THE MARSHALL STREET ADVANCED POLLUTION CONTROL FACILITY (CLEARWATER, FLORIDA) CONVERSION TO 4-STAGE BARDENPHO TO IMPROVE BIOLOGICAL NITROGEN REMOVAL

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ABSTRACT

The City of Clearwater's Marshall Street Advanced Pollution Control Facility (MSAPCF) consisted of a five-stage Bardenpho process to achieve biological nutrient removal (BNR). The MSAPCF has a permitted capacity of 10.0 million gallons per day (MGD) annual average daily flow (AADF) and effluent total nitrogen (TN) and total phosphorus (TP) limitations of 3.0 mg N/L and 1 .0 mg P/L, respectively. The plant effluent TN often exceeded of 3.0 mg N/L due to poor denitrification performance which elevated effluent nitrate-N concentrations. In addition, the plant had to rely on chemical precipitation with alum to comply with the effluent TP limitation of 1.0 mg P/L due to insufficient enhanced biological phosphorus removal (EBPR). The plant data indicated that $CBOD_5$ to ammonia-N ratio in the primary clarifier effluent was less than 5.0 which is considered as moderate for BNR (Grady et al., 1999). The organic substrate requirement of a five-stage Bardenpho system is high since the goal is to remove both nitrogen and phosphorus by biological treatment. Additionally, the plant's mixed liquor recirculation (MLR) flow from the first aeration basins was previously designed to cascade through an elevated Parshall flume, stepped channels, and through an elevated channel and with several elevated port openings into the first anoxic basins. The excessive mixing and agitation of the MLR flow entrained air and provided dissolved oxygen to the anoxic tanks reducing denitrification performance. The MSAPCF performance and alternative scenarios were evaluated with the calibrated Biowin process model. As a result of evaluation study, the plant process configuration was converted to a four-stage Bardenpho by redirecting MLR flow to the existing fermentation tanks to lower effluent nitrate-N. This resulted in an increased anoxic solids retention time (SRT) and elimination of the phosphorus accumulating organisms (PAO) from the system thereby making all the volatile fatty acids available for the denitrifiers. After the conversion, the alum dosing rate was not changed to maintain effluent TP below 1.0 mg/L suggesting that the POA played a little role for the removal of phosphorus before the process conversion. The oxygen mass loading from the current cascade effect of the MLR flows was also lowered by redesign of the MLR system and piping. After these changes, the average effluent nitrate-N concentration was reduced to 1.5 mg/L. In addition, the effluent nitrate-N had diurnal variations that exceeded 5.0 mg/L during night time flows and loads. Following the design upgrades, diurnal variations of effluent nitrate-N concentrations are usually below 2.5 mg/L. In summary, these modifications eliminated the need for addition of external organic substrate (i.e. methanol) to improve denitrification performance of the MSAPCF.

KEYWORDS

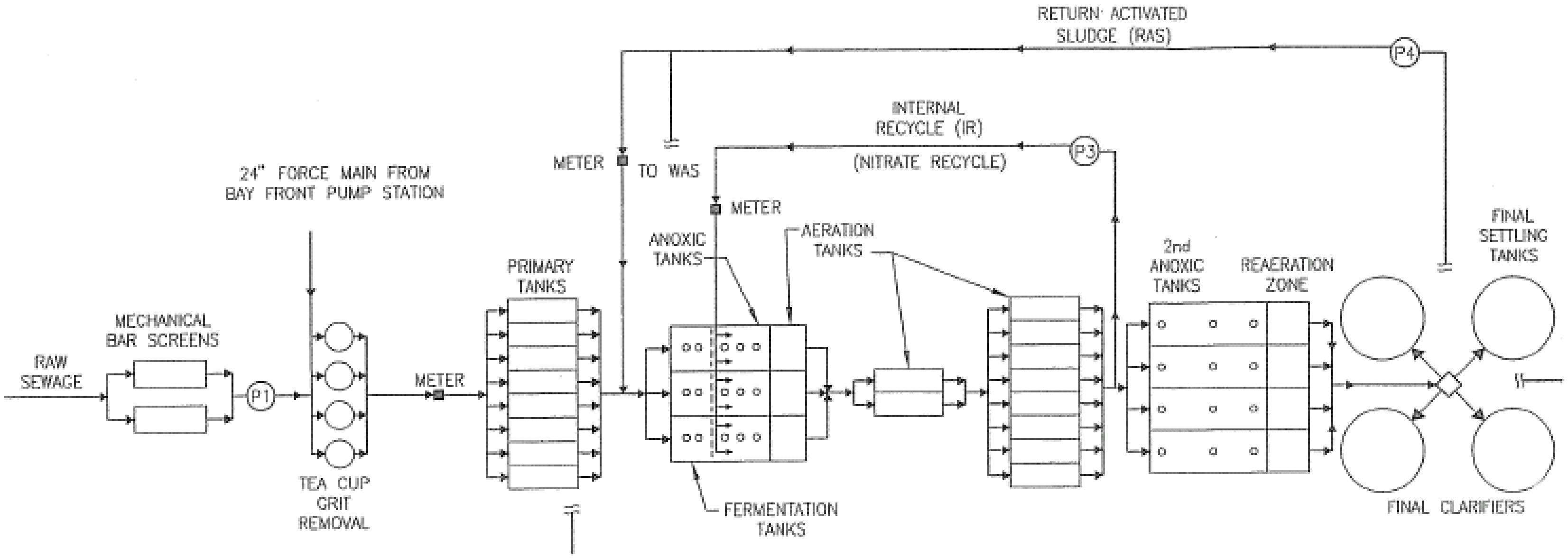
Biological nutrient removal, Bardenpho process, denitrification, enhance biological phosphorus removal

