PILOT SCALE TESTS OF A UNIQUE APPROACH FOR BNR UPGRADE OF A SHORT SRT HIGH PURITY OXYGEN SYSTEM AT PIMA COUNTY, AZ

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ABSTRACT

The Ina Road Water Pollution Control Facility (WPCF) is a major wastewater treatment facility of the Pima County Wastewater Management Division (PCWMD). The Ina Road facility includes a 25 MGD UNOX™ High Purity Oxygen System plant which has been in service for approximately 27 years and was designed for secondary treatment only. Future discharge requirements for the facility are expected to include reduction of NH_3-N and Total Nitrogen discharges. This presents a significant problem for the Ina Road facility since;

(a) the UNOX HPO system hydraulic detention time is 1.8 hours;
(b) the existing UNOX HPO system footprint has limited opportunity for expansion, and;
(c) the Ina Road WPCF currently processes anaerobically digested biosolids from two treatment plants, the Ina Road WPCF and the Roger Road WPCF (41 MGD) which results in an internal return stream from the solids handling facility which increases the NH3-N concentration into the secondary process by about 13 mg/l.

Due to the unique nature of the Ina Road WPCF operating conditions, centrate characteristics, and the potential significant capital cost savings compared to a conventional BNR upgrade approach, a pilot plant demonstration of the InNitri™ Process for biological nutrient removal was operated from October, 2003, through January, 2004. The InNitri™ Process treats the high concentration NH3-N centrate stream in a side stream reactor to grow nitrifying microorganisms and then introduces these nitrifiers as seed into the short SRT secondary treatment reactor. The nitrifier seed supplement in the short SRT secondary treatment system is the key element in maximizing capacity and achieving nitrification in the limited footprint and with the limited hydraulic detention time. The InNitri™ Process requires the addition of a small aeration tank and clarifier for treating the centrate return stream and growing nitrifiers. This additional system is typically about 2 to 5% of the main stream aeration tankage.

The pilot program operated in the fall and winter when the wastewater temperature was low. The pilot plant consisted of a multi-stage UNOX™ HPO system with a preceding, staged anoxic zone in a conventional BNR configuration and a complete centrate nitrification system consisting of an aeration basin and secondary clarifier.

The pilot study demonstrated the centrate could be completely nitrified starting with a feed NH_3-N concentration in excess of 800 mg/l and ending with an effluent concentration of 0 mg/l NH_3-N. Operation of the HPO system with an initial anoxic zone was stable and produced effluent $CBOD_5$ concentrations under 10 mg/l at an F/M of about 0.7. When seeded with nitrifiers from the centrate nitrification system, the HPO system removed an average of 20 mg/l of NH_3-N. When seeding was stopped for several days, the HPO system nitrification performance declined, indicating that the addition of seed nitrifiers was maintaining the nitrification reaction under the operating conditions.

KEYWORDS

Biological Nutrient Removal, BNR, Centrate Treatment, Denitrification, High Purity Oxygen, Nitrification, Short SRT

INTRODUCTION

The Ina Road Water Pollution Control Facility (WPCF) is currently undergoing an expansion which includes new facilities for 12.5 MGD biological nutrient removal (BNR) system. This expansion does not upgrade the existing 25 MGD plant which is designed only for secondary treatment. As part on the Contract between the Pima County Wastewater Management Department and Malcolm Pirnie, Inc., Mixing and Mass Transfer Technologies, (M^2T) installed and operated a pilot plant demonstrating the InNitri™ process with the UNOX™ process for enhanced nitrification/denitrification. The combined processes have been proposed by M^2T as an innovative approach to add full BNR treatment for the existing 25 MGD facility.

BACKGROUND

The Ina Road WPCF currently processes biosolids from two treatment plants, the Ina Road WPCF and the Roger Road WPCF. Digested waste solids from the two plants are thickened with centrifuges at the Ina Road WPCF. The resulting liquid centrate stream is returned to the plant headworks. Typically, this increases the influent ammonia concentration to the UNOX HPO System from an average concentration of 25 mg/l NH_3-N to 38 mg/l NH_3-N, a 50% increase in ammonia nitrogen. The resulting effluent concentration of NH_3-N discharged is in excess of 20 mg/l. The County has a goal of significantly reducing the discharge of NH_3-N from the facility within the next few years and a long term goal of reducing the Total Nitrogen discharge from the facility. These effluent quality improvements are coupled with a goal of increasing the beneficial reuse of the effluent in the community.

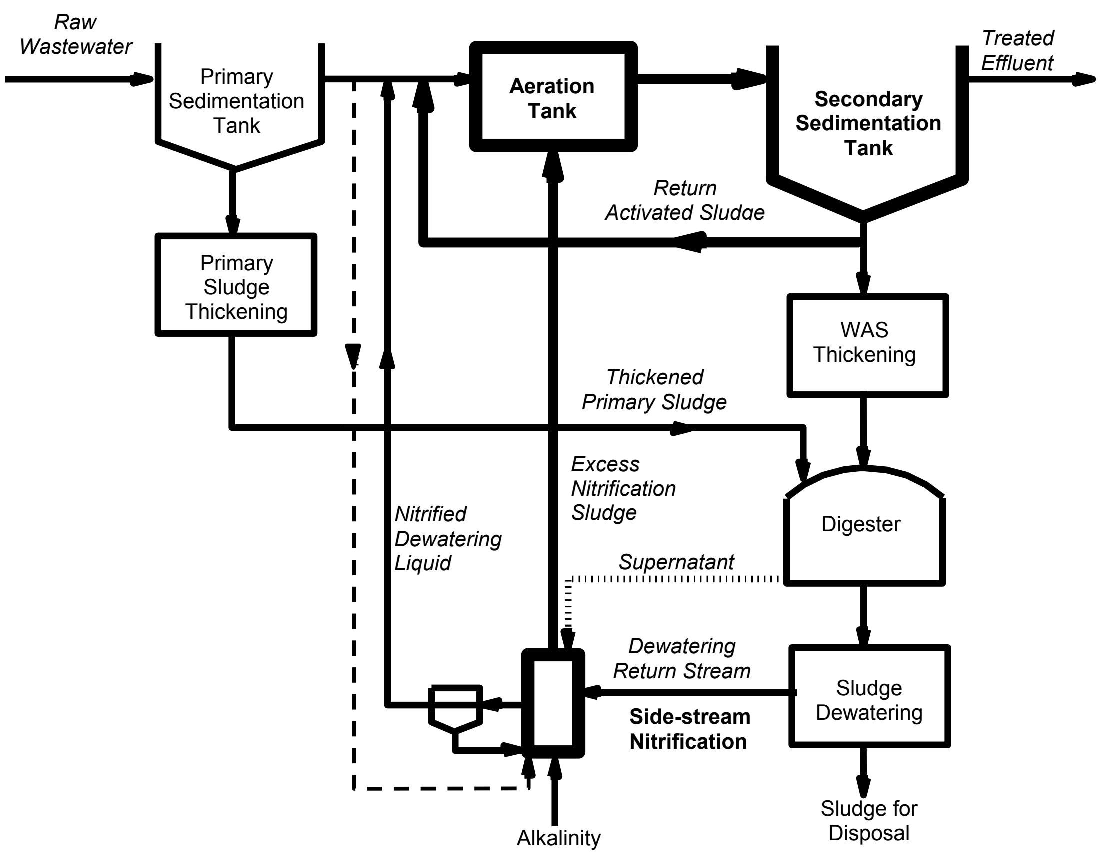
PROPOSED TECHNOLOGY

The InNitri™ process uses the same treatment steps as a conventional BNR process, but requires significantly less tank volume and retention time in the mainstream nitrification section of the process.

A schematic diagram of the InNitri™ process as proposed for the Ina Road WPCF is presented below. It consists of the existing secondary treatment plant (primary sedimentation, UNOX

HPO secondary tank, secondary clarification) with sludge thickening followed by anaerobic digestion and digested sludge thickening. The upgrade to provide year-round nitrification using the InNitri™ process requires the addition of a small treatment system with a primary clarifier, an aeration tank and secondary clarifier for growing nitrifying seed sludge. This additional system is typically about 2 to 5% of the main stream tank volume. In this system, the warm (typically 30 to 35°C), sludge thickening centrate containing a high ammonia content (up to 1000 mg/l) is nitrified in the side-stream nitrification aeration tank. The resulting waste MLSS, which contains a high percentage of nitrifiers, is discharged into the main aeration tank and provides the main activated sludge process with a seed of nitrification organisms.

Schematic Diagram of the **InNitri™** Process



The explanation of the InNitri™ Process is relatively simple. At steady state operation, a constant amount of nitrifying organisms is lost from the main system in the effluent from the clarifier and in the waste sludge flow. In conventional systems, an equivalent amount of organisms must be grown each day to balance the system. The SRT of the system must be sufficient for each existing organism to reproduce before it exits the system. In the InNitri™ Process, new organisms are introduced from the centrate nitrification system. The amount of organisms needed to be grown in the main treatment stream is reduced by the amount of organisms supplied from the centrate treatment system.. Since a smaller amount of nitrifiers need to be grown in the main treatment plant, the nitrification section (oxic section) can be smaller and the MLSS concentration lower since higher SRT is not required. Lower MLSS concentrations to the final settling tanks allows better performance at higher flows.

PILOT PLANT PROGRAM FOR THE INA ROAD WPCF

Due to the unique nature of the Ina Road WPCF operating conditions, centrate characteristics, the innovative approach, and the potential significant capital cost savings, it was decided that the process should be piloted on site to validate the proposed process on the actual waste streams to be treated.

The program intended to investigate:

- Nitrification design parameters and performance on centrate stream.
- Nitrification design and performance of modified HPO reactor train.
- Denitrification design and performance of modified HPO reactor train.
- Seeding effects on short SRT HPO system nitrification capability.

The Pilot Plant consisted of a trailer mounted UNOX™ HPO system with 4 oxygenation stages and pumps for primary effluent feed from the main plant primary clarifiers, sludge recycle and wasting. An external secondary clarifier was used and a 600 gallon tank with partitions to create 4 mixing zones was installed to create a staged anoxic zone preceding the aeration tanks.

The centrate treatment system consisted of a centrate feed holding tank, primary clarifier (used in the latter period of the program), a diffused air treatment tank and a secondary clarifier and associated feed and recycle pumps.

Table 1 provides the sizing characteristics for the major pilot plant equipment. Dates of operation are provided for the centrate treatment system reactor and secondary clarifiers to reflect modifications that were made during the course of the program.

TABLE 1
PILOT PLANT SIZING SELECTIONS

Centrate Treatment System	
Primary Clarifier 12/31/03 – 01/31/04 Operation Surface Area	 2.53 ft^2
Reactor Volume 10/07/03 – 01/09/04 01/09/04 - end	 500 gallons 567 gallons
Secondary Clarifier (10/10 - 12/10) Surface Area	 1.33 ft^2
Secondary Clarifier (installed 12/11) Surface Area	 2.53 ft^2

TABLE 1 (cont.) **UNOX™ HPO-BNR System**	
Anoxic Reactor Volume Stage 1 Stage 2 Stage 3 Stage 4 Aerobic Reactor Volume Stage 1 – HPO Aeration Stage 2 – HPO Aeration Stage 3 – HPO Aeration Stage 4 - Air Aeration for CO_2 Stripping	 150 gallons 150 gallons 150 gallons 150 gallons 400 gallons 400 gallons 400 gallons 400 gallons
Secondary Clarifier Diameter Surface Area	 8 ft, 2 inches 52.4 ft2

The design flow rates for the pilot plant program were selected based on the equivalent full scale Hydraulic Retention Time (HRT) for the UNOX HPO system. The existing rating of 25 MGD for the Ina Road WPCF establishes a pilot plant feed flow of about 14.25 gpm for an equivalent HRT. The volume of the anoxic tank in the pilot plant was chosen to approximate 38% of the volume of the aerobic tanks. The available secondary clarifier for the UNOX™ HPO pilot plant would operate at an overflow rate of 412 gal/day/ft2 at a flow of 15 gpm into the pilot plant. This overflow rate is below the full scale overflow rate for the 4 existing clarifiers at the 25 MGD plant rating. MLSS settleability was determined daily by SVI measurements which can be used to project full scale clarifier performance. As part of the BNR operation, MLSS was recycled from the final aerobic stage to the first anoxic stage.

