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AERATED ANOXIC BIOLOGICAL NdeN PROCESS

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Abstract: *The conventional practice for an anoxic denitrification basin has been to minimize oxygen input on the basis that it is detrimental to the process. For existing secondary treatment systems, allotting 25-35% of the aeration volume for an unaerated anoxic zone will significantly reduce plant capacity. Further, one group has held that bulking control is best achieved by eliminating all forms of oxygen from the initial contact or biological selector zones. The Phoenix 91st Avenue WWTP was designed with nitrate recycle to aerated selector zones and the anoxic zones were provided with a dense array of fine bubble diffusers. The prototype NdeN process was able to maintain the 1.31 m^3/s secondary capacity with aerated anoxic zone receiving 20-25% of the total airflow. Net sludge yields were 30-50% higher than anticipated due to primary clarifier solids losses at higher flows which reduced SRT_T to $\leq$ 5 days. At 5.0-5.5 day SRT_T, effluent averaged 8.3 mg/L TN, 1.75 mg/L NH_4N and 5.7 mg/L NO_3N.* ***Nitrobacter*** *N oxidation rates were unexplainably lower than the* ***Nitrosomonas*** *N oxidation rates causing effluent NO_2N.*

Keywords: Activated Sludge, nitrification, denitrification, aerated anoxic, bio-selection, upgrading for nutrient removal, *Nitrosomonas* and *Nitrobacter* growth rates..

Background. The 91st Avenue WWTP provides service for seven cities in the Phoenix, AZ, area; Glendale, Mesa, Phoenix, Scottsdale, Tempe, Tolleson, and Youngtown. The plant design capacity is 6.74 m^3/s when operating in a secondary treatment mode. The balance of the City of Phoenix wastewater is processed by the 23rd Avenue WWTP, a 1.62 m^3/s secondary treatment plant converted to nitrification-denitrification (NdeN) mode of operation in 1991 and now operating at 1.4-1.6 m^3/s producing an effluent TN of $\leq$ 8 mg/L.

The 91st Avenue WWTP consists of three separate primary stages which were then sub-divided into five secondary treatment stages. The design capacity in secondary treatment for the newest stage, Plant IIIA, was 1.31 m^3/s. This plant was selected for the prototype NdeN process. Two primary clarifiers (42.7 m diameter, 2.74 m deep), two four-pass aeration basins (384 m long, 7.62 m wide, 4.72 m deep), and eight secondary clarifiers (57.9 m long, 12.2 m wide, 3.81 m deep).

The wastewater is primarily of domestic origin except that it contains the excess biological sludge produced from 5 plants (including 23rd Avenue) treating up to 2.40 m^3/s. The Phoenix area WWTPs are subjected to higher December to March period flow and organic loadings due to increased tourism and part-time (winter) residents. The peak organic loadings occur at lowest wastewater temperatures of 19-21°C.

The future total nitrogen (TN) effluent requirement for the 91st Avenue WWTP is 10 mg/L. Based on an influent TKN of 40-50 mg/L, 75-80% NdeN will be necessary. Also, to minimize effluent toxicity, an un-ionized NH_4N level of ≤ 0.02 mg/L and a total NH_4N of ≤ 1.0 mg/L would be required in a 100% effluent stream at 25°C and a pH of 7.5. Therefore, effluent design targets would be ≤ 8 mg/L TN and ≤ 0.75 mg/L NH_4N.

Process Design. The most economical method to remove nitrogen from wastewater is using the influent wastewater organics to reduce (denitrify) the nitrates (NO_3N) to nitrogen gas in a previously nitrified mixed liquor. The anoxic (A_X) or denitrification (deN) zone is placed ahead of the nitrification (N) or oxic (O_X) zone and large volumes of the nitrified wastewater are recycled from O_X to the A_X zone. Typically, the A_X is mechanically mixed to exclude the introduction of oxygen which is considered to interfere with the deN process. The NdeN process for the 91st Avenue WWTP was provided with aerated anoxic selectors followed by aerated anoxic denitrification zones.