INTRODUCTION AND BACKGROUND

The MSAPCF is owned and operated by the City of Clearwater along with two other wastewater treatment facilities. The facility was originally brought on line in 1930 and has been expanded and updated several times since inception. It was upgraded from a conventional secondary treatment plant to an advanced wastewater treatment facility with 5-stage Bardenpho process in the ~~early~~ **late** 1990's. Fermentation, anoxic and aeration basins were added during upgrades. Currently, the MSAPCF is permitted to treat wastewater flows up to 10.0 MGD AADF. Figure 1 shows process flow schematic of the MSAPCF. The facility consists of the following components: preliminary treatment consisting of two mechanically cleaned fine bar screens, a four unit vortex-cyclonic grit removal system with associated grit classifier; primary treatment consisting of eight rectangular sedimentation basins; a biological treatment process consisting of three fermentation basins, three first anoxic basin, thirteen aeration basins, four second anoxic basins, and four re-aeration basins; four 100-ft diameter secondary clarifiers.

The MSAPCF effluent limitations for TN and TP are 3.0 and 1.0 mg/L, respectively. Although the facility influent AADF have been about 5.0 to 7.0 MGD AADF, 50-70% of its design capacity, BNR performance of the facility was not sufficient. The effluent TN concentration often exceeded 3.0 mg/L. In addition, the plant must rely on chemical precipitation with alum to comply with the TP effluent limit of 1.0 mg/L. This project was part of a larger wastewater infrastructure assessment project conducted for the City of Clearwater, and the purpose was to identify performance limiting factors for BNR, and develop recommendations to improve the performance of the facility. Specifically, the primary goal of this study was to optimize the facility's ability to meet the current effluent TN limit consistently. This required both operational process optimization and physical modifications.

Figure 1 – The MSAPCF four and five-stage Bardenpho process flow schematic.



METHODOLOGY

Analysis of Operational Issues

The analysis of the plant performance was started with the workshops conducted with operators to discuss plant operation and performance under varying flows and loads. The workshops were followed by several plant inspections. From the information provided by the MSAPCF staff and facility inspections, several operational and design issues were identified.

The first issue identified was the reaeration of the MLR flow. As the MLR flows were conveyed into the first anoxic basins, the turbulence of the flow caused by the design layout was reaerating the mixed liquor. Such reaeration is undesirable since it inputs a large mass of oxygen into the first anoxic zone, which reduces the efficiency of denitrification. The worst of the reaeration appeared to occur from the discharge of the MLR pumps and during flow through the Parshall flume and stepped open channel (not shown), and again as the MLR flow “freefalls” into the head end of the first anoxic basins (Figure 2). This aeration impeded the denitrification process as oxygen was effectively introduced as the wastewater was theoretically entering an oxygen-free zone. During facility inspections, DO levels in the MLR flow were measured to be 3.0 mg/L prior to the cascade into the anoxic basins.