The centrate treatment system aeration reactor volume was selected to provide a reactor loading value of about 44 pounds per day of NH_3-N per 1000 cubic feet of reactor volume. This was a loading value below what had been successfully achieved at other locations. This was based on a feed concentration of 700 mg/l of NH_3-N and a desired flow rate of 500 gallons per day. The HRT was 1.0 day at the design flow. The centrate treatment system clarifier was designed to provide an overflow rate of 375 gpd/ft2 at a flow of 500 gallons per day.

INFLUENT CHARACTERISTICS

The feed wastewater characteristics were determined by laboratory analysis of composite samples. One composite sampler was located at the headworks of the facility and is considered "RAW" wastewater strength. A second sampler was located at the effluent from the primary clarifiers and is designated as "PRIMARY EFFLUENT". The wastewater lab on site did all the laboratory analysis for the pilot plant program.

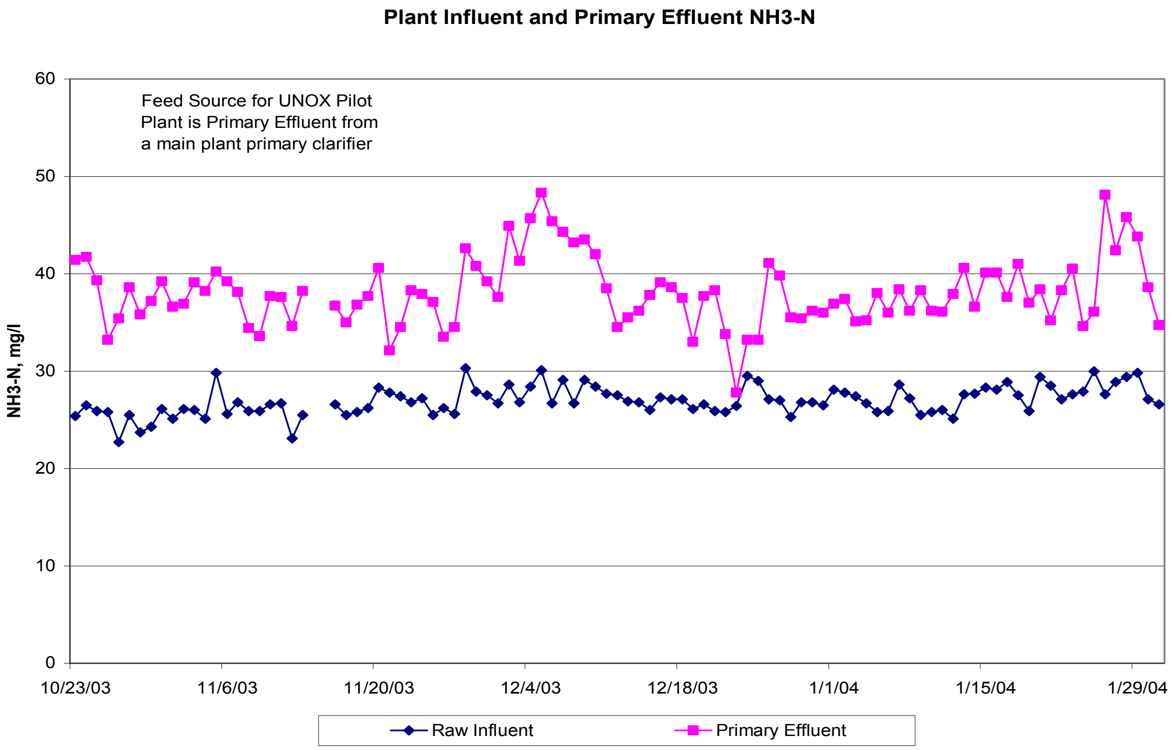
Table 2 presents the average raw influent and primary effluent wastewater values for selected constituents during the program. The 90th percentile concentration in Table 2 is from a sorted plot of the daily values. Figure1 shows the daily variation in the Raw and Primary Effluent NH_3-N over the course of the program.

TABLE 2
SELECTED INFLUENT CONSTITUENTS

	Average Concentration	**90th Percentile Concentration**
Raw Plant Influent		
NH_3-N, mg/l	27.0	29
TKN-N, mg/l	39.6	44.9
Alkalinity, mg/l	274	285
Primary Effluent		
BOD_5, mg/l	142	171
COD, mg/l	361	415
TSS, mg/l	72	84
NH_3-N, mg/l	38.1	
TKN-N, mg/l	45.8	

Since the current plant operation feeds the centrate to the inlet of the primary clarifiers, the concentrations of NH_3-N, TKN-N, and alkalinity in the primary effluent are higher than would be treated in the proposed InNitri™ – UNOX™-BNR project. The raw samples represent the concentrations of NH_3-N, TKN-N, and alkalinity expected to be entering the UNOX™ system should the centrate nitrification system be installed.

FIGURE 1

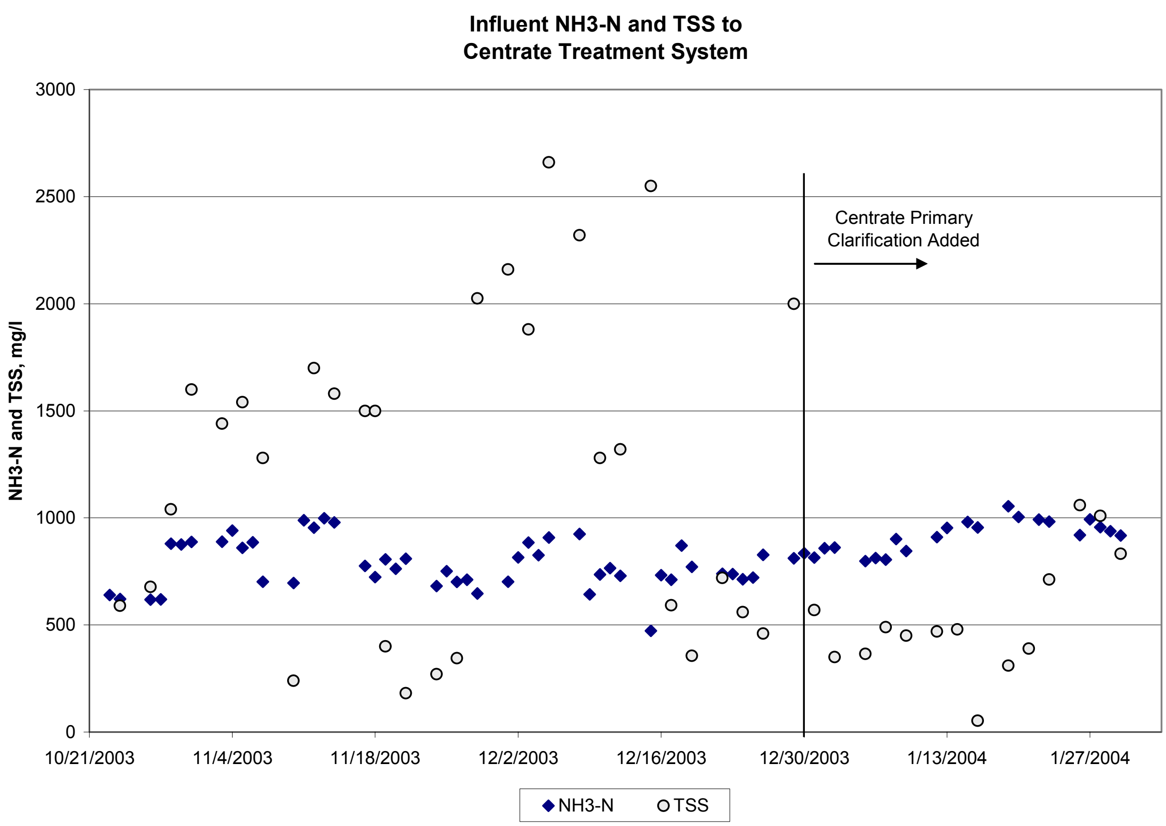


The feed centrate for the program was batch delivered by trucks or by pumping from the centrate line to the primary clarifiers. The centrate temperature was typically above 30 °C when it was delivered. Because the centrate holding tank was sized for a minimum of 3 days supply, the feed quality was constant for several days and then varied when a new batch of centrate was delivered. This resulted in significant variation in concentrations being fed to the system. The most noticeable variability in feed quality was the TSS concentration from delivery to delivery. A primary clarifier had been designed into the flow stream but it was not used initially since the TSS in the centrate was in the range of 400-800 mg/l. Increasing variability and periods of high centrate TSS concentrations resulted in the decision to start using the primary clarifier on December 31, 2003. The primary clarifier reduced the average TSS concentration but the influent still showed variations in TSS concentration. Table 3 presents the main measured centrate characteristics for the feed to the centrate treatment system reactor. Samples were taken manually first thing in the morning for lab collection. Figure 2 shows the variation on the influent concentrations to the centrate treatment system reactor.

TABLE 3
MAIN CENTRATE CHARACTERISTICS

	Average Concentration	**90th Percentile Concentration**
Centrate		
TSS, without clarification, mg/l	1124	2160
TSS, with clarification, mg/l	583	1060
NH_3-N, mg/l	810	981
TKN-N, mg/l	834	1017

FIGURE 2



PILOT PLANT PROCESS PERFORMANCE

UNOX™ System Process Overview

The UNOX™ System was set up as a BNR system with a staged anoxic zone, a high purity oxygen aeration zone and a final stage using air as the oxygen source. The design was to simulate a full scale process where the final aeration stage is open to the air to strip excess dissolved CO_2 from the mixed liquor before it is recycled. Excess CO_2 is dissolved in a high purity oxygen activated sludge system and will depress the pH which results in a decrease of the rate of nitrification.

Following start up of the system, there were three periods of gradually increasing feed flow and an extended period of operation at 15 gpm feed flow. Note 15 gpm into the pilot plant results in an aerobic hydraulic retention time equal to 25 MGD flow into the existing 4 train, 3 stage UNOX™ System. This paper focuses on the final month of operation at a constant flow of 15 gpm.

During the program, the reported effluent Total BOD_5 concentrations from the pilot plant were significantly higher than expected. Since it was believed that the Total BOD_5 tests being run were reading high due to ongoing nitrification in the test bottles, two series of tests comparing Carbonaceous BOD_5 ($CBOD_5$) with Total BOD_5 were run. The results of these 12 tests indicated that the effluent Carbonaceous BOD_5 averaged about 9 mg/l. It was concluded that the $CBOD_5$ removal was excellent and that calculation of percentage removals was not appropriate using the Total BOD_5 results reported.

The following series of graphs show other observations or relationships derived from the UNOX™ system pilot plant operation.

Figure 3 shows the relationship between the effluent TSS and SVI. Figure 4 shows the relationship of effluent TSS to the clarifier mass loading. Figure 5 shows the daily effluent TSS and the Clarifier Overflow Rate for the program. In all three Figures there does not seem to be a dependency of effluent TSS on the other values. This suggests that within the range of values observed, the clarifier performance was not significantly influenced by SVI, mass loading, or overflow rates. Review of the RAS concentrations and MLSS concentrations over the course of the study showed no dependence on these concentrations and the daily SVI values.

