITR. (mg/d)	DENITR. %	UNIT DENITR. (mg/hr/gVSS)	COD:NOx
0							
34 APR 23	577.3	108.71	6.64	359.33	30.39	0.70	1.12
41 APR 30	645.7	83.10	7.56	229.18	14.50	0.34	0.85
43 MAY 2	685.5	86.88	6.93	161.10	10.23	0.21	1.04
45 MAY 4	713.9	81.51	6.76	370.61	24.01	0.45	4.20
48 MAY 7	790.9	132.74	4.21	406.31	28.91	0.31	0.00
50 MAY 9	577.3	77.72	3.74	314.76	24.27	0.31	3.41
55 MAY 14	890.3	121.33	4.80	380.06	23.08	0.25	2.56
57 MAY 16	974.5	113.17	4.33	1330.66	99.91	0.89	7.13
59 MAY 18	626.0	79.98	2.44	557.83	99.88	0.78	17.77
62 MAY 21	719.5	89.91	2.63	613.78	98.96	0.72	9.19
64 MAY 23	680.2	93.80	2.88	608.31	99.62	0.84	8.08
69 MAY 28	827.6	105.47	2.68	1182.03	100.00	0.65	11.41
71 MAY 30	671.4	81.07	2.13	536.20	99.87	0.63	15.91
73 JNE 1	734.0	74.93	2.48	587.95	99.89	0.68	14.48
76 JNE 4	673.9	65.77	2.13	358.56	99.70	0.63	41.71
78 JNE 6	621.7	58.76	1.91	326.81	99.79	0.61	32.04
80 JNE 8	606.9	63.57	2.37	335.79	99.88	0.78	24.05
83 JNE 11	643.2	56.06	2.41	359.95	99.92	0.75	41.93
85 JNE 13	486.5	31.87	1.91	2052.07	99.97	0.78	9.65
87 JNE 15	537.0	54.68	2.03	104.87	98.94	0.75	193.83
92 JNE 20	288.3	36.74	0.88	104.21	99.21	0.61	196.75

METHANOL SYSTEM

DAY No.	DATE	INFLUENT BOD5 (mg/L)	ANOXIC BOD5 (mg/L)	AEROBIC BOD5 (mg/L)	EFFLUENT BOD5 (mg/L)
0					
13	OCT 29	25	24	12	10
21	NOV 6	31	28	17	8
24	NOV 9	26	24	14	8
28	NOV 13	21	32	15	8
31	NOV 16	19	19	10	6
35	NOV 20	17	28	14	4
38	NOV 23	15	13	9	4
42	NOV 27	13	10	10	3
45	NOV 30	20	12	10	4
49	DEC 4	27	12	12	4
52	DEC 7	21	15.	10	4
56	DEC 11	15	12	7	3
59	DEC 14	13	10	8	2
63	DEC 18	27	13	9	3
66	DEC 21	23	11	9	3
70	DEC 25	20	9	7	2
73	DEC 28	12	12	9	3
78	JAN 2	11	11	6	2
80	JAN 4	17	12	8	3
84	JAN 8	22	45	9	4
87	JAN 11	23	12	9	4
91	JAN 15	25	90	7	4
94	JAN 18	50	60	8	3
98	JAN 22	58	59	7	4
101	JAN 25	19	44	8	4
105	JAN 29	13	110	7	4
108	FEB 1	33	57	7	6
112	FEB 5	23	100	62	5
115	FEB 8	28	92	7	5
119	FEB 12	31	176	10	3
122	FEB 15	18	135	8	6
126	FEB 19	21	216	12	3
129	FEB 22	18	156	8	4
133	FEB 26	22	237	98	6
136	FEB 29	26	216	8	3
140	MAR 4	25	379	13	5
143	MAR 7	22	310	9	6