Each MLR pump is rated for 12 MGD. Normal operations at the plant entailed the use of three MLR pumps providing an estimated total MLR flow rate of 36 MGD. It was estimated that the MLR flow added approximately 900 lbs/day of oxygen to the first anoxic basins. To put this into perspective, the total average day oxygen demand for the entire plant was estimated to be 10,500 lbs/ day. Therefore, about 8.5% of the plant’s total oxygen demand was being provided by the oxygen contained in the MLR flow. The operational staff found that the nitrate-N levels in the effluent fluctuate diurnally, with the highest levels found during the periods from 1:00 AM to 5:00 AM suggesting that the plant influent flows and loads were lower and DO in MLR had more profound effect. Three of the four MLR pumps were operated manually providing 36 MGD all the time. This was too much MLR flow compared to the influent flows of 3.0 to 4.0 MGD at night times. MLR flow should be adjusted to be at 400% of influent flows.

Based on DO measurements taken within the first anoxic basins, it is estimated that the oxygen introduced from this freefall essentially creates an aerobic zone within the initial portion of the first anoxic basins. This induced aerobic zone is estimated to occupy approximately 1/3 of the total volume of the first anoxic basins, leaving only 2/3 of the basin for actual anoxic treatment. The plant staff used a common strategy to minimize the DO returned to the first anoxic basins with MLR. DO level in the aeration basins 6 through 13 was maintained between 0.5 and 1.0 mg/L. These DO levels also allowed simultaneous nitrification and denitrification to occur in those aeration basins. This operation did not affect nitrification efficiency at the plant evidenced by the average effluent ammonia-N concentrations of 0.1 mg/L.

The flows and loads analysis of 2001, 2002, and 2003 plant data clearly suggest that the plant influent may not contain sufficient concentrations of $CBOD_5$ during several months of the year to allow for optimal efficiency of the BNR process. The plant was designed for the influent $CBOD_5$ concentration of 220 mg/L. However, the average daily influent $CBOD_5$ concentration was 166 mg/L for the last three years. Complicating this issue is the fact that the plant operates primary clarifiers which remove a portion of the influent $CBOD_5$ associated with particulate material. Primary clarifier effluent had an average $CBOD_5$ concentration of 120 mg/L which is relatively low and can be a limiting factor for BNR. **The primary clarifiers and anaerobic digester were rehabilitated and brought online to remove copper, a permit requirement, and to reduce the hauling costs.** ~~For a time, primary sludge was pumped from the primary clarifiers to the first anoxic basins to improve denitrification, and overall nitrogen removal. (John: Did this help? Why did you stop?)~~ For modeling purposes, primary clarifier effluent $CBOD_5$ concentration of 120 mg/L was used for the worst-case scenario simulations.

Figure 2 – Picture showing the MLR flow input into the first anoxic basins at the MSAPCF.

Wastewater Treatment Process Modeling

The five-stage Bardenpho process configuration of the MSAPCF was set up in the BioWin wastewater treatment process model. The model was calibrated using the plant operational parameters and effluent concentrations. The model was used to evaluate the performance of the plant at the current and projected future flows and loads. In addition, several alternative scenarios aimed at improving nitrogen removal performance under a variety of conditions were also simulated with the calibrated model.

Table 1 summarizes the influent concentrations used for the plant design, current influent concentrations shown in daily monitoring report (DMR) data, and the primary clarifier effluent concentrations used for modeling the BNR processes.

Table 1 - Summary of annual average influent concentrations used for modeling.

Parameter	Design Influent Concentrations	Current Influent Concentrations	Primary Clarifier Effluent Concentrations Used For Modeling
$CBOD_5$ (mg/L)	220.0	166.0	120.0
TSS (mg/L)	200.0	213.00	135.0
TKN (mg N/L)	31.0	30.0	30.0
Ammonia-N (mg N/L)	25.0	26.0	26.0
TP (mg P/L)	5.0	4.6	4.6

The calibrated model was able to closely simulate the observed conditions at the MSAPCF, as evidenced by the strong agreement between the effluent concentrations predicted by the Biowin model and the DMR data (2001, 2002, and 2003) with a few exceptions.