FIGURE 3

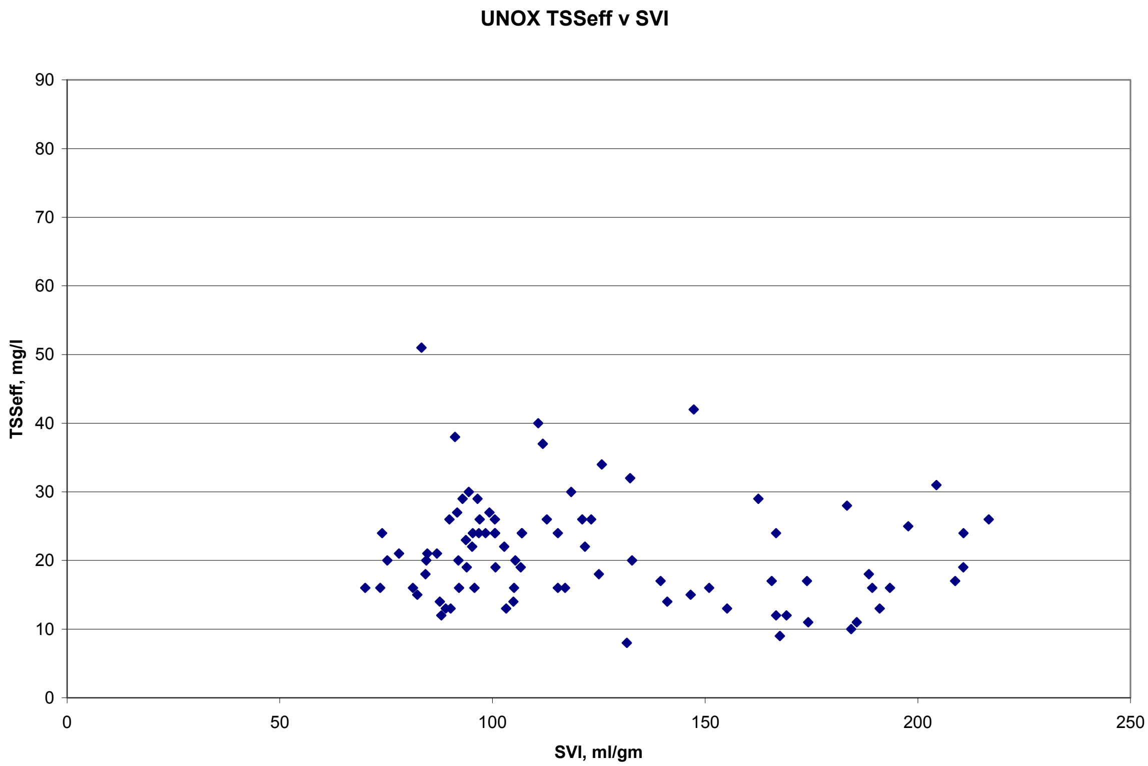


FIGURE 4

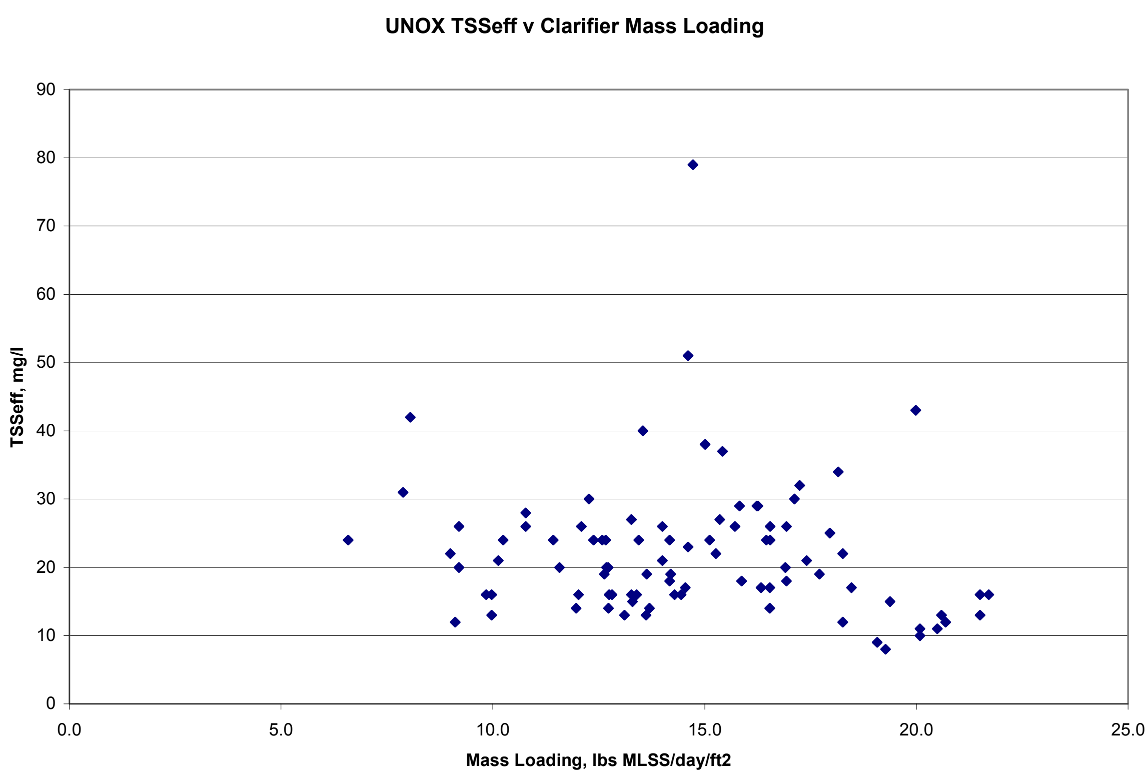
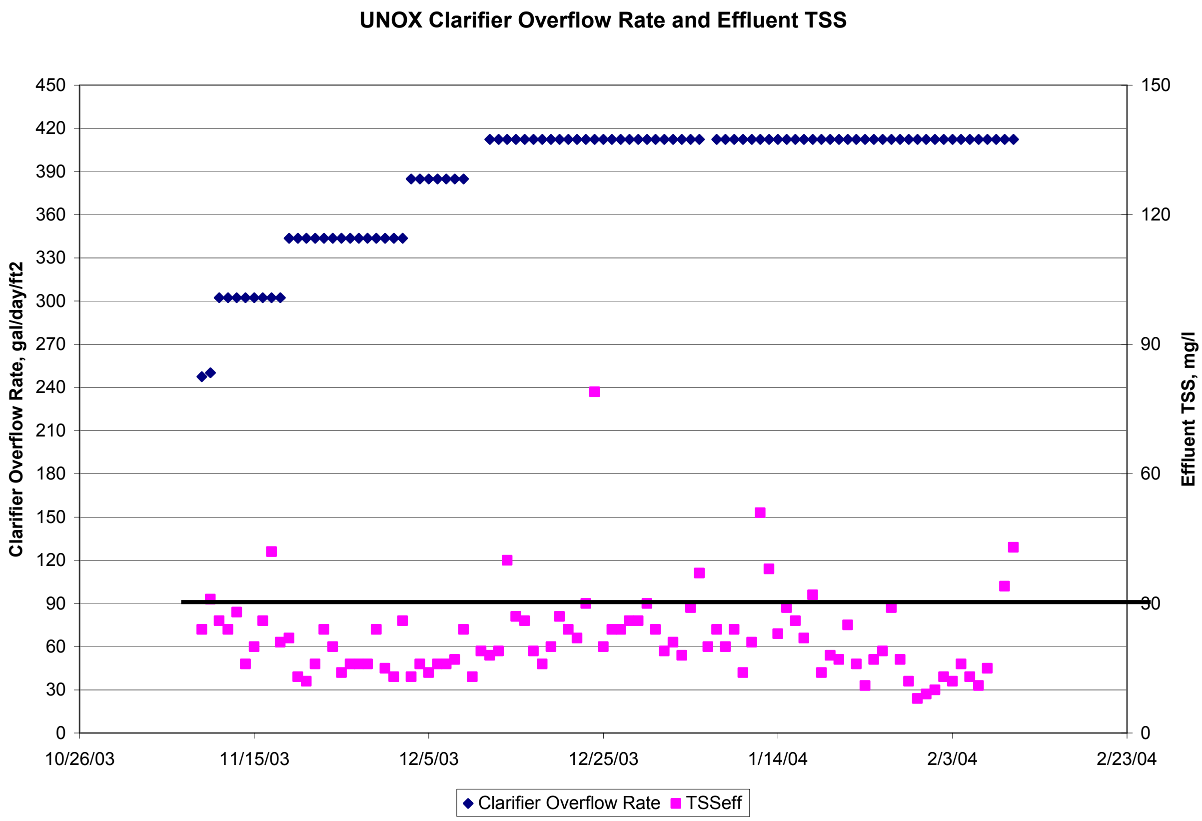


FIGURE 5



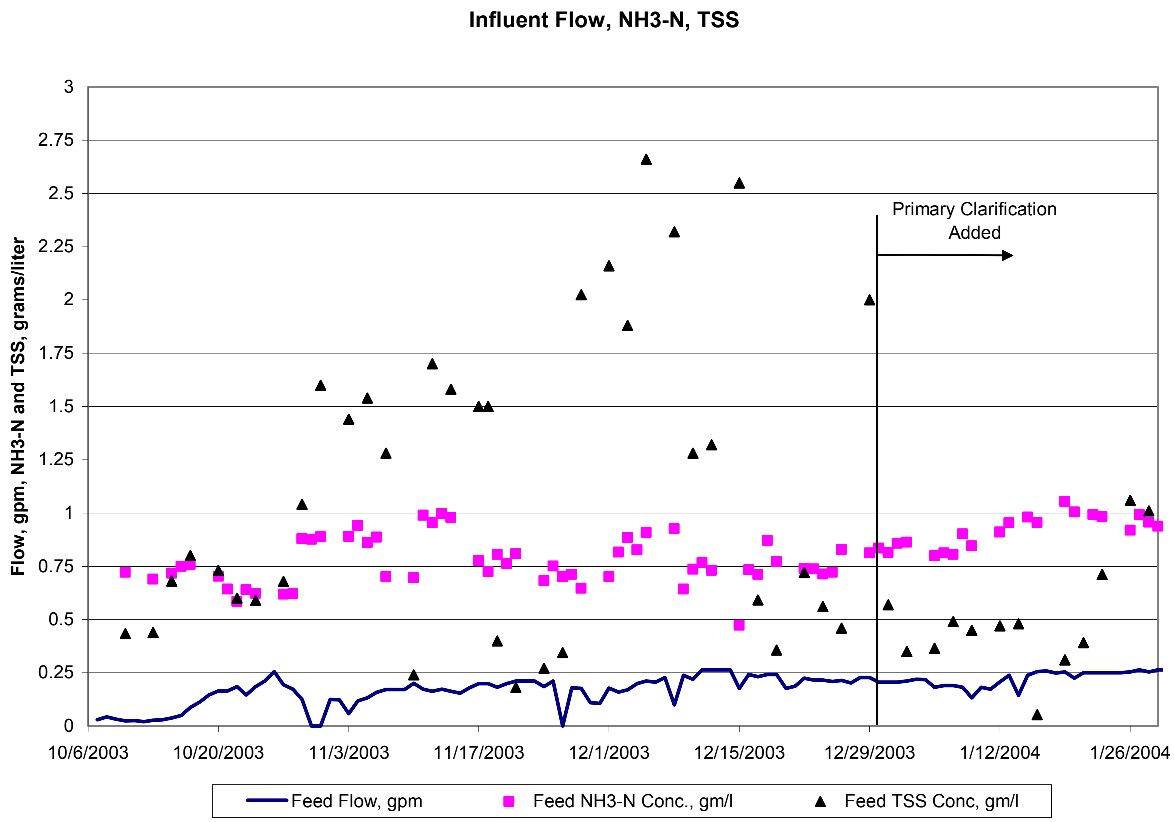
Centrate Treatment System Process Overview

The centrate treatment system was designed as a complete mixed aeration reactor with continuous feed of centrate from a storage tank. It included a secondary clarifier and recycle pumping. An automatic alkalinity addition system fed a 50% caustic solution to the reactor when the reactor pH was reduced to 6.9 to raise the pH up to 7.2, where it was shut down. Two compressors were provided to supply air to the diffusers. The air flow to the diffusers could be adjusted manually.