METHANOL SYSTEM

DAY No.	DATE	TOTAL BOD REMOVAL %	ANOXIC BOD REMOVAL (mg/d)	ANOXIC BOD REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC BOD REMOVAL (mg/d)	AEROBIC BOD REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
13	OCT 29	95.22	390.21	58.36	12.51	339.60	50.00	5.32
21	NOV 6	98.25	1152.27	76.87	41.75	470.47	39.29	8.38
24	NOV 9	98.30	1102.72	79.47	38.61	429.20	41.67	6.77
28	NOV 13	99.00	2083.19	84.33	72.94	715.87	53.13	11.30
31	NOV 16	98.87	1282.96	85.18	41.12	361.89	47.37	5.35
35	NOV 20	99.51	2190.41	84.92	67.61	737.38	50.00	11.05
38	NOV 23	99.50	2020.18	92.93	51.33	200.28	30.77	2.62
42	NOV 27	99.25	1270.88	90.77	31.52	0.00	0.00	0.00
45	NOV 30	99.11	1130.12	88.93	32.93	48.10	16.67	0.62
49	DEC 4	99.16	1197.87	89.62	42.66	0.00	0.00	0.00
52	DEC 7	99.33	1596.98	89.60	32.62	145.95	33.33	1.87
56	DEC 11	99.56	1915.91	92.69	51.17	146.25	41.67	1.98
59	DEC 14	99.38	825.43	86.29	22.05	44.58	20.00	0.60
63	DEC 18	99.13	932.70	84.53	23.13	90.12	30.77	0.99
66	DEC 21	99.52	1856.68	92.98	40.50	60.22	18.18	0.65
70	DEC 25	99.73	1920.97	94.39	52.66	59.42	22.22	0.69
73	DEC 28	99.55	1804.65	92.24	45.03	91.41	25.00	1.10
78	JAN 2	99.72	1913.50	92.92	46.63	152.25	45.45	1.71
80	JAN 4	99.57	1939.78	92.49	39.43	124.16	33.33	1.39
84	JAN 8	99.57	2197.71	77.43	57.59	1250.64	80.00	14.72
87	JAN 11	99.56	2597.96	94.74	61.86	104.16	25.00	1.04
91	JAN 15	99.73	3247.76	71.08	74.76	3764.05	92.22	33.37
94	JAN 18	99.82	3527.40	80.58	70.66	2335.32	86.67	18.15
98	JAN 22	99.46	1317.85	61.01	23.37	1836.12	88.14	14.77
101	JAN 25	99.55	2177.53	77.53	37.03	1280.52	81.82	10.50
105	JAN 29	99.74	2652.71	62.51	38.92	4679.29	93.64	34.33
108	FEB 1	99.58	3271.59	80.56	48.51	2272.50	87.72	16.05
112	FEB 5	99.72	4161.96	73.97	50.85	2066.44	38.00	11.79
115	FEB 8	99.70	4055.35	74.96	47.87	4631.65	92.39	25.46
119	FEB 12	99.86	3657.70	58.30	36.99	9863.72	94.32	49.04
122	FEB 15	99.69	3747.99	65.65	38.18	7534.91	94.07	37.83
126	FEB 19	99.87	3962.66	55.19	38.04	13647.60	94.44	61.81
129	FEB 22	99.83	4600.12	66.05	35.04	9957.44	94.87	38.78
133	FEB 26	99.78	4704.39	57.23	42.61	10112.25	58.65	44.73
136	FEB 29	99.89	4662.31	60.10	38.39	15005.12	96.30	60.00
140	MAR 4	99.88	5647.92	49.68	39.95	35073.78	96.57	126.42
143	MAR 7	99.84	6368.46	58.51	47.90	28700.35	97.10	107.15

GLUCOSE SYSTEM

DAY No.	DATE	INFLUENT BOD5 (mg/L)	ANOXIC BOD5 (mg/L)	AEROBIC BOD5 (mg/L)	EFFLUENT BOD5 (mg/L)
0					
13	OCT 29	25	20	12	9
21	NOV 6	31	29	16	6
24	NOV 9	36	38	23	9
28	NOV 13	21	33	17	11
31	NOV 16	19	25	11	7
35	NOV 20	17	26	13	4
38	NOV 23	15	14	11	4
42	NOV 27	13	15	10	3
45	NOV 30	20	14	9	4
49	DEC 4	27	16	11	4
52	DEC 7	21	24	9	4
56	DEC 11	15	14	6	3
59	DEC 14	13	15	7	3
63	DEC 18	27	16	11	3
66	DEC 21	24	14	8	3
70	DEC 25	20	13	8	2
73	DEC 28	12	12	8	3
78	JAN 2	11	13	5	2
80	JAN 4	16	21	7	3
84	JAN 8	22	17	9	3
87	JAN 11	23	20	8	4
91	JAN 15	25	25	9	4
94	JAN 18	50	24	9	4
98	JAN 22	58	18	8	3
101	JAN 25	19	14	8	3
105	JAN 29	13	12	6	4
108	FEB 1	33	14	7	7
112	FEB 5	23	18	10	4
115	FEB 8	28	13	9	6
119	FEB 12	31	54	9	4
122	FEB 15	18	23	12	6
126	FEB 19	21	73	12	5
129	FEB 22	18	22	11	5
133	FEB 26	22	252	12	125
136	FEB 29	26	36	16	8
140	MAR 4	25	70	83	65
143	MAR 7	22	33	41	31