Alum was added to the head end of the second anoxic basins (John; Can you confirm this? **Yes)** since operational practice found the biological process was unable to achieve such low levels, and the plant cannot meet the effluent TP limit of 1.0 mg/L without chemical addition. In addition, ferrous sulfate is added for odor control at the plant influent. Ferrous sulfate is also a chemical that enhances the precipitation of phosphorus. Alum and ferrous sulfate are each added at the feeding rate of 300 gallons/day. These chemical precipitation processes are not accounted for in the model as the BioWin version used at the time did not have the capability. Given these factors, the apparent discrepancy of the model calibration for effluent phosphorus levels was not unexpected. As such, the model calibration to existing DMR data was determined to be sufficient to allow the model to be used for predictive purposes.

The discrepancy between the actual and predicted concentrations for and TN is most likely reflective of the mode of operation practiced at the plant. As noted previously, the staff has found that nitrate levels in the plant effluent fluctuate diurnally, with the highest levels found from 1:00 to 5:00 AM. To assure that the facility continues to meet TN discharge limits, the operators adopted a policy of coordinating filling of the on-site reuse water storage basin during these periods of high nitrate-N levels. Therefore, while the nitrate levels recorded on the plant's DMRs are accurate for what is in the plant effluent flow, the values would likely be higher if all of the plant's effluent were discharged via the outfall.

Steady state simulations were run with the BioWin model. The steady state solution predicted average effluent concentrations for the specified conditions. However, the Biowin® model does not take into consideration reuse water withdrawals or the nitrogen load that those flows contain. Since the model assumes all effluent is discharged via the outfall, the level of TN predicted by the model is approximately 15% higher than the DMR data. Currently, approximately 25% of the MSAPCF effluent, on average, is sent to the reclaimed water system. Therefore, the TN level predicted by the model is likely a reasonably accurate reflection of what the effluent TN level would be if there was no reclaimed water use.

Following calibration of the model, the effluent quality was evaluated under various plant configurations and operational improvements. The model simulation results suggested that with the current plant configuration and assuming the worst-case scenario of low influent $CBOD_5$ concentrations, the plant would be expected to struggle to meet its effluent TN limits at virtually any flow. The model predicts effluent TN concentrations of 3.0 mg/L or higher. It should be remembered, however, that these TN levels do not take into consideration any nitrogen contained in effluent sent to the reuse water system.

The simulation results suggested that most of the TN in the effluent may be present in the form of nitrate-N, implying insufficient denitrification performance. The results also indicate that the effluent may contain about 0.10 mg/L of ammonia-N, suggesting excellent nitrification performance by the biological process. These results are consistent with current plant operations data. Based on the available information concerning the MSAPCF, the following reasons are believed to be contributing factors to the poor denitrification and nitrogen removal predicted by the model:

- Primary clarifier effluent $CBOD_5$ concentration of 120 mg/L.
- Oxygen mass input to the first anoxic basins at the rate of 900 lbs/day at MLR flow of 36 MGD.

One alternative evaluated with the model simulations was the conversion of the plant process configuration to four-stage Bardenpho. This conversion could be accomplished by repiping the MLR flow to fermentation basins. Therefore, the fermentation basins would become first anoxic basin and PAO would be eliminated from the system. This alternative seemed feasible since most of the phosphorus removal was accomplished with chemical precipitation, a five-stage Bardenpho configuration was not required. Therefore, to improve plant operations for nitrogen removal, this alternative was evaluated using the model. Table 2 presents the basin volumes with five-stage and four-stage Bardenpho configurations. The model simulations with four-stage Bardenpho configuration predicted that the plant’s nitrogen removal capabilities would improve and lower effluent nitrate-N levels could be achieved.

Table 2 – Five- and four-Stage Bardenpho process basin volumes used in process modeling of the MSAPCF

Basins	Five-Stage Bardenpho Process Configuration Basin Volumes (MG)	Four-Stage Bardenpho Process Configuration Basin Volumes (MG)
Fermentation	0.750	-
First Anoxic	1.000	1.750
Aerobic 1, 2, 3	0.743	0.743
Aerobic 4, 5	0.254	0.254
Aerobic 6, 7, 8, 9, 10, 11, 12, 13	1.016	1.016
Second Anoxic	1.120	1.120
Re-Aeration	0.252	0.252