The reactor was seeded with a nitrifying sludge from another plant. Since the nitrification reaction can be inhibited by NH_3-N and NO_2-N concentrations above about 100 mg/l, the startup flow to the reactor was low and as the amount of nitrification increased, the flow was increased. Daily analysis of the reactor for NH_3-N, NO_2-N, and NO_3-N was done. Results of these analyses were used to determine when the feed flow to the reactor could be increased.

Figure 6 presents the feed flow, the influent NH_3-N and influent TSS concentrations into the centrate treatment system reactor over the duration of the program. Figure 6 shows the variation in influent NH_3-N concentration was between 600-1000 mg/l. This variation may be an artifact of the batch supply of centrate into the storage tank. Figure 6 also shows the TSS concentration variation was significantly greater than the NH_3-N concentration variation. This variation had an impact on the system, especially when the concentration of TSS was either very high or very low. When it was low, the reactor MLSS declined due to seeding and loss of solids in the effluent. When it was very high, the reactor MLSS became very high without increasing the activity in the system. Figure 6 shows that when primary clarification was started, the influent TSS concentration became stable in the range of 400-500 mg/l.

FIGURE 6



The Ina Road WPCF currently produces about 350,000 gallons per day of centrate from their centrifuge sludge thickening facility. This represents a flow ratio of about 1 gallon of centrate for 70 gallons of main plant flow, at a main plant flow rate of 25 MGD. Note that this flow is derived from thickening digested sludge from both the Ina Road and Rogers Road plants. This flow represents a full scale relationship of between 350,000 and 500,000 gallons per day of centrate being available for the full scale centrate treatment system for seeding into the 25 MGD UNOX™ system. Thus the feed rates tested for the centrate treatment system and UNOX™ System are comparable to the full scale operation being considered.

Temperature Effect

As the program progressed, the average ambient temperatures decreased, especially at night, causing a drop in the centrate reactor temperature below 20° C. In addition, the primary effluent temperature decreased. To increase the temperature and conserve the heat of the centrate feed, the centrate holding tank, the centrate treatment system reactor, the centrate secondary clarifier and the interconnecting lines were insulated. This action allowed the reactor temperature to be maintained above 25°C. As the program progressed further into winter, it was decided to add heat blankets to the centrate treatment system reactor. These were installed in the first week of December. Measurements of the centrate feed temperatures indicated a full scale system, with its deeper tanks and smaller ratio of tank surface to tank volume should maintain adequate operating temperatures without supplemental heat addition, even in the winter. The temperature problems in the pilot scale are not unusual, given the small tanks and exposed piping.

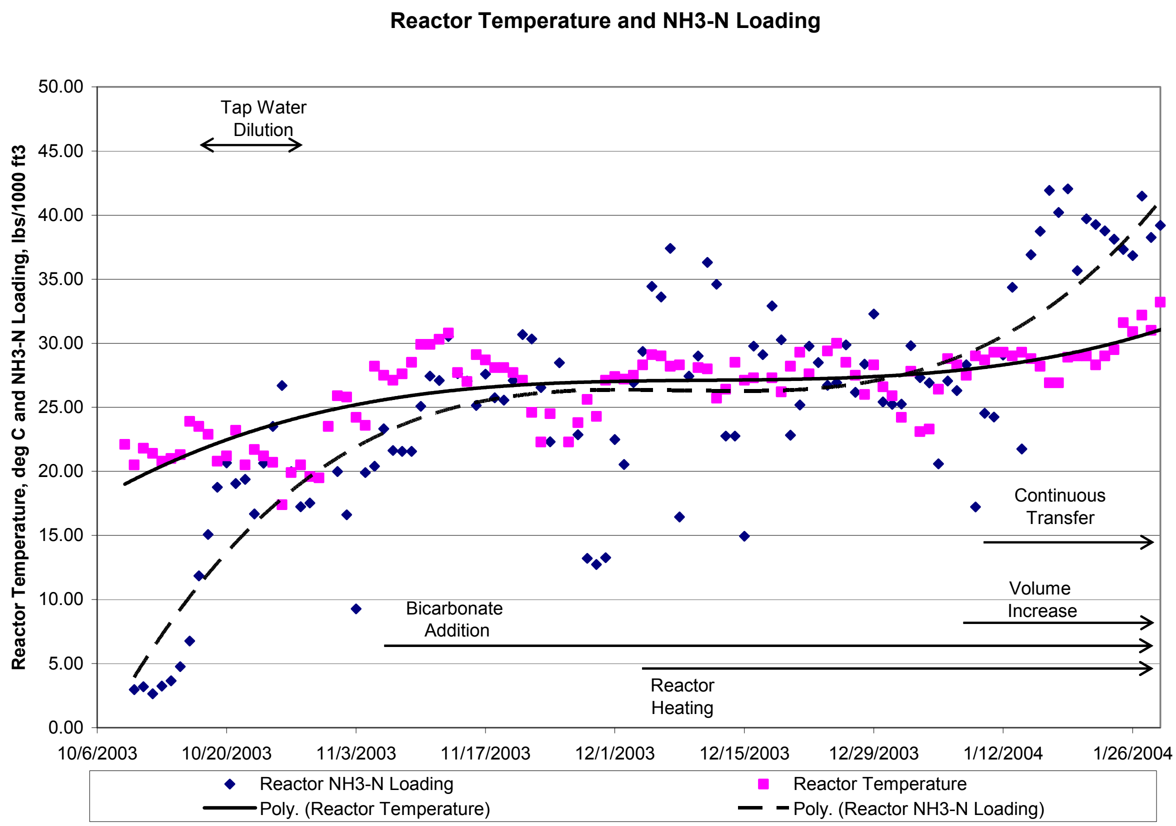
TSS Capture Issues

A constant concern in the operation of the system was the high TSS concentration in the effluent from the centrate system.. Several attempts were made to add polymer to the centrate treatment system reactor effluent. Several polymers were tested in static settling tests and a couple of different polymer injection/mixing systems were tried. While the jar tests showed good flocculation of the MLSS could be achieved with several polymers, in the continuous addition mode of operation, either no improvement was seen, or the polymer caused immediate floation of the MLSS as if a dissolved air flotation system was in operation. On December 10th, a new, larger secondary clarifier was installed. A larger centerwell and mixer were installed to promote flocculation of the polymer. However, polymer addition still promoted flotation and it was not instituted. Even though the new clarifier significantly lowered the overflow rate, there was not a significant improvement in the effluent TSS.

On January 8th, the operating volume of the reactor was increased by raising the level of the MLSS effluent pipe. This resulted in a volume increase of slightly over 10%. On January 9th, the method of transferring seed from the centrate treatment system reactor to the UNOX™ system was modified. Prior to this date, seed transfer was essentially a batch operation with the pumping of the seed quantity occurring over about a 1 hour period. Since the seed removal was significantly quicker than the feed flow rate, the reactor level dropped significantly and the system operated as a batch reactor (with the recycle turned off) for several hours until the feed and dilution flows refilled the tank. At the conclusion of the transfer, the amount of nitrifiers left in the centrate treatment system reactor was only about 80% of the amount before the transfer. It was suspected that the step change in loading and the reduction of available nitrifiers could be limiting the capacity of the system. A small pump system was installed in place of the previous transfer pump. It was set up to transfer seed over a period of 8-24 hours. At this rate, the centrate treatment system reactor was always full, maximizing the amount of nitrifiers available and eliminating the need to turn off the recycle system during seed transfer.

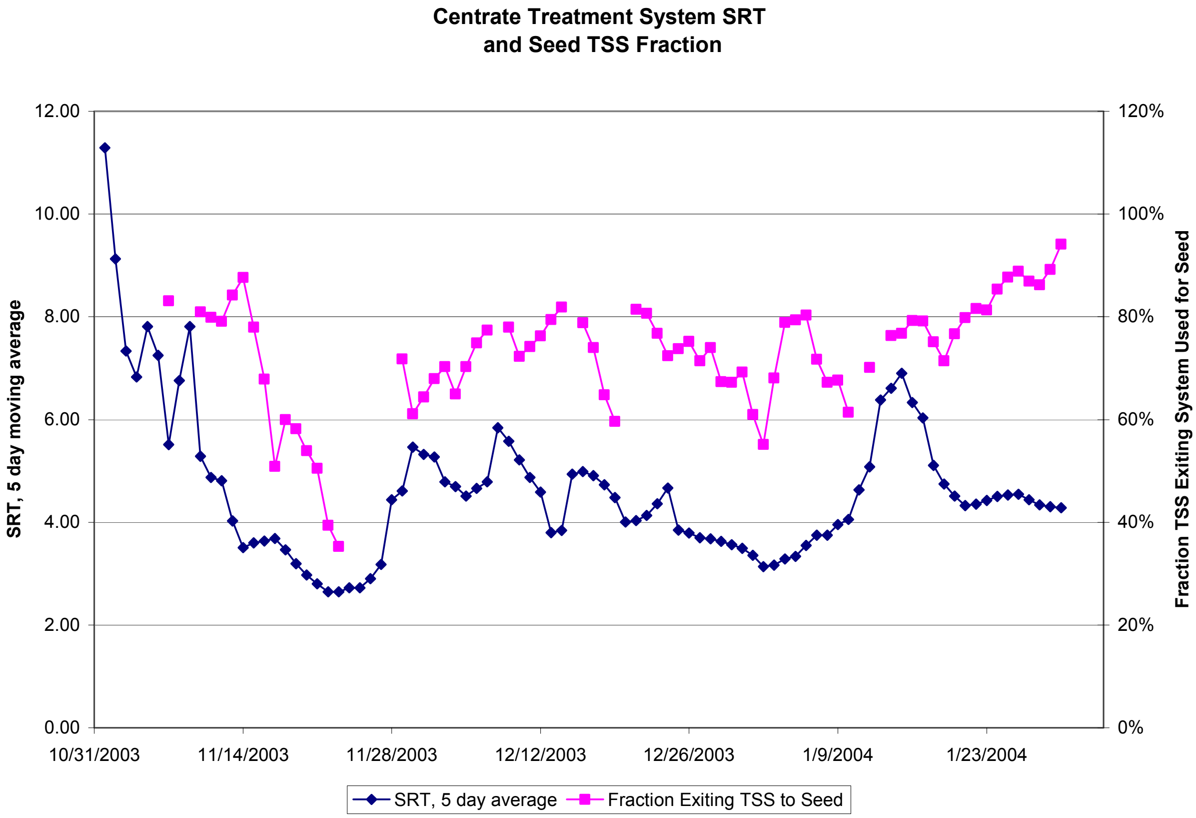
Figure 7 shows the reactor temperature and the rate of NH_3-N removed in the reactor over the course of the program. Since the removal rate of NH_3-N in the reactor averaged 98%, a graph based on feed loading would be essentially the same. Note that towards the end of the program, the NH_3-N removal capacity improved significantly. At this same time, the reactor temperature average a few degrees higher, the volume was 10% greater, and the seed transfer was continuous, not batch. It is impossible to isolate the individual effects on the increase of observed load capacity.