GLUCOSE SYSTEM

DAY No.	DATE	TOTAL BOD REMOVAL %	ANOXIC BOD REMOVAL (mg/d)	ANOXIC BOD REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC BOD REMOVAL (mg/d)	AEROBIC BOD REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
13	OCT 29	96.11	558.61	63.18	16.63	586.24	40.00	9.62
21	NOV 6	98.92	1262.45	75.12	35.33	954.46	44.83	13.93
24	NOV 9	98.18	910.21	61.89	20.39	956.25	39.47	11.32
28	NOV 13	98.95	2692.72	84.55	55.82	2094.56	48.48	22.15
31	NOV 16	98.86	1389.84	79.34	23.16	1210.72	56.00	10.34
35	NOV 20	99.56	2298.87	85.59	30.60	1389.57	50.00	10.57
38	NOV 23	99.49	1981.1	90.57	28.37	272.22	21.43	2.06
42	NOV 27	99.65	2524.93	91.61	33.29	562.10	33.33	3.97
45	NOV 30	99.24	1311.92	86.74	17.30	681.60	35.71	4.93
49	DEC 4	99.27	1346.24	85.25	19.75	702.80	31.25	5.44
52	DEC 7	99.33	1463.3	80.81	20.39	1852.20	62.50	13.98
56	DEC 11	99.58	1883.23	89.89	27.34	1153.04	57.14	8.93
59	DEC 14	99.64	2240.7	90.91	32.53	1031.52	53.33	7.99
63	DEC 18	99.69	2608.68	91.85	37.87	722.30	31.25	5.59
66	DEC 21	99.59	1941.64	90.32	22.10	797.22	42.86	4.83
70	DEC 25	99.76	2017.79	91.40	25.79	688.00	38.46	4.83
73	DEC 28	99.57	2094.25	91.99	24.86	520.76	33.33	3.27
78	JAN 2	99.75	2160.26	91.79	24.73	1078.96	61.54	6.63
80	JAN 4	99.64	2161.38	88.07	25.66	1931.16	66.67	10.82
84	JAN 8	99.76	3428.66	92.91	37.35	1155.20	47.06	6.82
87	JAN 11	99.67	3325.92	91.89	33.31	1688.16	60.00	8.95
91	JAN 15	99.63	3001.75	88.84	32.83	2433.28	64.00	13.78
94	JAN 18	99.65	2887.47	88.72	32.96	2164.50	62.50	12.49
98	JAN 22	99.57	1856.39	87.51	21.25	1037.20	55.56	6.41
101	JAN 25	99.66	2531.52	92.44	29.06	826.74	42.86	5.20
105	JAN 29	99.54	2536.67	93.35	27.96	846.30	50.00	4.88
108	FEB 1	99.17	2500.17	92.20	25.16	952.70	50.00	5.65
112	FEB 5	99.72	4075.75	93.80	36.52	1159.76	44.44	5.32
115	FEB 8	99.59	3992.02	95.40	38.41	555.28	30.77	2.69
119	FEB 12	99.76	4090.14	83.59	35.65	6384.15	83.33	28.12
122	FEB 15	99.62	4126.45	92.40	34.05	1438.25	47.83	6.60
126	FEB 19	99.72	4453.2	80.24	34.62	8480.22	83.56	32.36
129	FEB 22	99.74	5036.08	93.93	43.72	1482.58	50.00	6.71
133	FEB 26	97.30	11528.04	74.72	117.73	34675.20	95.24	202.92
136	FEB 29	69.23	-365.7	-211.12	-4.26	2719.40	55.56	16.19
140	MAR 4	-160.00	-181.95	-21.46	-3.93	-1855.23	-18.57	-20.45
143	MAR 7	-40.91	-56.34	-12.90	-1.42	-1095.52	-24.24	-14.92