Plant Modifications

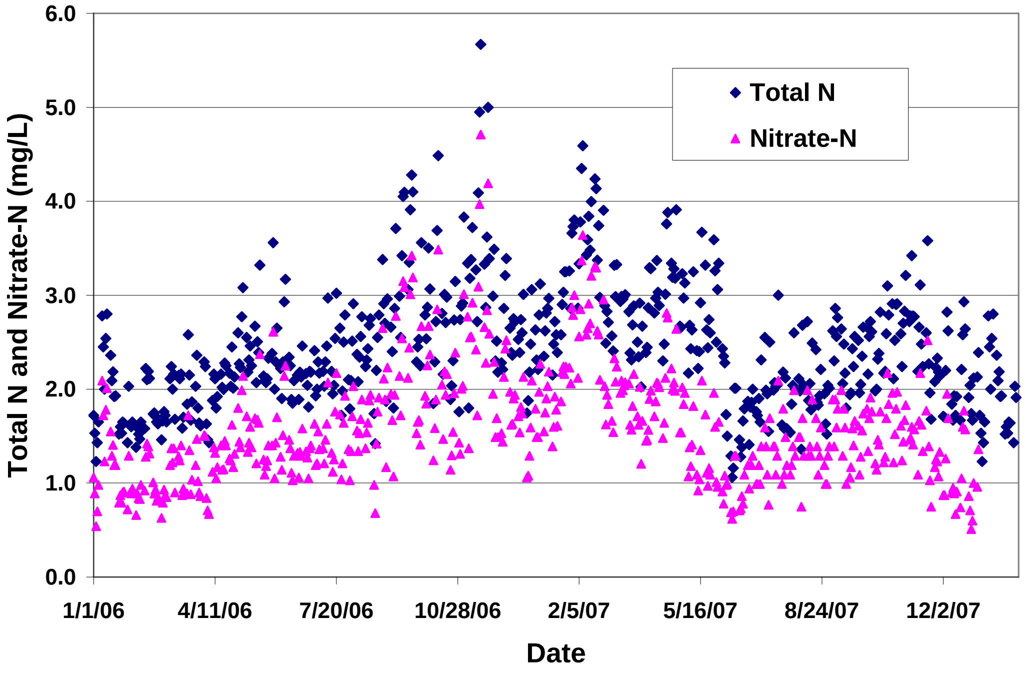
Among the alternatives evaluated, five-stage Bardenpho process configuration conversion to four-stage Bardenpho was implemented. This conversion was accomplished by redirecting the MLR flow to the fermentation basin. In addition, MLR piping layout was redesigned to prevent reaeration and oxygen input to the first anoxic basin. The project design was completed and construction started in November 2006. The construction was finished by March 2007. During the construction, some of the fermentation and anoxic basins were taken out of service and temporary IR piping was used. Grit accumulated in fermentation and anoxic basin was also cleaned during this time.

The new process configuration has a dedicated MLR pump and discharge pipe to each of the three anoxic/aeration treatment trains. The new MLR piping layout returned mixed liquor to the fermentation basins and eliminated reaeration of the MLR flow. Equal flow split is achieved by dedicating an MLR pump per anoxic/aeration treatment train. A firm capacity of 40 MGD of MLR flow is provided by three pumps, each operating at the re-rated capacity of 13.33 MGD when the plant is at the design capacity of 10 MGD. MLR pump flow rates would be adjusted to the required MLR flows to match the current annual average daily flow using the existing VFDs. The fourth pump is an installed standby pump that can be used to pump to any anoxic/aeration treatment train.