The unaerated A_X (including the selectors) volume necessary to produce a 80%$^+$ removal of TN would typically occupy 25-33% of the total biological volume. Thus, a conventional process design with 6 days oxic sludge retention time (SRT_{OX}) for nitrification at 20°C would then employ 8-9 days total SRT_T for NdeN.

The employment of 8-9 day SRT_T was estimated to reduce the biological treatment capacity to $\leq$ 5.1 m^3/s (75%) of the current secondary treatment capacity. Based on limited studies at Columbus, OH (Albertson, *et al.,* 1992) and 23rd Avenue WWTP (Albertson and Hendricks, 1992) and the literature, a prototype NdeN design was proposed and accepted for full-scale testing. In this design the A_X zones after the biological selectors would be heavily aerated using densely packed membrane diffusers. However, the operating D.O. would be essentially zero in these zones. While this appears contrary to accepted practice, Jansen and Behrens (1979) had presented formulations to indicate that nitrification and denitrification can co-exist with D.O. present.

The aeration basins (2) were modified and retrofitted for bio-selection and NdeN. The retrofitted 384 m long basins (Figure 1) were divided into two A_X selector zones with coarse bubble diffusers (CBD). Three further A_X zones, which are heavily aerated using fine bubble stone diffusers (FBD),

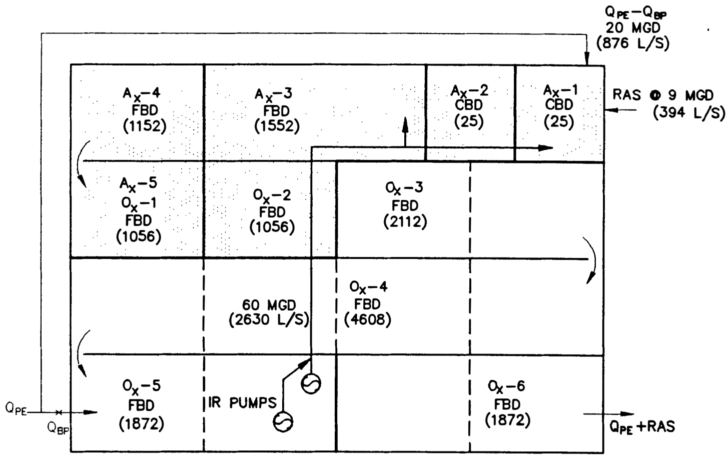

Figure 1. Aerated Selector and Anoxic NdeN Basin at 91st Avenue WWTP.

and are followed by five O_X zones with a target D.O. of 2-3 mg/L. Submerged partitions (12) in the basins were constructed of wood planking and steel supports and are designed to cause a slight head loss to prevent flotables from being entrapped. The two internal recycle (IR) pumps/basin were low head propeller pumps capable of transferring 2.63 m^3/s at 1.2 m of head to Zones SA_X-1 and SA_X-3. The flow split is approximately 33% to SA_X-1 and 67% to S_X-3. The 122 cm∅ fiberglass IR pipe was placed submerged within the basin by coring the walls between Passes 1-2, 2-3 and 3-4.

Algal growths were controlled in one of eight secondary clarifiers by metallic covers over the launders and weirs. Secondary clarifier limitations are being evaluated in one clarifier by stacking flights two high (38 cm deep), increasing the flight speed to 1.22 m/min, increasing the inlet area about 1000%, installing a 0.9 m high waterfall baffle at the 0.33 length of the basin and adding a cover over the return sludge outlet to reduce short-circuiting. These changes are still under evaluation, but based on initial observations, will be implemented in all 8 secondary clarifiers.

The design target was a flow of least 1.31 m^3/s and aeration capacity to 1.75 m^3/s was installed. The minimum SRT_T would be 5.1 days at 1.76 m^3/d and a PE COD of 370 mg/L. The 5-day SRT_T was based on a MLSS of 3050 mg/L and a net sludge yield (Y_N') coefficient of 0.32 kg/kg COD_R and a total sludge yield (Y_N) of 16,480 kg/d. The minimum SRT_{OX} would be about 3.5-3.8 days at 1.75 m^3/s and about 5.1 day SRT_{OX} at 1.31 m^3/d.