ACETATE SYSTEM

DAY No.	DATE	INFLUENT BOD5 (mg/L)	ANOXIC BOD5 (mg/L)	AEROBIC BOD5 (mg/L)	EFFLUENT BOD5 (mg/L)
0					
19	APR 8	34	15	12	7
26	APR 15	25	55	9	3
30	APR 19	18	25	9	3
33	APR 22	18	10	6	5
40	APR 29	14	35	4	2
44	MAY 3	12	34	5	3
47	MAY 6	25	45	9	4
51	MAY 10	36	37	13	6
54	MAY 13	60	72	14	6
58	MAY 17	19	60	7	5
65	MAY 24	39	143	18	10
72	MAY 31	18	86	8	7
75	JNE 3	20	156	23	14
79	JNE 7	21	213	18	8
82	JNE 10	23	315	28	10
86	JNE 14	30	330	34	10
89	JNE 17	27	414	55	18
92	JNE 20	32	465	151	42

DAY No.	DATE	TOTAL BOD REMOVAL %	ANOXIC BOD REMOVAL (mg/d)	ANOXIC BOD REMOVAL %	UNIT ANOXIC REMOVA (mg/hr/gV	AEROBIC BOD REMOVAL (mg/d)	AEROBIC BOD REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
19	APR 8	79.41	20.43	8.34	0.68	413.91	20.00	6.48
26	APR 15	99.72	2522.58	75.39	49.81	5472.62	83.64	54.81
30	APR 19	99.72	2829.7	88.37	48.52	1838.40	64.00	16.23
33	APR 22	99.23	1853.36	92.74	35.10	538.00	40.00	5.17
40	APR 29	99.74	1874.58	78.88	45.95	4071.54	88.57	49.90
44	MAY 3	99.59	1718.92	77.17	37.70	3594.84	85.29	39.84
47	MAY 6	99.56	2162.57	76.22	48.71	4607.64	80.00	51.33
51	MAY 10	99.38	2592.39	82.02	65.07	3320.64	64.86	42.18
54	MAY 13	99.61	3762.06	77.64	62.45	8876.90	80.56	76.42
58	MAY 17	99.62	2960.13	76.86	50.97	6829.05	88.33	56.46
65	MAY 24	99.18	2061.75	48.52	30.25	15037.50	87.41	111.89
72	MAY 31	99.50	3484.63	72.50	44.95	9856.86	90.70	68.00
75	JNE 3	99.02	3116.06	55.99	39.11	15654.10	85.26	100.35
79	JNE 7	99.62	3881.66	54.39	47.15	29109.60	91.55	175.27
82	JNE 10	99.63	3581.12	43.25	42.03	42166.04	91.11	251.71
86	JNE 14	99.61	3711.84	42.46	49.89	45359.04	89.70	282.08
89	JNE 17	99.40	4364.04	40.67	58.66	52191.42	86.71	324.57
92	JNE 20	98.75	4708.77	40.40	136.25	44569.16	67.53	459.67

YEAST WASTE SYSTEM

DAY No.	DATE	YEAST WASTE SOLUTION BOD (g/L)	INFLUENT BOD5 (mg/L)	ANOXIC BOD5 (mg/L)	AEROBIC BOD5 (mg/L)	EFFLUENT BOD5 (mg/L)
0						
19	APR 8	0.000	34	16	12	7
26	APR 15	1.815	25	17	15	5
30	APR 19	1.035	18	34	16	14
33	APR 22	1.560	18	21	11	4
40	APR 29	1.173	14	11	4	2
44	MAY 3	3.000	12	21	13	4
47	MAY 6	1.440	25	22	10	4
51	MAY 10	1.223	36	32	16	7
54	MAY 13	1.355	60	46	14	8
58	MAY 17	1.965	19	51	11	5
65	MAY 24	1.795	39	49	11	12
72	MAY 31	3.480	18	64	10	5
75	JNE 3	5.500	20	336	65	35
79	JNE 7	7.125	21	385	35	30
82	JNE 10	7.800	23	458	29	23
86	JNE 14	7.200	30	395	26	13
89	JNE 17	7.400	27	396	27	9
92	JNE 20	10.000	32	660	20	55