RESULTS AND DISCUSSION

The MSAPCF effluent nitrate-N and TN concentrations for 2006 and 2007 are shown in Figure 3. These measurements were taken from the flow weighted composite daily effluent samples for compliance with the surface water discharge limitations which is 3.0 mg/L for TN. These data do not represent the actual nitrogen removal performance of the plant since on-site reuse water storage basin is filled with the plant effluent containing high nitrate levels. Nevertheless, Figure 3 shows that the effluent TN exceeded 3.0 mg/L many times before the plant modification construction started in November 2006. When some of the fermentation and anoxic basins were taken out of service during construction period of five months (November through March 2007), nitrogen removal performance of the plant was also negatively affected. Following the completion of the construction, plant effluent nitrate-N concentrations were always less than 2.0 mg/L except for a few days for the rest of 2007. However, effluent TN also exceeded 3.0 mg/L for the whole month of May 2007 after the construction was completed. It was found that the high effluent TN concentrations observed in May 2007 were caused by high effluent ammonia-N concentrations which were about 0.50 mg/L. It was not clear what caused high effluent ammonia-N.(John, do you have any comments for this? This was just after construction and understanding the adjustments and reaction of the process changes took time to develop the parameters that would best Nitrify and denitrify. May was simply a trial period developing these parameters. The effluent TKN concentrations were between 1.0 and 1.75 mg/L in May 2007. The plant effluent data showed that the effluent ammonia-N concentration is generally about 0.10 mgN/L. In addition, effluent TKN concentration was usually about 1.0 mg/L or less. This means, effluent inert soluble organic nitrogen is about 0.9 mg/L which is in good agreement with the fact that the concentration of soluble inert organic nitrogen in domestic wastewater typically ranges from 1.0 to 2.0 mg/L (Grady et al., 1999). It is clear from these figures that the main objective for the MSAPCF is to maintain effluent NO_X (nitrate-N and nitrite-N) concentrations below 1.8 mg/L not to exceed effluent TN concentration of 3.0 mg/L.

Figure 3. Effluent Nitrate-N and Total N Concentrations measured at the MSAPCF



The plant utilizes an online nitrate-N analyzer for monitoring purposes. Since many measurements are taken by this analyzer everyday, it is possible to get a better idea about the nitrogen removal performance of the plant. Effluent nitrate-N data by 3-hour intervals presented in Figure 4 showed that the average effluent nitrate-N concentration was reduced to 1.5 mg/L after the modifications were completed. In addition, the effluent nitrate-N had diurnal variations that exceeded 5.0 mg/L during night time flows and loads. Following the design upgrades, diurnal variations of effluent nitrate-N concentrations are usually below 2.5 mg/L.

Figure 3. Effluent nitrate-N concentrations measured by an online analyzer at the MSAPCF