The construction of the demonstration facility was completed late September, 1992, and data collection was started on October 3, 1992. The low SRT_T aerated anoxic process has been evaluated since startup and current work is ongoing evaluating effects of improved primary clarification.

Operating Results

The design and operating results from 7 days/week composite testing are summarized in Table 1. The PE COD concentrations and the solids yield coefficients were significantly higher than expected. As a result, there was difficulty in maintaining the minimum design SRT_T target of 5.0-5.5 days. The inability to maintain the target SRT_T, due to the higher sludge yield, resulted in reduction of the flow rate in Periods B and C. The total net sludge yields, kg/1000 m^3, were 133%, 152%, and 133% of design for Periods A, B, and C, respectively. The removals of COD, BOD_5, and TSS were stable throughout the study.

The biological selectors have generally maintained the DSVI in the range of 75 ± 10 mL/g. However, chlorine feed to the RAS has been periodically (0-2 day/10 days) employed to keep the DSVI below 85 mL/g when SRT was $\leq$ 5 days. The existing clarifier capacity is solids limited when the DSVI increases to greater than 90 mL/g. Microscopic examination did not indicate significant amounts of filaments present in the sludge. The clarifier inlet shear and resulting turbulence caused a stable light fluffy blanket to develop above the dense phase during peak flow periods. Modifications to all final clarifiers have not been initiated, but the initial observations of the first clarifier conversion indicate that an increase in capacity will be achieved.

Based on the high sludge yields, lab testing of primary clarification was conducted. This analysis suggested that the primary clarifier efficiency may be limiting the aeration capacity, and resulted in a full-scale study of the performance characteristics vs flow. At 1.5 m/hr the primary clarifier TSS removals are 60-65%, but removals decrease to 40-45% at 2.2 m/hr during peak flow periods. Microscopic analysis of the overflow solids revealed significant levels of activated sludge comprised the TSS in the overflow. The presence of WAS would explain higher yield coefficients.

Table 1. Design Basis and Performance of the NdeN Process

	Target Design Basis	Process Data Period A (10/3-12/14)	Period B (12/15-2/20)	Period C (2/20-4/5)
Flow - m^3/s	1.75	1.54	1.43	1.25
Temperature - °C	20	27.1	23.9	24.4
PE COD - mg/L	370	438	435	415
PE TSS - mg/L	103	126	133	118
PE TKN - mg/L	37.0	37.9	44.9	36.4
SRT$_T$ - days	5.1	5.0	5.0	5.7
Y$_N$' - kg/kg	0.32	0.35	0.41	0.38
MLSS - mg/L	3050	3385	3397	3196
RSS - mg/L	10,000	9683	9171	9749
Y$_N$ - kg/1000 m^3	109	145	166	145
FE COD - mg/L	40	27	42	43
FE BOD$_5$ - mg/L	6	3.4	5.5	4.0
FE TSS - mg/L	10	4	12	13
FE TKN - mg/L	2.0	2.2	5.4	3.2
FE NH$_4$N - mg/L	0.5	1.4	2.8	1.2
FE NO$_3$N - mg/L	6.0	5.6	2.6	6.1
FE NO$_2$N	—	NM	1.0	0.3
FE TN - mg/L	8.0	7.8	11.0	9.6

The actual oxygen transfer efficiency of the system was monitored using an equivalent oxygen balance accounting for COD removal, sludge wasting, and nitrification-denitrification. The oxygen efficiency decreased with SRTs less than 5 days at 25-30°C and with less than 5.5 days at 22-25°C. Figure 2 provides a summary of 230 days of data comparing FE COD and SCOD vs the actual oxygen transfer efficiency. The average DO level of the four passes was 2.0-2.5 mg/L.