DAY No.	DATE	TOTAL BOD REMOVAL %	ANOXIC BOD REMOVAL (mg/d)	ANOXIC BOD REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC BOD REMOVAL (mg/d)	AEROBIC BOD REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
19	APR 8	79.41	4.98	2.08	0.14	590.60	25.00	7.50
26	APR 15	99.18	1722.115	87.13	33.69	1927.92	11.76	18.59
30	APR 19	96.64	849.05	64.51	16.93	19219.32	52.94	186.23
33	APR 22	99.16	1151.56	79.94	26.66	8277.60	47.62	95.28
40	APR 29	99.45	979.239	86.37	22.42	6349.35	63.64	74.31
44	MAY 3	99.60	2872.73	90.70	48.46	8080.24	38.10	76.52
47	MAY 6	99.42	2017.17	86.88	19.28	17962.20	54.55	95.71
51	MAY 10	98.59	1270.641	74.42	16.49	18890.40	50.00	122.22
54	MAY 13	97.52	596.925	48.21	6.72	21406.08	69.57	115.53
58	MAY 17	99.40	1930.31	73.64	15.68	50382.00	78.43	196.56
65	MAY 24	97.29	796.83	53.58	5.73	26907.42	77.55	113.94
72	MAY 31	99.51	2458.3	73.05	16.44	50391.18	84.38	170.42
75	JNE 3	98.92	5479.3	54.34	33.57	463057.70	80.65	1463.89
79	JNE 7	98.46	1526.79	21.84	12.57	326266.50	90.91	1272.89
82	JNE 10	99.14	2656.86	29.63	19.46	478240.62	93.67	1795.20
86	JNE 14	99.54	3643.6	39.45	27.11	459095.04	93.42	1732.70
89	JNE 17	99.61	2486	30.36	18.50	394239.60	93.18	1487.92
92	JNE 20	98.67	2550.44	21.91	16.32	733932.80	95.97	2248.57

METHANOL SYSTEM

DAY No.	DATE	METHANOL SOLUTION COD (mg/L)	INFLUENT COD (mg/L)	ANOXIC COD (mg/L)	AEROBIC COD (mg/L)	EFFLUENT COD (mg/L)
0						
17	NOV 2	12.77	355	291	289	285
26	NOV 11	28.02	374	325	321	309
33	NOV 18	25.64	324	278	269	257
43	NOV 28	9.26	324	372	250	301
47	DEC 2	9.26	340	271	271	250
54	DEC 9	14.48	365	313	290	281
59	DEC 14	7.36	359	294	286	273
68	DEC 23	14.96	428	307	286	271
82	JAN 6	19.71	366	294	256	267
89	JAN 13	30.27	303	376	257	249
96	JAN 20	20.42	361	331	253	239
103	JAN 27	30.63	298	358	251	225
110	FEB 3	39.29	253	482	284	288
117	FEB 10	44.40	350	542	297	273
124	FEB 17	51.88	318	621	272	266
131	FEB 24	57.69	327	705	263	263
138	MAR 2	80.61	387	864	281	220
143	MAR 7	80.61	363	742	295	274

DAY No.	DATE	TOTAL COD REMOVAL %	ANOXIC COD REMOVAL (mg/d)	ANOXIC COD REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC COD REMOVAL (mg/d)	AEROBIC COD REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
17	NOV 2	45.30	673.94	25.89	22.65	55.04	0.69	0.96
26	NOV 11	52.17	800.01	27.11	28.01	172.44	1.23	2.72
33	NOV 18	69.16	1369.44	43.01	43.23	365.04	3.24	4.94
43	NOV 28	60.65	303.28	9.68	7.52	2952.40	32.80	33.98
47	DEC 2	68.68	1250.31	41.86	34.27	0.00	0.00	0.00
54	DEC 9	71.15	1627.36	42.94	45.20	667.46	7.35	8.58
59	DEC 14	59.28	851.09	30.79	22.16	178.32	2.72	2.19
68	DEC 23	76.43	1978.54	48.69	41.64	626.22	6.84	6.13
82	JAN 6	79.41	2733.84	57.33	67.40	1320.88	12.93	13.83
89	JAN 13	85.09	2487.50	41.81	50.07	5399.03	31.65	46.48
96	JAN 20	79.57	1966.70	38.14	35.47	2814.24	23.56	22.99
103	JAN 27	86.49	2562.66	42.62	38.41	4901.67	29.89	36.34
110	FEB 3	86.68	2478.37	35.36	31.48	10721.70	41.08	66.09
117	FEB 10	88.61	2444.88	29.94	24.73	14567.70	45.20	71.75
124	FEB 17	90.15	2124.87	23.33	20.59	23365.55	56.20	111.65
131	FEB 24	91.60	1683.96	17.23	14.80	32075.94	62.70	138.93
138	MAR 2	94.54	2429.28	17.81	18.78	55863.06	67.48	188.62
143	MAR 7	93.13	4168.64	32.82	31.35	42621.45	60.24	159.13