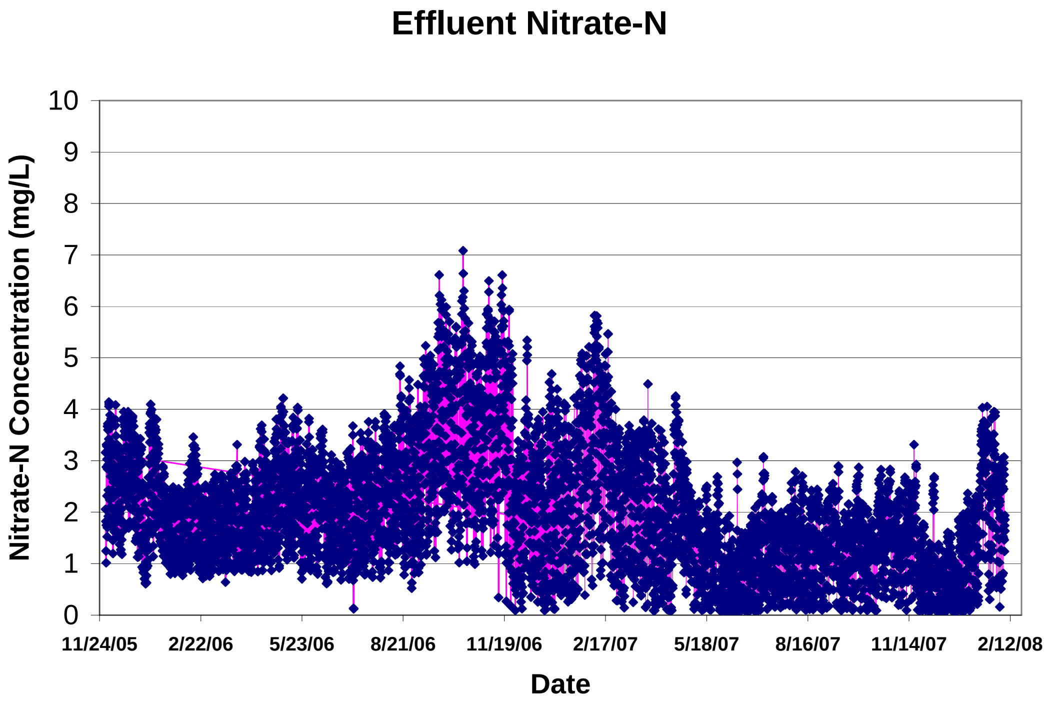
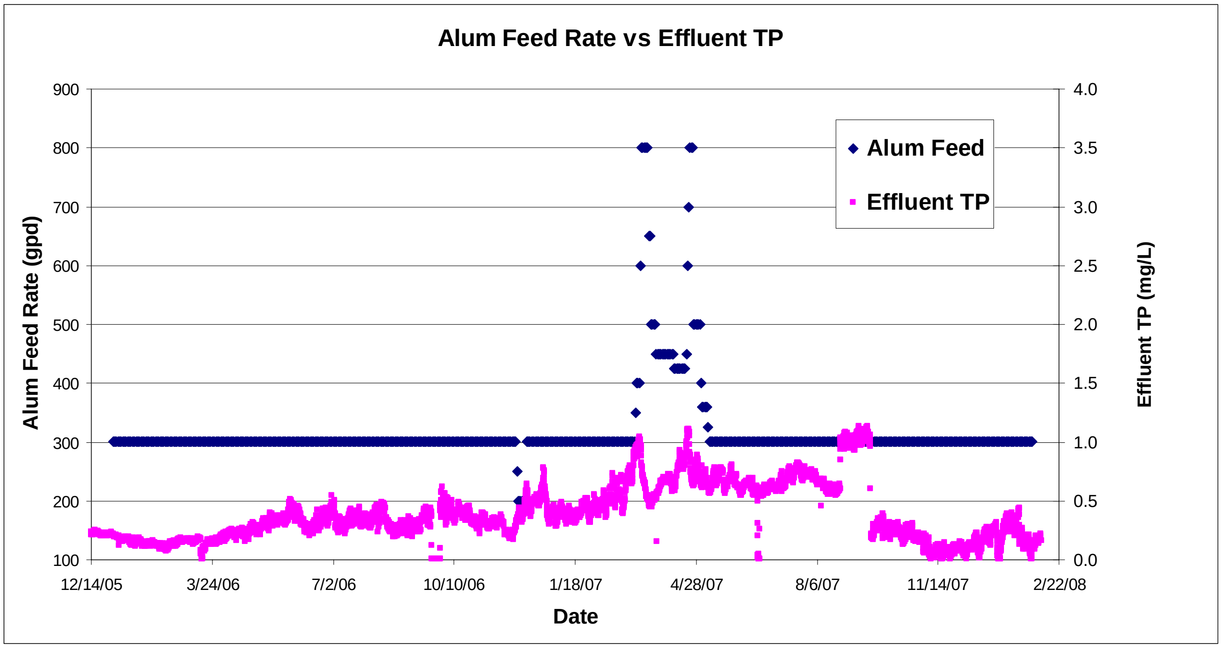


Figure 5 shows alum feeding rate and effluent TP concentrations for 2006 and 2007. Alum was added to the second anoxic basins at the rate of 300 gallons/day. Ferrous sulfate was also added to the plant influent for odor control purposes at the rate of 300 gallons/day. According to the data presented in Figure 4, effluent TP approached 1.0 mg/L towards the end of the construction. However, later in 2007 effluent TP went below 0.5 mg/L while alum and ferrous sulfate feeding rates were maintained at 300 gallons/day. The data suggested that PAOs played a very little role in the removal of phosphorus.

Figure 5. Alum feed rates used and effluent TP measured at the MSAPCF.



CONCLUSIONS

The following results have been observed after the conversion of the MSAPCF to 4-stage Bardenpho process:

- Conversion of fermentation basins to first anoxic basins increased first anoxic basin volume thereby increasing first anoxic SRT. This modification provided better denitrification efficiency which resulted in the reduction of effluent nitrate-N and TN.
- MLR piping configuration modifications reduced aeration of the MLR flow and oxygen input to first anoxic basins which also helped optimizing denitrification and reducing effluent nitrate-N and TN.
- After the conversion, the alum dosing rate was not changed to maintain effluent TP below 1.0 mg/L suggesting that the POA played a little role for the removal of phosphorus before the process conversion.
- After the modifications, the average effluent nitrate-N concentration was reduced to 1.5 mg/L. In addition, the effluent nitrate-N had diurnal variations that exceeded 5.0 mg/L during night time flows and loads. Diurnal variations of effluent nitrate-N concentrations have been usually below 2.5 mg/L since the design upgrades completed.

- These modifications eliminated the need for addition of external organic substrate (i.e. methanol) to improve denitrification performance.

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