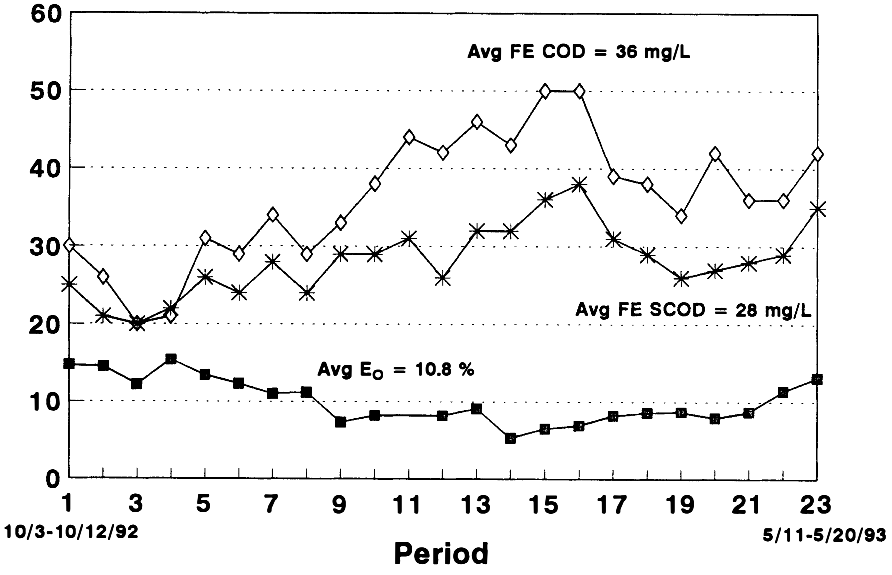

Figure 2. Impact of Final Effluent COD$_6$ on the Uncorrected Oxygen Transfer Efficiency.

The rapid removal of SCOD in the initial A_X zones enhances oxygen transfer by improving αF. The SCOD has decreased to the effluent range within 12 minutes of passage through the aeration as indicated by an average 34 mg/L SCOD in A_X-3. However, the reduction in oxygen transfer was associated with SRT less than 5.5 days and the small increases in effluent SCOD and COD.

Nitrification and Denitrification Kinetics

Three different test methods were used to develop nitrification and denitrification rate data as a function of dissolved oxygen concentration and plant operating conditions. These tests were 1) a plant profile test, 2) batch rate test, and 3) a reactor flow-through test. The plant profile test involved sampling each basin in the anoxic-aerobic system at time intervals approximately equal to the time that a selected influent volume would travel through the basins, including the effects of return sludge and internal recycle flows. Batch tests involved transporting mixed liquor samples from selected basins to laboratory reactors. A time lag of about 10-15 minutes occurred for each test. The flow-through test at the basin involved pumping mixed liquor to a small reactor and was developed to provide an easier test to determine nitrification and denitrification rates under more controlled conditions for DO concentration.

Figure 3 shows an example of the basin profile data for November 18, 1992 sampling. NH_4N, NO_3N, DO and SCOD concentrations are plotted as a function of the nominal detention time. The nominal detention time of the first 5 anoxic basins was only about 20 minutes. The SCOD profile shows that most of the SCOD is removed by A_X-3 and more than half of it is removed in A_X-1 that has only about a 4-5 minute nominal detention time. The NH_4N concentration drops in A_X-3 due to the internal recycle flow dilution. The figure further shows a linear decrease in ammonia concentration in the aerobic portion of the basin due to nitrification.

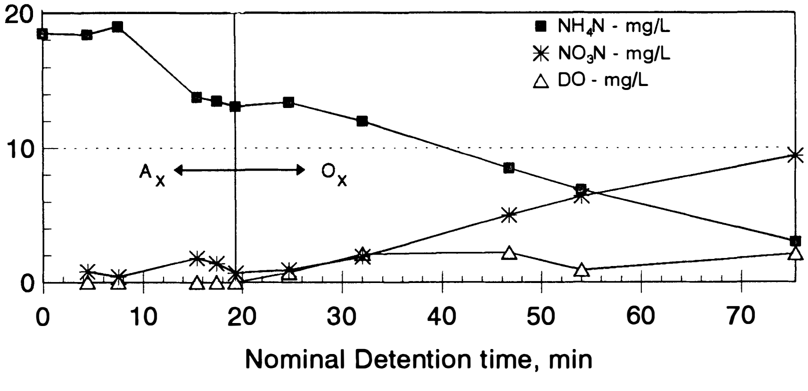

Figure 3. Aeration Basin NH_4N, NO_3N and D.O. Profiles

The NH_4N profile was used to evaluate the basin nitrification rate and estimate the maximum specific growth rate of the *Nitrosomonas* bacteria. The following mass balance for NH_4N removal was developed and used to fit the data to determine $\hat{\mu}_N$, the maximum specific growth rate:

$$N_n = N_{n-1} - (\hat{\mu}_N/Y)\,(X_n)\,(V_n/Q_n)\,(N_n)\,/\,(K_n + N) \qquad (1)$$

where N_n = NH_4 concentration of basin n, mg/L
N_{n-1} = NH_4 concentration of previous basin, mg/L
X_n = Nitrifier concentration, mg/L
Y = *Nitrosomonas* yield coefficient, g/g

V_n/Q_n = Nominal detention time of basin based on volume and test flow, days
K_n = Nitrification half velocity constant; assumed to be 0.5 mg/L.

The value for V_n/Q_n was based on the recorded influent and return activated sludge flows and assumed internal recycle flow during the test. The nitrifier biomass concentration was calculated from the daily plant data average operating conditions around the test period as follows:

$$X_n = Y(N_{OX})(SRT)/(V/Q) \tag{2}$$

where N_{OX} = Influent nitrogen concentration oxidized, mg/L
Q = Influent flow rate, m^3/d
V = Basin volume, 104,126 m^3
SRT = Average solids retention time, days

The value for N_{OX} was calculated based on nitrogen used for synthesis, the average influent TKN concentration, and the average effluent NH_4N concentration around the test period. The nitrogen used for synthesis was based on an assumption of 8 percent nitrogen in the waste sludge, the measured solids yield and the average COD removal.

A spreadsheet program was used to solve equation 1 using the observed NH_4N concentration in each stage. A least squares error was calculated between the observed value and calculated value. The $\hat{\mu}_N$ value that resulted in the minimal sum of the least squares error was selected as the "best fit" $\hat{\mu}_N$ value. This results in a calculated NH_4N profile closest to the measured NH_4N profile.

The best fit $\hat{\mu}_N$ values are summarized in Table 2, and the values range from 0.35-0.59 d^{-1} with an average value of 0.49 d^{-1}. There is not a clear temperature effect on the maximum specific growth rate value with the value at the lowest temperature 22°C being close to the average value. These results are shown as estimated $\hat{\mu}_N$ values, since the calculation is dependent on many factors including nitrogen in sludge production, the average SRT, an average influent total nitrogen concentration and the organic nitrogen that is hydrolyzed to NH_4N.

During batch testing both nitrite and nitrate nitrogen concentrations were measured to compare *Nitrosomonas* and *Nitrobacter* kinetics. Table 3 summarizes nitrification batch test results and the calculated $\hat{\mu}_N$ values. The $\hat{\mu}_N$ values were calculated from zero order ammonia oxidation rates during tests with an initial concentration of 10-30 mg/L of NH_4N.

Table 2. Aeration Tank Profile Nitrification Summary

	Influent	Temp		Effluent, mg/L			Avg	Calc
Date	**Flow, m^3/s**	**°C**	**NH_4N, mg/L**	**NH_4N**	**NO_3N**	**NO_2N**	**SRT_T d**	**Nitrif. $\hat{\mu}_N$, d**
10/12/92	0.88	31	32.0	2.2	9.3	2.5	4.8	0.59
10/26/92	1.00	29	32.0	1.0	0.5	0.2	5.1	0.47
11/4/92	0.93	27	35.0	1.0	11.4	0.4	5.1	0.40
11/9/92	0.46	27	34.8	0.2	5.8	0.0	5.6	0.35
11/10/92	0.53	27	39.0	0.3	8.7	0.1	5.6	0.40
11/17/92	0.96	27	35.8	2.9	10.0	0.7	5.1	0.52
11/18/92	0.96	27	35.8	3.0	8.7	0.7	5.1	0.58
1/5/93	0.83	22	39.2	3.5	7.9	3.7	5.1	0.50
4/17/93	0.74	25	38.0	1.2	13.6	0.10	5.8	0.58

$$\hat{\mu}_N = \left(\frac{d_n/dt\,(Y)}{X_n}\right)$$

where:

d_n/dt = NH_4N or NO_2N oxidation rate, mg/L·d
Y = yield coefficient of *Nitrosomonas*, g/g
X_n = *Nitrosomonas* biomass concentration, mg/L