GLUCOSE SYSTEM

DAY No.	DATE	GLUCOSE SOLUTION COD (g/L)	INFLUENT COD (mg/L)	ANOXIC COD (mg/L)	AEROBIC COD (mg/L)	EFFLUENT COD (mg/L)
0						
17	NOV 2	25.79	355	306	304	304
26	NOV 11	25.79	374	333	331	317
33	NOV 18	25.79	324	274	270	261
43	NOV 28	11.56	324	271	262	267
47	DEC 2	11.56	340	273	263	245
54	DEC 9	15.62	365	310	274	276
59	DEC 14	20.97	359	294	288	264
68	DEC 23	17.33	428	305	262	251
82	JAN 6	27.82	366	271	262	256
89	JAN 13	23.75	303	257	245	229
96	JAN 20	21.51	361	287	265	233
103	JAN 27	20.87	298	272	227	221
110	FEB 3	32.53	253	373	312	284
117	FEB 10	37.45	350	392	284	278
124	FEB 17	43.76	318	465	276	258
131	FEB 24	107	327	1005	997	834
138	MAR 2	0	387	336	371	342
143	MAR 7	0	363	344	328	332

GLUCOSE SYSTEM

DAY No.	DATE	TOTAL COD REMOVAL %	ANOXIC COD REMOVAL (mg/d)	ANOXIC COD REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC COD REMOVAL (mg/d)	AEROBIC COD REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
17	NOV 2	61.78	1380.34	23.28	40.79	127.74	0.65	2.10
26	NOV 11	54.90	914.04	15.70	18.95	105.48	0.60	1.12
33	NOV 18	75.43	2074.49	33.80	28.53	383.32	1.46	2.97
43	NOV 28	68.48	1647.22	29.59	21.72	1327.14	3.32	9.37
47	DEC 2	71.99	1433.14	26.00	18.49	1509.40	3.66	10.48
54	DEC 9	73.40	1703.6	27.62	23.27	4982.40	11.61	36.55
59	DEC 14	77.48	2221.68	33.59	32.25	773.64	2.04	5.99
68	DEC 23	77.35	1930.41	29.38	22.79	6072.03	14.10	38.45
82	JAN 6	83.85	3755.67	48.85	38.83	1309.59	3.32	7.41
89	JAN 13	82.60	2916.47	42.96	29.71	1752.84	4.67	9.41
96	JAN 20	82.58	2429.65	36.18	28.92	3254.46	7.67	18.89
103	JAN 27	81.50	2213.51	35.46	25.62	6561.45	16.54	40.68
110	FEB 3	81.75	2682.91	32.16	25.29	8672.37	16.35	43.96
117	FEB 10	87.04	3258.74	35.43	28.71	15460.20	27.55	69.72
124	FEB 17	88.37	2724.45	28.13	16.33	27210.33	40.65	108.60
131	FEB 24	82.43	9280.02	37.29	62.98	1132.24	0.80	3.92
138	MAR 2	11.63	233.16	4.38	3.26	-5080.60	-10.42	-36.50
143	MAR 7	8.54	-88.14	-1.74	-2.23	2191.04	4.65	29.83