FIGURE 7



As mentioned above, TSS in the effluent of the centrate treatment system was higher than anticipated. Since the effluent TSS contains nitrifiers that were grown in the reactor, the larger than expected effluent TSS loss meant that the amount of seed transferred to the UNOX™ reactor was lower than the amount of nitrifiers produced in the centrate reactor. Figure 8 shows the calculated SRT of the centrate treatment system and the fraction of daily solids leaving the system that were used for seed to the UNOX™ System. As seen in Figure 8, a significant fraction of the nitrifiers grown in the centrate treatment system reactor did not get used to seed the UNOX™ System. In the full scale system, it is expected that the full scale clarifier will improve the TSS capture. The use of polymer can improve the TSS capture and the centrate treatment system reactor clarifier effluent can be fed into the UNOX™ System to eliminate the effluent TSS loss entirely. Either of these situations will significantly improve the fraction of nitrifiers developed that are seeded into the UNOX™ System.

FIGURE 8



InNitri™-UNOX™ System Nitrification Performance

Figure 9 shows the NH_3-N removals across the UNOX™ system for the program. Figure 10 shows a calculated UNOX™ System NH_3-N effluent that is derived by subtracting the NH_3-N removal (mg/l) from the corresponding NH_3-N concentration in the raw influent to the plant. This calculation represents the probable result of the pilot plant if the NH_3-N contribution from the centrate feed to the primary tanks did not exist. The period of January 6th – January 30th is shown on Figures 9 and 10. This period operated at a constant 15 gpm into the UNOX™ System and has been selected for further discussion in this paper. The period of deteriorating NH_3-N effluent concentrations in Figure 9 and 10 from 12/20-1/6 corresponds to the Christmas-New Years holiday period. There were several minor operating upsets during this period while work was performed to maintain an acceptable reactor temperature and modify the secondary clarifier.

FIGURE 9

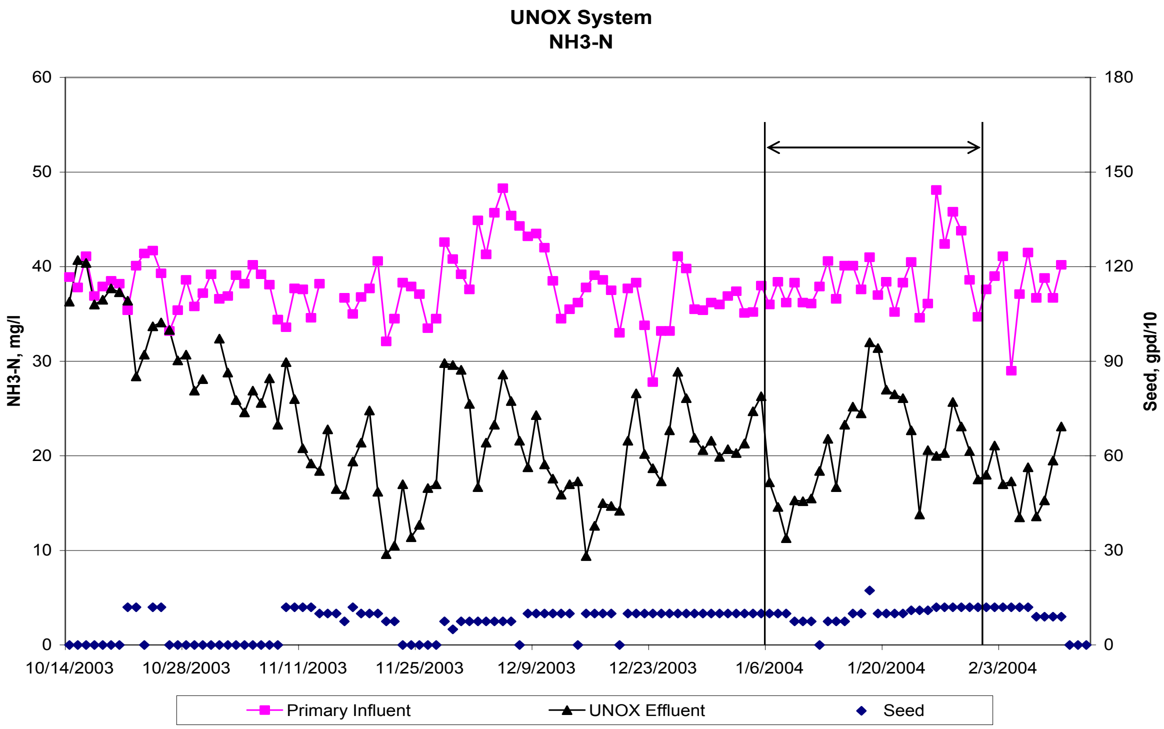
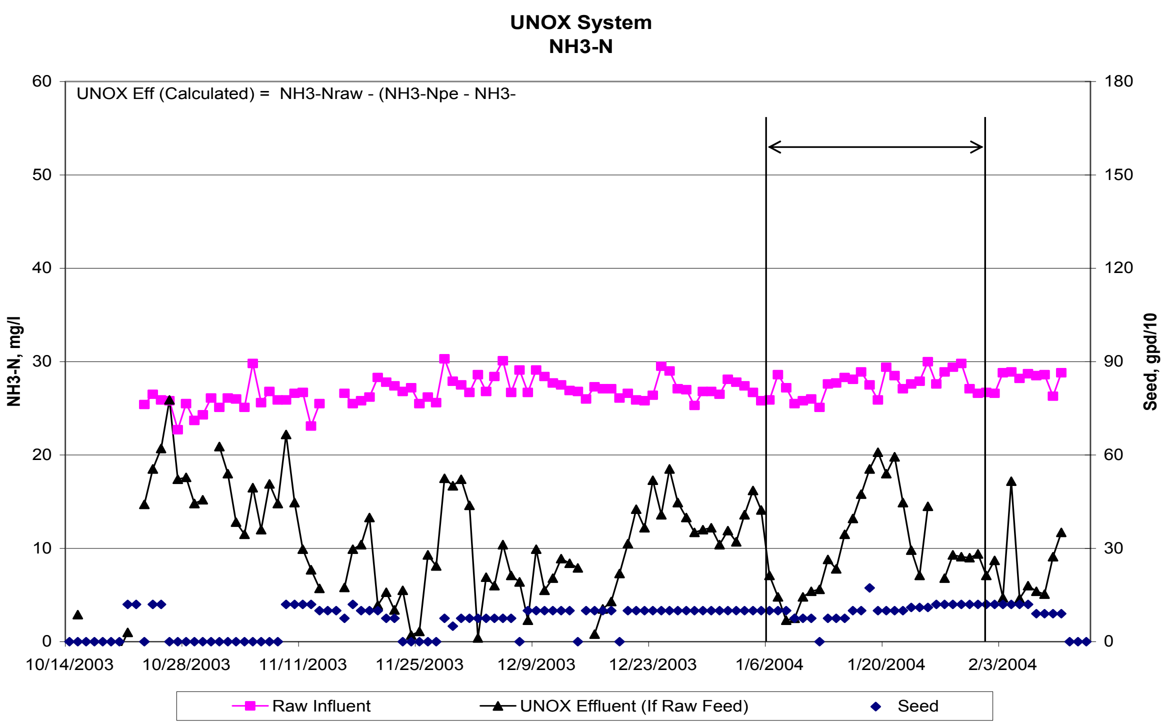