The nitrifier biomass concentration was calculated as before from the plant daily data using average SRT values and ammonia removal values for the period when the MLSS was removed for the batch tests. This analysis assumes that both nitrifiers process all the ammonia removed from solution. The results in Table 3 shows that the average $\hat{\mu}_N$ value for *Nitrosomonas* is in the same range as that determined from the plant profile data. The data further shows a lower rate of nitrogen oxidation by the *Nitrobacter* compared to the *Nitrosomonas* during zero order ammonia oxidation rates. *Nitrobacter* nitrogen oxidation rate was about 70 percent of that for the *Nitrosomonas*. The flow through reactor tests also showed a similar relationship between NH_4N and NO_2N oxidation rates.

Table 3. Estimated Maximum Specific Growth Rates from Batch Nitrification Tests (T = 23 - 27°C)

MLSS Source Basin	Test Avg DO Conc, mg/L	***Nitrosomonas*** $\hat{\mu}_m$, d^{-1}	NO_2N/NH_4N Oxidation Rate
O_X-6	2.4	0.41	0.78
O_X-6	2.4	0.48	0.81
O_X-6	2.5	0.32	0.69
O_X-6	2.6	0.54	0.70
O_X-6	2.5	0.50	0.72
O_X-6	2.5	0.50	0.64
O_X-6	3.0	0.41	0.66
A_X-1	2.5	0.47	0.66
AVG	–	0.45	0.71

Flow-through reactor tests were also done to investigate the effect of DO concentration on nitrification rates, using mixed liquor from basins A_X-1 and O_X-2. Ammonia was added to the flow-through reactor during the tests so that zero order nitrification rates were observed and maximum specific growth rates were then calculated from the rate data. The results of these tests are shown in Figure 4. The nitrification rates were effected by DO concentration for both systems. The nitrification rates at DO concentrations of 0.70 and 1.5 mg/L were lower for A_X-1 and this may be related to the higher oxygen demand of the floc in A_X-1. As the DO concentration is increased from 0.70 mg/L to 2.4 mg/L, the $\hat{\mu}_N$ value for the O_X-2 mixed liquor about doubles, from 0.19 d^{-1} to 0.41 d^{-1}.

Specific denitrification rates (SDNRs) calculated in terms of gNO_3N reduced per g MLSS·d were determined by performing mass balance calculations for nitrate nitrogen around A_X-1 and A_X-3 using the plant profile test data. The balance accounted for the influent, recycle sludge and internal recycle flow rates and the nitrate nitrogen concentrations in each basin. Batch tests and flow-through reactor tests were also conducted to determine SDNRs at zero DO concentrations using mixed liquor from basin A_X-1. The SDNRs for A_X-1 and A_X-3 for the plant profile data averaged 0.20 and 0.09 g/g-d, respectively. While the SDNRs in A_X-1 ranged from 0.16 to 0.28 g/g·d, the values could not be correlated with changes in temperature or influent COD concentrations. It is interesting to note that the following empirical equation (Stensel, 1981) developed for first-stage anoxic basins predicts average SDNR values of 0.21 and 0.06 for A_X-1 and A_X-3, respectively, or very similar to the values determined for 91st Avenue. The equation is SDNR = 0.03 (F/M) + 0.029 at a temperature range of 18-23°C.

The SDNRs for the flow-through reactor testing were similar to that determined by the profile mass balances, while lower SDNRs were observed from the batch testing. The lower values can be explained by the lack of a continuous influent substrate addition during the batch testing.