ACETATE SYSTEM

DAY No.	DATE	ACETATE SOLUTION COD (g/L)	INFLUENT COD (mg/L)	ANOXIC COD (mg/L)	AEROBIC COD (mg/L)	EFFLUENT COD (mg/L)
0						
17	APR 6	0	366	276	264	287
24	APR 13	30.42	173	280	206	231
31	APR 20	15.63	206	181	169	185
45	MAY 4	23.49	337	276	160	240
50	MAY 9	23.49	342	268	256	256
59	MAY 18	37.19	329	410	297	321
64	MAY 23	37.19	323	379	287	271
71	JNE 1	41.89	312	552	328	320
80	JNE 8	51.13	337	583	321	302
87	JNE 15	59.68	312	760	320	280
92	JNE 20	76.77	356	876	828	372

DAY No.	DATE	TOTAL COD REMOVAL %	ANOXIC COD REMOVAL (mg/d)	ANOXIC COD REMOVAL %	UNIT ANOXIC REMOVAL (mg/hr/gVSS)	AEROBIC COD REMOVAL (mg/d)	AEROBIC COD REMOVAL %	UNIT AEROBIC REMOVAL (mg/hr/gVSS)
0								
17	APR 6	21.58	439.14	8.97	9.89	1633.80	4.35	17.19
24	APR 13	84.82	3473.01	44.82	97.78	11859.98	26.43	161.49
31	APR 20	76.30	1858.43	40.60	31.87	1512.24	6.63	13.35
45	MAY 4	79.89	2284.88	34.51	50.11	14466.36	42.03	160.31
50	MAY 9	80.07	2896.06	41.89	72.69	1619.88	4.48	20.58
59	MAY 18	80.45	2469.93	28.48	42.53	13235.69	27.56	109.42
64	MAY 23	81.67	2101.2	26.87	30.83	10220.28	24.27	76.04
71	JNE 1	82.66	1173.28	12.37	15.14	28461.44	40.58	196.34
80	JNE 8	88.72	2851.06	24.62	34.63	39554.14	44.94	238.16
87	JNE 15	90.14	1310.72	10.07	17.62	70136.00	57.89	436.17
92	JNE 20	89.87	2172.99	14.24	62.88	6813.12	5.48	70.27

YEAST WASTE SYSTEM

		YEAST WASTE SOLUTION COD	INFLUENT COD	ANOXIC COD	AEROBIC COD	EFFLUENT COD
DAY No.	DATE	(g/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
0						
17	APR 6	0.000	366	287	264	278
24	APR 13	0.000	256	193	189	193
31	APR 20	2.305	206	169	165	193
45	MAY 4	9.878	337	244	220	191
50	MAY 9	4.980	342	285	215	215
59	MAY 18	6.827	329	374	217	241
64	MAY 23	5.657	323	287	239	157
71	JNE 1	10.180	312	476	260	232
80	JNE 8	7.329	337	468	290	310
87	JNE 15	15.840	312	792	280	264
92	JNE 20	18.240	356	1115	256	316

		TOTAL COD REMOVAL	ANOXIC COD REMOVAL	ANOXIC COD REMOVAL	UNIT ANOXIC REMOVAL	AEROBIC COD REMOVAL	AEROBIC COD REMOVAL	UNIT AEROBIC REMOVAL
DAY No.	DATE	%	(mg/d)	%	(mg/hr/gVSS)	(mg/d)	%	(mg/hr/gVSS)
0								
17	APR 6	24.04	157.81	3.58	3.26	3354	8.01	34.09
24	APR 13	24.61	214.2	6.72	5.31	4214	2.07	51.34
31	APR 20	81.39	2724.045	52.99	54.31	4125	2.37	39.97
45	MAY 4	92.19	6193.286	64.32	104.48	16106	9.84	152.52
50	MAY 9	89.68	4871.82	55.55	63.24	77328	24.56	500.31
59	MAY 18	94.29	8407.228	63.16	68.28	230336	41.98	898.63
64	MAY 23	92.09	3712.264	48.45	31.37	42516	16.72	180.03
71	JNE 1	93.24	5437.74	45.78	36.37	183714	45.38	621.33
80	JNE 8	92.08	6081.427	49.87	50.08	198659	38.03	775.04
87	JNE 15	96.25	13272.48	54.40	98.75	671258	64.65	2533.43
92	JNE 20	95.96	9774.49	38.90	62.56	985075	77.04	3018.00