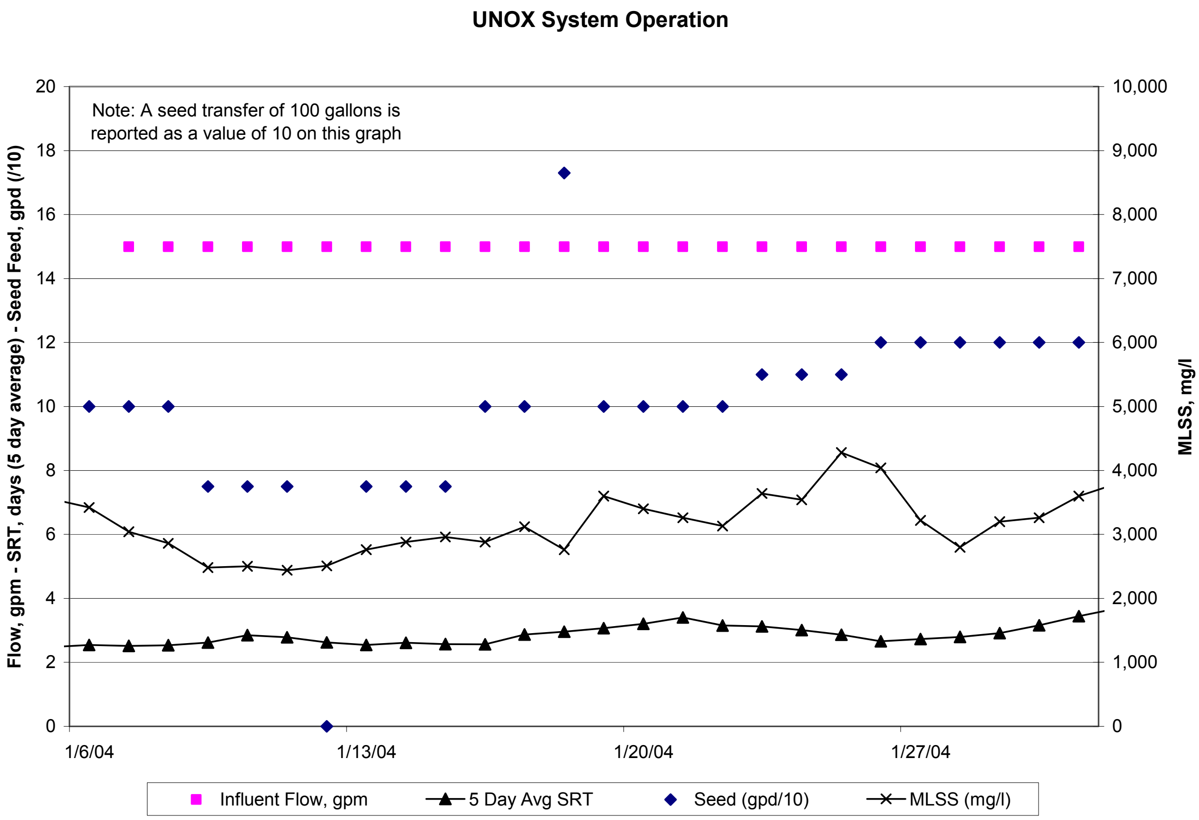
FIGURE 10



System Performance – January 6th – January 30th

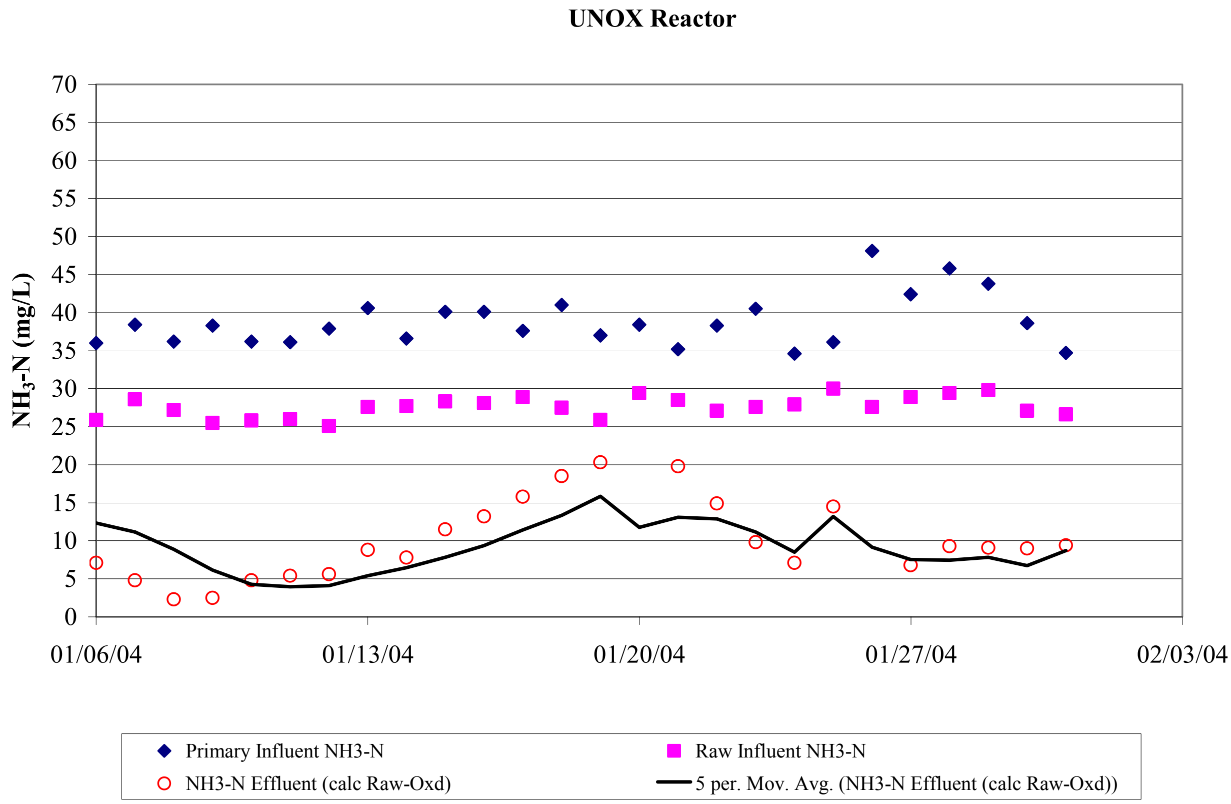
Figure 11 is a plot of the UNOX™ feed rate and centrate treatment system seed rate and SRT for the UNOX™ System. The SRT of the system was maintained around 3 days by controlled wasting of MLSS. At the beginning of this period the Primary Effluent temperature ran about 24.5 °C and at the end of the period, it was about 23 °C.

FIGURE 11



As discussed earlier, the difference between the Raw and Primary Effluent NH_3-N concentrations is the NH_3-N returned to the plant in the centrate. In an effort to compensate for the effect of having the centrate NH_3-N in the primary effluent, Figure 12 was developed. It shows a calculated effluent concentration based on the mg/l removed in UNOX™ being subtracted from the Raw NH_3-N concentration. This represents the UNOX™ effluent NH_3-N when the centrate treatment system removes the centrate NH_3-N and reduces the NH_3-N in the primary effluent and seeds the UNOX™ System.

FIGURE 12



As mentioned earlier, the high effluent TSS concentration from the centrate treatment system reactor reduced the amount of nitrifiers that were eventually transferred to the UNOX™ System as seed. In an effort to better quantify the amount of nitrifiers transferred, a simple balance on nitrifiers present in the centrate treatment system reactor was generated.

A growth factor of 0.25 pounds of nitrifiers produced per pound of NH_3-N oxidized was selected for this analysis. This factor neglects the loss of nitrifiers due to endogenous decay in the reactor which introduces a small error in the pounds present in the reactor. From the mass of NH_3-N oxidized each NH_3-N the estimated mass of nitrifiers produced in the InNitri reactor was calculated. Each day, the nitrifiers present in the centrate treatment system reactor was calculated by subtracting from the previous day's value the mass lost in seed transfer and effluent TSS and then adding the production based on the mass of NH_3-N oxidized that day. From this value, the pounds of nitrifiers that were transferred in the seed can be estimated.

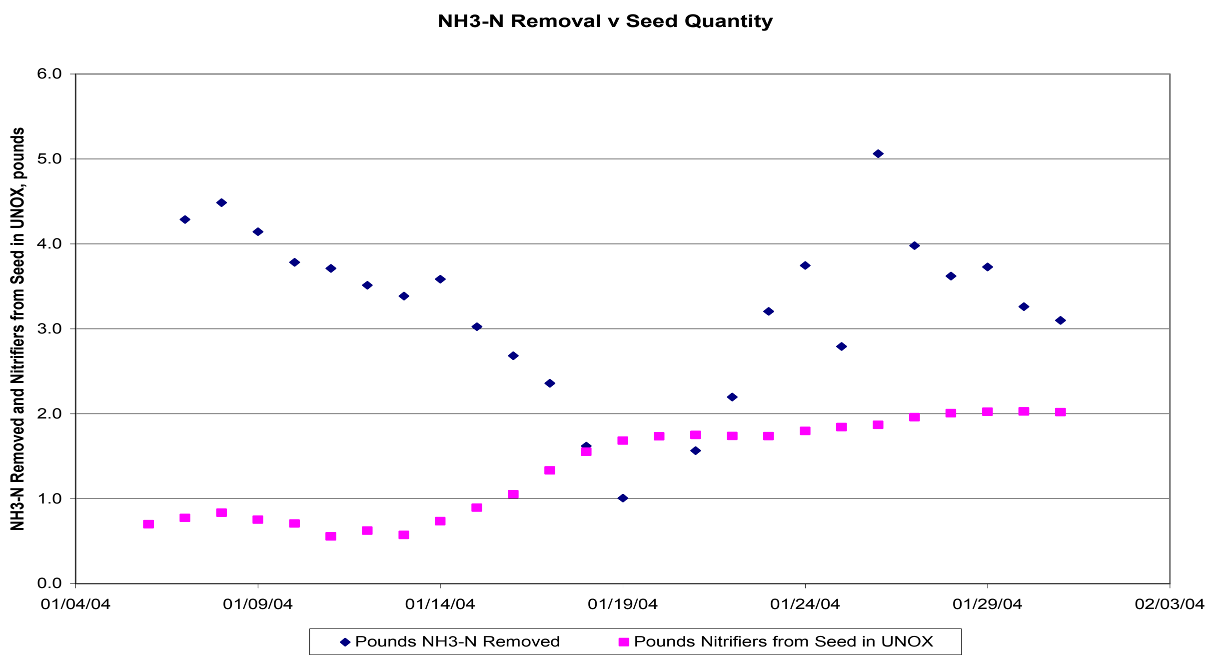
Once the pounds of nitrifiers seeded into the UNOX™ System each day was determined, a separate simple balance of seed nitrifiers in the UNOX™ System was calculated. For this calculation, the mean cell residence time (MCRT) for the system was first calculated. This calculation accounts for the TSS in the clarifier and anoxic volume in addition to the aerobic volume. The MCRT averaged about 4.7 days. Since the seed is uniformly dispersed among all the TSS in the UNOX™ System, the seed transferred is gradually wasted with the MLSS. For simplicity, it was assumed that the MCRT was about 5 days and the amount of seed in the system can be estimated as follows.

Lbs seed in UNOX™ = lbs seed today (N) + 80% * pounds seed yesterday (N-1)
+ 60% * pounds seed previous day (N-2) + 40% * pounds seed previous day (N-3) + 20% * pounds seed previous day (N-4).

Figure 13 compares the pounds of nitrifier seed in the UNOX™ System with the pounds of NH_3-N oxidized every day. Note that the UNOX™ System continued to gain in seed nitrifiers during this period. This is a result of improved performance of the centrate treatment system reactor following the modifications on volume, temperature control and clarification. While the quantity of seed nitrifiers was constant or increasing, the pounds of NH_3-N oxidized declined for the early part of the period and recovered in the latter part of the period. The observation that the same levels of NH_3-N removal are occurring at twice the calculated seed concentration suggest that there was less growth of nitrifiers in the UNOX™ System to supplement the seed nitrifiers for this period. A lower growth rate of nitrifiers supplemental to the seed nitrifiers is consistent with the conventional design relationships since both the UNOX™ System temperature and system SRT were lower in this period.

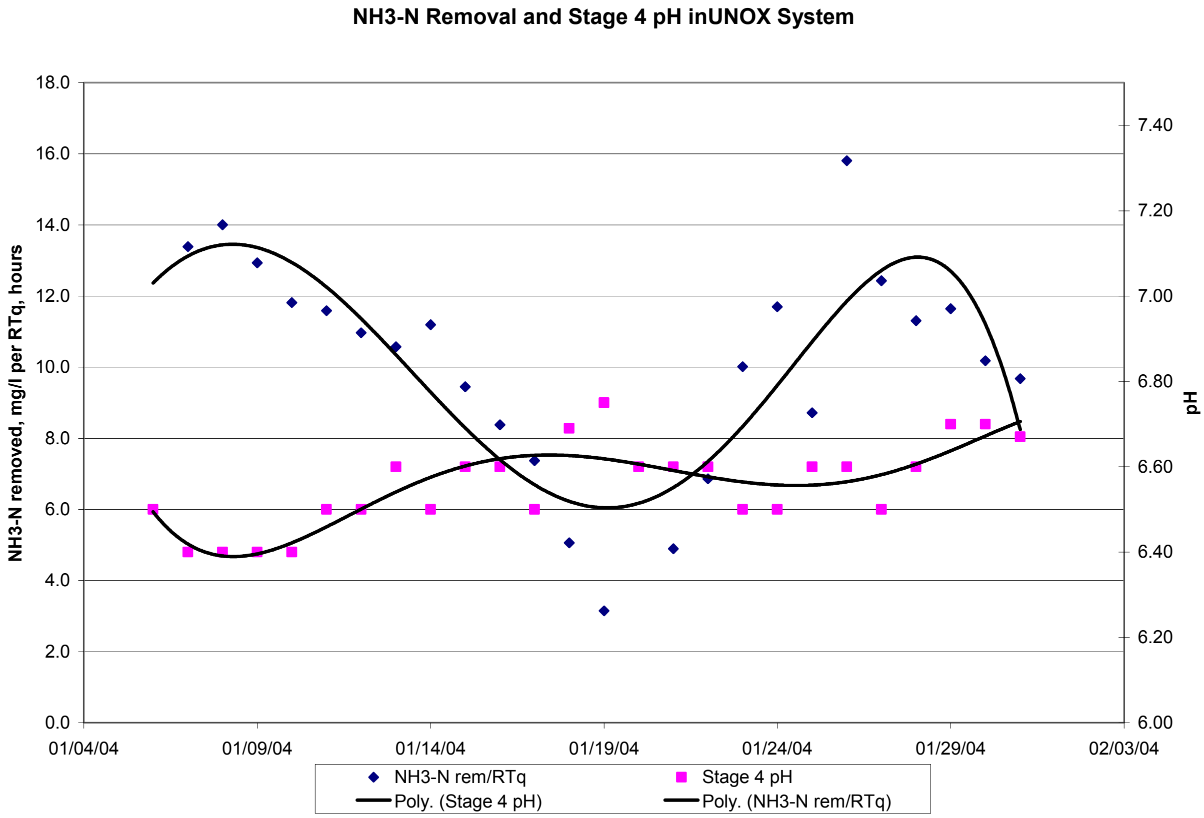
If we look at the ratio of total TSS seeded to that exiting the system over this period, we find that only 70% of the TSS leaving the centrate treatment system reactor was seeded into the UNOX™ System. An evaluation based on a nominal effluent TSS of 50 mg/l from the centrate treatment system clarifier shows that over 90% of the TSS should have been seeded. This would have resulted in 1.3 times the pounds of seed being transferred to the UNOX™ System which would result in improved NH_3-N removals.

FIGURE 13



The data on NH_3-N removed was compared to a variety of variables. No trend was found when compared with MLSS in the reactor, temperature in the reactor, or average SRT in the system. A slight reverse trend was found where the Stage 4 pH increased when the NH_3-N removal decreased indicating the UNOX™ System pH was dependent on the acid production/alkalinity reduction of the nitrification reaction. It also indicates the NH_3-N removal was not influenced by the pH variations in the UNOX™ System. Figure 14 shows this relationship.