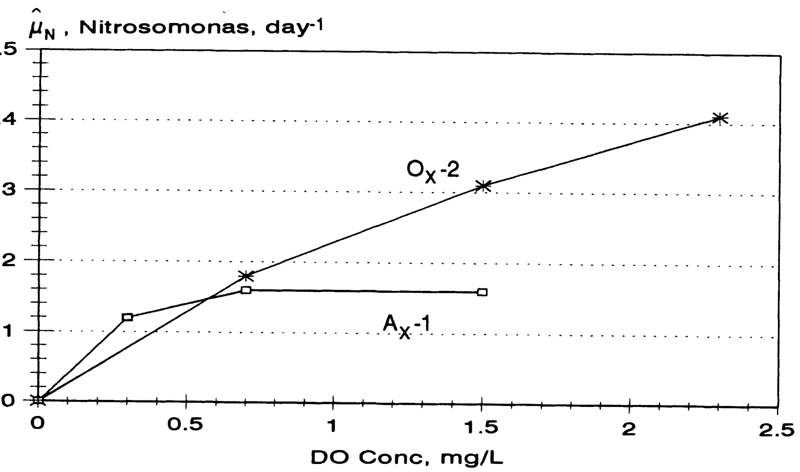

Figure 4. Nitrification Rates vs D.O. in A_x-1 and O_x-2.

Batch test and flow-through reactor testing were also done to observe the effect of DO concentration on SDNR values. The results indicate the potential for denitrification at reduced rates with residual DO concentrations in the basin. For the batch tests using A_X-1 mixed liquor, the SDNR was not seriously inhibited at a DO concentration of 0.15 mg/L. At DO concentrations of 0.40 and 0.80 mg/L a significant SDNR existed, but a similar effect was not observed for A_X-1 mixed liquor in the flow-through tests. However, with O_X-2 mixed liquor, low SDNR values were observed for DO concentrations ranging from 0.7 to 2.3 mg/L. While more data is needed to develop better relationships between SDNR and DO concentration, these test results suggest that denitrification may occur with DO present in the mixed liquor.

Approximate mass nitrogen balances were prepared and the results of this analysis are included in Table 4. The calculated denitrification level based on the IR and RAS recycle to the total flow through the anoxic zones did not account for the TN removed even with the assumption all NO_3N was removed in the RAS and Q + IR + RAS leaving the anoxic zone A_X-5. Calculated denitrification in Table 4 is equal to (IR + RAS)/Q + IR + RAS.

Table 4. Approximate Mass Nitrogen Balances and Denitrification.

Test Period kg/d	PE TKN kg/d	WAS OrgN kg/d	FE TN kg/d	FE NO_xN %	TN Rem %	Approx deN %	Calc deN %
A	2292	512	484	351	78.8	78.9	68.8
B	2521	519	466	358	81.5	79.3	70.7
C	1787	392	471	314	71.5	74.6	71.8

Discussion of the Study Results

While the fully aerated NdeN process did surpass the secondary treatment capacity of 1.31 m^3/s, it did not achieve its goal of 1.75 m^3/s. The reason for the inability to process the flow was an inability to maintain SRT_T at about 6 days to provide 4-4.5 SRT_{OX} required for complete nitrification. The problem was attributed to higher than anticipated COD and TSS from the primary clarifier which increased sludge yield to 133-153% of design.

The higher than anticipated yield appears to be due to WAS generated from an upstream NdeN plant at 23rd Avenue. Historically, the problem of primary clarification losses at 91st Avenue apparently occurred after conversion of 23rd Avenue to NdeN. Recent ongoing tests at reduced clarification overflow rates are producing PE COD levels and yield coefficients well within the original design criteria which define the need and value of increased primary clarification capacity. Also, these results indicate the treatment capacity will then be about 1.60 to 1.75 m^3/s.

The detailed analysis of the results has indicated that the minimum SRT_T and SRT_{OX} to produce the necessary NH_4N and TN at a $NO_2N < 0.2$ mg/L is ≥ 6 and 4.1 days, respectively. A lower yield coefficient due to improve primary treatment would increase nitrifier populations 130-150% and this could result in an SRT_T of more than 6 days satisfying effluent criteria at 1.75 m^3/s and controlling NO_2N production.

Due to the practice of aerating the A_X-1 through A_X-5 with 20-25% of the total air flow, process failure was anticipated to be breakthrough of the anoxic zone by NO_3N. Since appreciable nitrification had occurred at 1.2 days, nitrification at 3.0-3.5 day SRT_{OX} was expected to be complete. However, full-scale results have consistently demonstrated that nitrification is lost first as evidenced by increasing NO_2N and NH_4N and lowered NO_3N concentrations. While the 20-25% of the air flow did satisfy an appreciable amount of the oxygen demand in the A_X zone, there was no indication that this reduced the total denitrification capacity of the 91st Avenue WWTP.

The nitrogen profiles and the nitrification rate studies have provided some insight to this situation. For 91st Avenue wastewater and the aerated NdeN process, the tests indicated that the *Nitrosomonas* NH_4N oxidation rate at high NH_4N levels was 20-30% higher than the NO_2N oxidation rate by *Nitrobacter*. While this is opposite to general experience, it does explain the sudden appearance of NO_2N when the SRT_T decreases since *Nitrobacter* is the limiting growth rate. The question arises whether this is due to aerated anoxic zones. The possibility of selective toxicity/inhibition of the *Nitrobacter* population will be evaluated.

The NO_2N appears in the effluent at lower SRTs and when excessive wasting of sludge occurred. Also, there is a buildup of NO_2N during the peak flow periods. During these periods the TKN loading is 40-60% higher than average and MLSS concentrations will decrease as the clarifier inventory (sludge depth) increases. Based on the respective growth/oxidation rates of *Nitrosomonas* and *Nitrobacter* found by the testing at 91st Avenue, the presence of NO_2N during stressed loading conditions would be expected.

The 23rd Avenue WWTP also has aerated anoxic zones and this facility has not observed problems of NO_2N production at SRT_T of 5.5 to 6 days except when toxic events occurred. The Santa Fe, NM, fully aerated staged anoxic-oxic process is producing an average of 9.1 mg/L TN, 3.0 mg/L NH_4N, 2.9 mg/L NO_3N and 0.10 mg/L NO_2N at 7-9 day SRT_T and 17-19°C. The ammonia is higher due to limitations in the aeration capacity in the oxic zones until plant modifications to increase oxygen transfer are completed.

Summary and Conclusions

1. The 91st Avenue Plant IIIA was converted to a prototype NdeN system to minimize the biological volume requirements for a ≤ 10 mg/L TN limit. The aerated NdeN process produced a settled effluent of 36 mg/L COD, 4.3 mg/L $CBOD_5$, 9 mg/L TSS, 1.7 mg/L NH_4N, 5.7 mg/L NO_3N and 8.3 mg/L TN at 5.2 day SRT_T for a 6^+ month period.

2. The secondary treatment capacity of 1.31 m^3/s was maintained in the NdeN mode, but the sludge yields have been 33 to 50% higher than anticipated due to a combination of stronger primary effluent and a higher sludge yield coefficient.

3. The higher sludge yield is due to poorer solids recovery by the primary clarifiers due to the daily peak flows and WAS discharged by upstream WWTP and DAF recycle.

4. The capacity of Plant IIIA in NdeN when fully modified will be 30-32 MGD (same capacity in as secondary treatment) and 36-40 MGD with added primary clarifiers.

5. While the aerated anoxic zones have reduced the nitrate nitrogen, there has been unexpected and unresolved difficulty in maximizing the nitrification rate. At zero order NH_4N removal rates, *Nitrosomonas* oxidation rates have exceeded *Nitrobacter* oxidation rates leading to excess NO_2N at low SRT and peak loadings.

6. Specific growth rates for *Nitrosomonas* average 0.49 day^{-1} with no effect of temperature between 25-31°C.

7. Average SNDR values ranged from 0.20 to 0.09 g/g MLSS·d in the staged aerated anoxic zones.

Acknowledgement

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