FIGURE 14



However Figure 15 does show a trend relating NH_3-N removal improving with higher DO concentrations in the system, up to a DO of around 4 mg/l. Note the shape of the computer generated trend line is consistent with the conventionally assumed dependence of nitrification on DO. Figure 16 shows the dependence of NH_3-N removals on DO in a different fashion. The plot shows the NH_3-N removal in mg/l removed per hour of retention time. Figure 16 shows the daily average DO concentration of the 4 stages and the daily NH_3-N removals. The computer generated trend lines also show the system DO has a direct influence on the NH_3-N removal observed in the system.

FIGURE 15

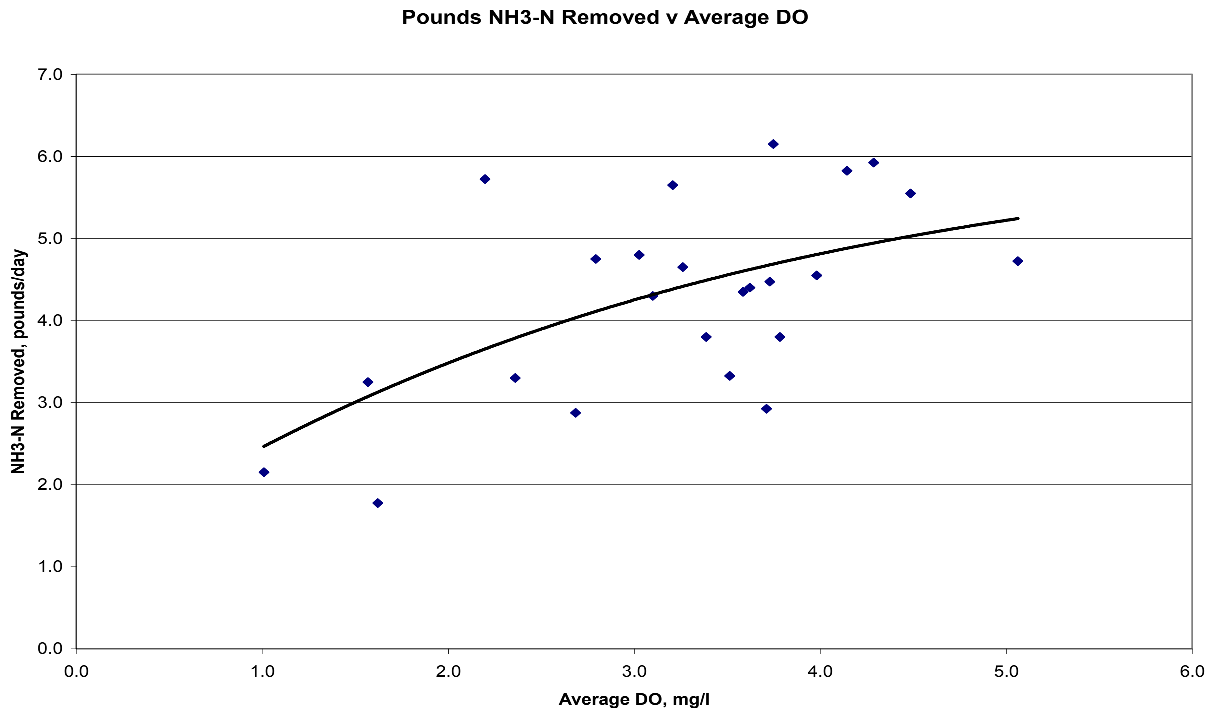
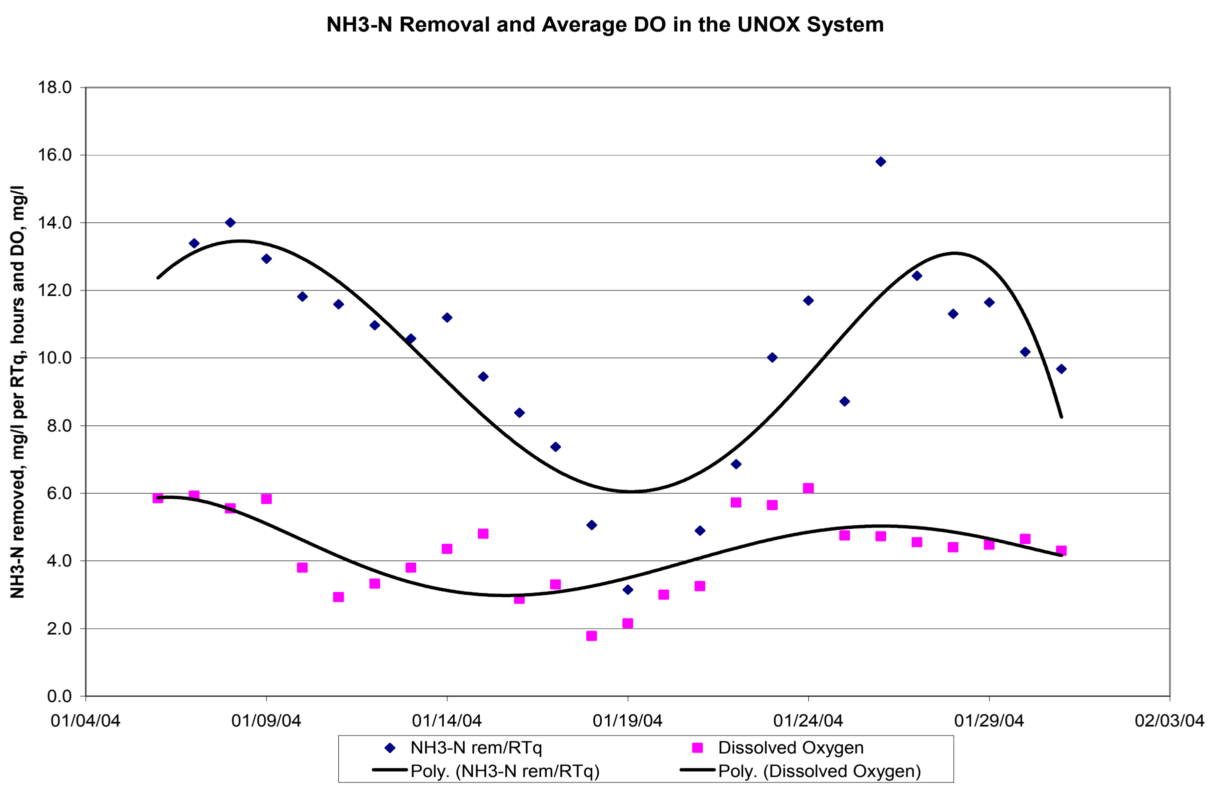


FIGURE 16



Denitrification in the pilot plant was also of interest. Figure 17 shows the concentrations of NO_2-N, NO_3-N, NOx-N (NO_2-N + NO_3-N), and ratio of feed flow to total flow into the anoxic stages. Throughout the program, the effluent NOx-N concentrations were consistently below the values expected based on the total of the clarifier recycle and the MLSS recycle flows to the anoxic zones. Figure 18 shows the ratio of observed NOx-N in the effluent to the calculated NOx-N expected based on the mg/l NH_3-N removed across the system. Note that typically only 40% of the expected NOx-N was observed in the effluent samples with several days reporting no significant effluent NOx-N. This low effluent NOx-N concentration suggests that there may be micro zones of anoxic conditions in the aerobic section that are consuming NOx-N before it even leaves the aerobic section. Figure 19 indicates a trend showing that as the average system DO increases, the observed NOx-N concentration rises toward the calculated NOx-N concentration, supporting a simultaneous denitrification hypothesis.

FIGURE 17

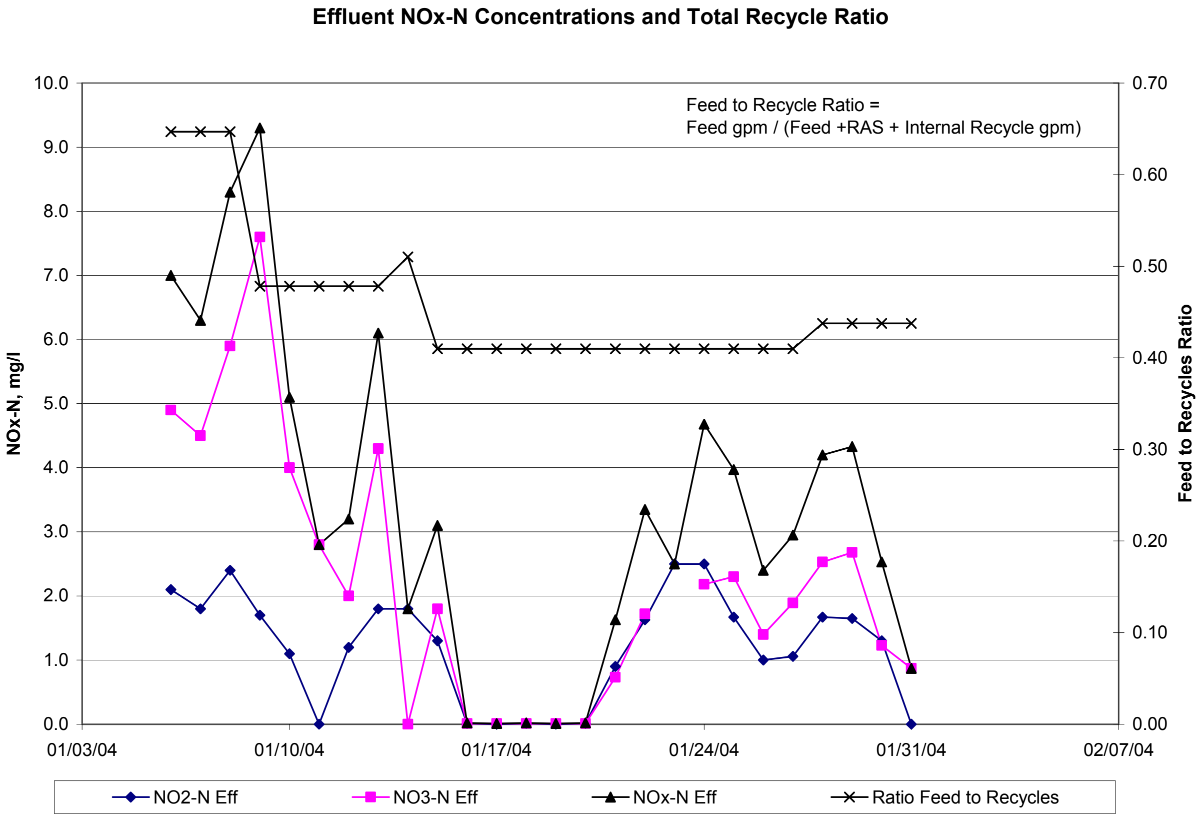


FIGURE 18

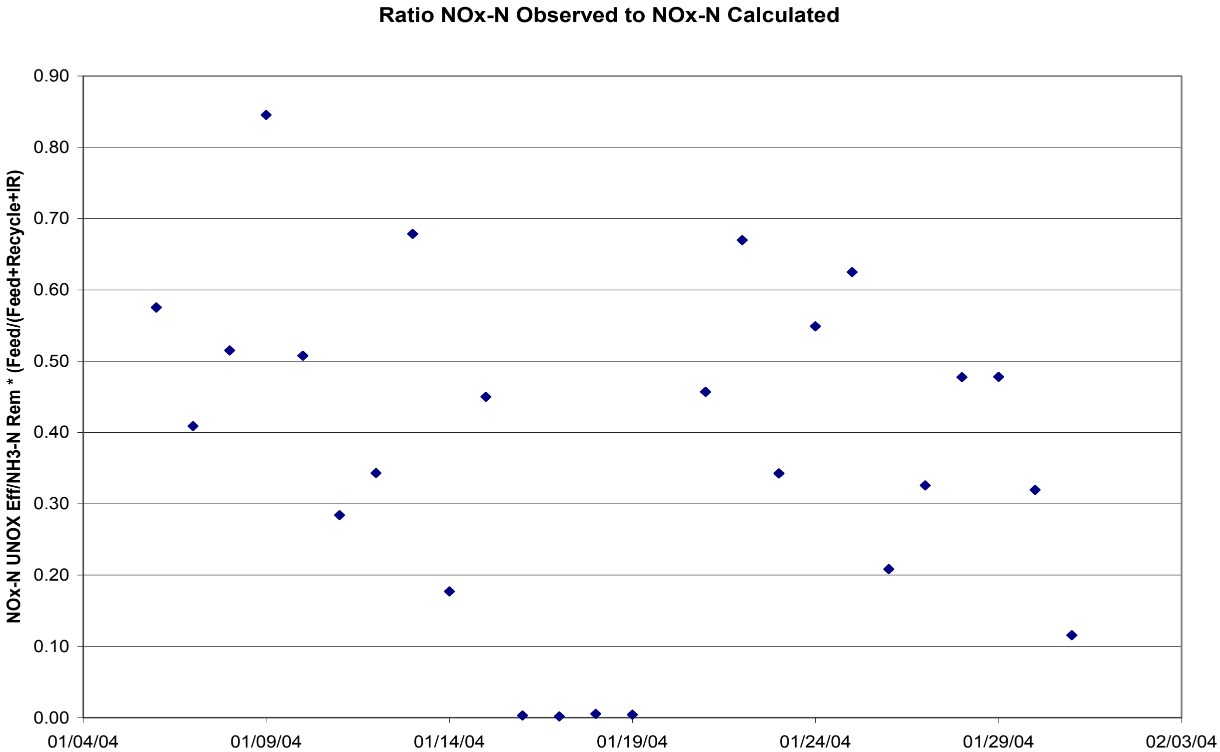
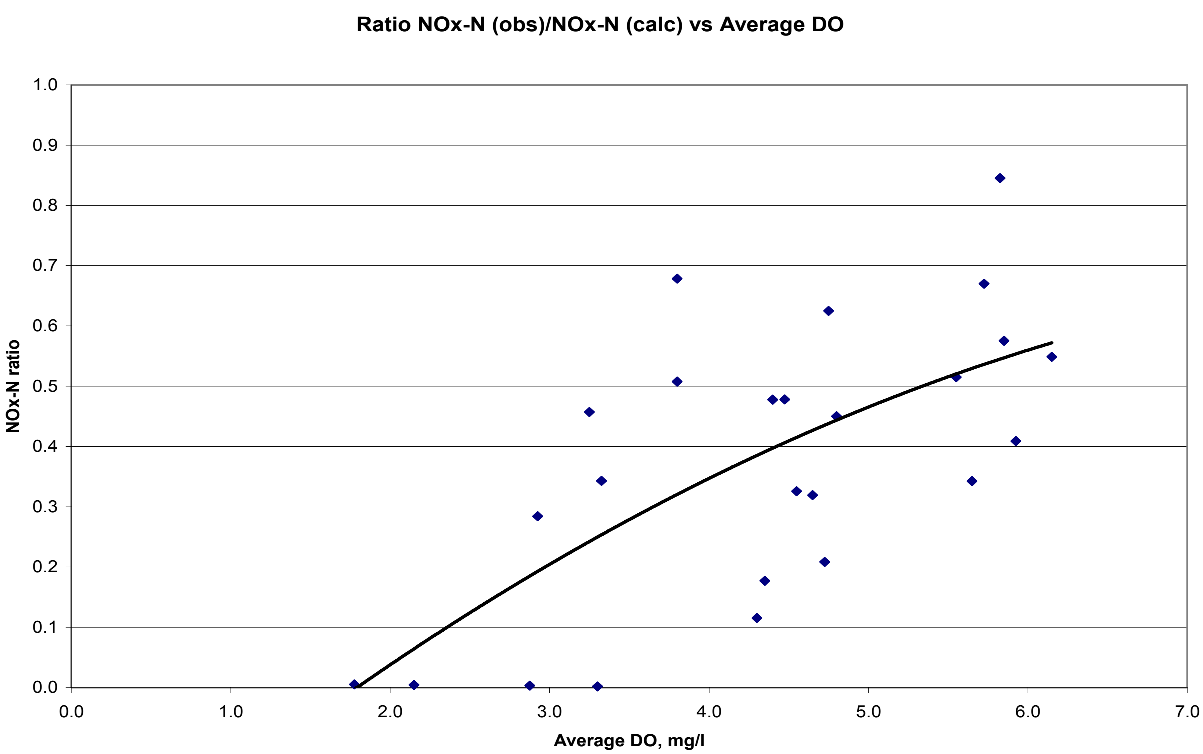


FIGURE 19



GENERAL CONCLUSIONS

Table 4 summarizes the general operating conditions for the centrate treatment system.

TABLE 4
CENTRATE TREATMENT SYSTEM SUMMARY PERFORMANCE

Operating Conditions	1/6/04 – 1/30/04
Duration, days	25
Average SRT, days	4.75
Average Feed NH_3-N, mg/l	940
Average Effluent NH_3-N, mg/l	4
Average Temperature, °C	29
Average Dissolved Oxygen, mg/l	3.1
Average / Maximum NH_3-N loading, lbs/1000ft3/day	35 / 42
Average Percent of Seed produced transferred to UNOX™ System, %	80%
Equivalent Centrate Flow for 25 MGD UNOX™ Flow, gpd (Based on observed seed transfer, assuming a 50 mg/l TSS concentration in the final clarifier effluent of the centrate nitrification system.)	250,000

Results of the pilot plant allow several general conclusions to be made on the design and operation of the centrate treatment system with the UNOX™ System.

- Complete nitrification of the centrate stream is achievable in a reasonable amount of time.

- Control of pH in the reactor seemed to be easily accomplished. During the program there were a couple of days where the caustic system malfunctioned. Separate episodes of very low pH and very high pH were observed on separate days. In both cases, upon correction of the problem, the centrate treatment system reactor recovered by the following day. Thus, even at low pH (about 5.4) or high pH (about 8.4) the system was only inhibited, not killed.

- Due to the small scale of the pilot plant, supplemental heat input and control of the centrate treatment system reactor temperature became important as the program progressed into winter. Heat losses due to exposed piping and small tanks were the major problems for the pilot plant. The historic centrate temperatures indicate there should be no need for heat addition in the full scale system. The expected winter centrate temperature is about 32 °C.

Table 5 summarizes the general operating conditions for the UNOX™ System.

TABLE 5
UNOX™ SYSTEM SUMMARY PERFORMANCE

Operating Conditions	1/6/04 – 1/30/04
Duration, days	25
Average SRT, days	2.85
Average Feed NH_3-N, mg/l	38.8
Average Effluent NH_3-N, mg/l	20.8
Average NH_3-NRemoval, mg/l	18.0
Average Effluent NOx-N, mg/l	3.3
Average Temperature, °C	23.6
Average Dissolved Oxygen, mg/l	4.3
Average / Maximum F/M, lbs BOD/lbs MLSS/day	0.74 / 1.16
Average MLSS, mg/l	3180

- The UNOX™ - BNR system with its anoxic step allowed stable operation of the system at MLSS concentrations of 3000 – 4000 mg/l. Effluent TSS and recycle solids concentrations showed acceptable separation and thickening was occurring in the clarifier at all MLSS concentrations observed.

- Nitrification in the UNOX™ System was established by seeding from the centrate system and declined during those periods when seeding did not occur due to problems in the centrate treatment system. Nitrification was also sensitive to the UNOX™ System dissolved oxygen concentration. Since the full scale UNOX™ System typically operates at greater than 4 mg/l DO, the full scale system will not be susceptible to any nitrification influences that may be related to low DO in the pilot plant.

- Based on the calculation of the amount of seed actually transferred to the UNOX™ System by accounting for the losses of seed, an equivalent centrate treatment system feed rate for a full scale system is given in Table 4. For the period discussed, the seed flow represented equivalent full scale nitrification of about 250,000 gallons of centrate per day. Treating the existing full scale centrate flow of 350,000 gpd would result in the full scale system receiving between 25% and 50% more seed than was fed to the pilot plant UNOX™ System. This will increase the NH_3-N removal across the UNOX™ System in full scale operation. At this time it is not possible to quantify the increase since the UNOX System removals are also dependent on SRT, temperature, and DO, based on the observations of the pilot plant.

- The UNOX™ System SRT was maintained in the 2-3 day range for most of the program. This is close to the minimum SRT needed to maintain nitrification on its own. Note that at this SRT range, it is probable that nitrification would not develop unassisted in the system since a nitrifying population would not be able to accumulate. However, even after seeding had established a nitrifying culture in the UNOX™ System, it never developed a stable steady state nitrification operation in the absence of seed addition. At the winter temperatures, the UNOX™ System SRT was below the calculated minimum critical SRT yet seeding did maintain a significant level of nitrification. This observation supports the conclusion that the seeding will maintain nitrification activity even when the SRT calculation would suggest nitrification would cease due to wash out of the nitrifiers. As discussed above, it appears that the shorter SRT and lower temperatures of the winter operation decreased the nitrification rates, which leads to the conclusion that winter operation would need more seed and/or longer SRT than was tested for complete nitrification to occur. The pilot plant results indicate that the UNOX™ System SRT is important for the system to nitrify, but there is no minimum threshold needed to realize measurable nitrification in a seeded full scale system.

- The use of air stripping to control the pH in the UNOX™ system was partially successful but was limited by the amount of air that could be injected and the contact time between the air and the contents of the final stage. Even with these limitations, the effluent pH was maintained above 6.5 for the entire program. In the full scale system, air stripping in the final UNOX™ stage can be designed to increase the stripping action beyond the limited amount available in the pilot plant. This would maintain or increase the average pH in the system due to better CO_2 stripping.

- In general, the full scale system is expected to nitrify as well as or better than the pilot plant system. Since a high DO is characteristic of the UNOX™ System, the SRT can be controlled by the operation of the system, and the system pH will be the same or higher due to improved CO_2 stripping, the full scale UNOX™ System will operate at more favorable nitrification conditions than were present in the pilot plant. Thus, effluent NH_3-N concentrations under 2 mg/l are expected to be achievable in the full scale system with full centrate treatment and seeding occurring.

SUMMARY AND CONCLUSIONS

The goals of the pilot plant program were accomplished.

- Centrate nitrification was demonstrated, design relationships were evaluated, and critical design parameters were established. These included acceptable reactor SRTs, pH range, DO range, and temperature ranges.
- Nitrification in the modified UNOX™- InNitri™ BNR train was accomplished at short SRTs and at pH values typical of UNOX™- HPO systems. Stable operation at MLSS concentrations greater than are routinely used in the full scale plant was demonstrated.
- Denitrification within the UNOX™- InNitri™ BNR system exceeded expectations, supporting a conclusion that in a full scale system, the minimum denitrification performance can be predicted using conventional design relationships.
- Seeding from the centrate nitrification system allowed the UNOX™- InNitri™ BNR system to provide significant nitrification and denitrification at SRT values significantly

below those considered necessary for a conventional system without the advantage of seeding.

The UNOX™- InNitri™ BNR System pilot program has identified several potential advantages over other systems or processes that may be considered for plant upgrades of UNOX™- HPO Systems to total nitrogen reduction systems. With the exception of the ability to operate at DO concentrations above 4 mg/l in the main reactor, these advantages will also exist in the upgrade of an air secondary treatment plant with mechanical or diffused aeration to a BNR nitrogen reduction system.

ACKNOWLEDGEMENTS

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