PROCESS DESIGN AND OPERATIONAL MODIFICATIONS OF OXIDATION DITCHES FOR BIOLOGICAL NUTRIENT REMOVAL

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ABSTRACT
An oxidation ditch system was modified for excess biological phosphorus and nitrogen removal by connecting two oxidation ditches in series with a small anaerobic cell (10 percent of total reactor volume). The process was operated with 40 to 50 percent of the influent flow entering the anaerobic cell. The rest of the influent was bypassed to the first oxidation ditch. The detention time in the anaerobic cell was adjusted as a process control parameter to develop low oxidation reduction potentials in cold weather or in situations where the influent flow entrained substantial quantities of dissolved oxygen. Average performance levels of 0.6 mg/L for total phosphorus and 4 mg/L for total nitrogen were achieved under temperate conditions. Secondary effluent alkalinity, turbidity and orthophosphorus measurements were used as alternative control parameters in addition to dissolved oxygen measurements in the oxidation ditch. Performance testing was carried out at a second oxidation ditch system to estimate the temperature sensitivity of nitrification. It was found that the temperature sensitivity coefficient was only 1.066 1/Celsius in the temperature range between 15 and 25 Celsius.

KEYWORDS
Biological Phosphorus Removal, Nitrogen Removal, Oxidation Ditch, Temperature Sensitivity, Modifications, Control Parameters, Operation

INTRODUCTION
Phased modifications for excess biological phosphorus and nitrogen removal were conducted at the Bowie WWTP, MD, USA. The plant receives 8.3 megalitres per day (8.3 m³/day) of flow. The modifications were designed to achieve permitted levels of 1 mg/L for total phosphorus and 6 mg/L for total nitrogen all year round. Additional performance tests for biological nitrogen removal were conducted at a barrier oxidation ditch system at the Patuxent Water Reclamation Facility. The facility receives 13.6 megalitres per day of flow. The temperature sensitivity of nitrification was evaluated.

PROCESS MODIFICATIONS AND OPERATIONS

Bowie WWTP
The Bowie WWTP was operated with one oxidation ditch in 1988. During the winter months, when liquid temperatures dropped below 12 Celsius, it was observed that the Mean Cell Residence Time (MCRT) necessary to maintain complete nitrification and effluent nitrates below 5 mg/L exceeded 15 days. With only one oxidation ditch in operation, the mixed liquor suspended solids exceeded 4000 mg/L. This had a negative impact on the performance of the secondary clarifiers.
In February, 1989, a second oxidation ditch, previously used as an aerobic digester, was put in service in parallel to the first. This allowed for an increase in the aerobic and anoxic MCRTs and reduced effluent total nitrogen to levels below 5 mg/L. Retrofit modifications to incorporate an anaerobic cell outside the oxidation ditch were completed in April, 1989. However, the anaerobic cell was connected to the first oxidation ditch only. To maintain process performance and balance influent loadings and solids concentrations in the oxidation ditches, it was necessary to connect them in series with the anaerobic cell. This was completed in June, 1989 (Figure 1). The volume of the anaerobic cell was 10 percent of the combined volume of the two oxidation ditches. The nominal HRT of the process was 39 hours.

The brush aerators were operated on timers to flow pace the aeration. A minimal amount of oxygen was injected in ditch 1 to maintain solids in suspension and encourage development of anaerobic conditions in the first pass in ditch 1 (Figure 1). This helped minimize recycle of nitrates with the mixed liquor recycle to the anaerobic cell. The aeration in ditch 2 was maintained within a range which would be adequate for phosphorus uptake and nitrification, and at the same time, ensure satisfactory denitrification farther away from the brush aerators. The total oxygen supply was controlled by adjusting the level of liquid in the oxidation ditches. This altered the depth of submergence and the amount of oxygen transferred by each brush aerator.

The increase in dissolved oxygen levels across each brush aerator was less than 0.5 mg/L. This was because internal recycle rates of 150 Q (flow across a cross-section of the ditch = 150 x influent flow) diluted the oxygen transferred per unit time by each aerator into a large volume. With multiple points of aeration (three to five brush aerators in operation at any time of the day), the amount of oxygen injected by each aerator varied from 15 to 40 percent of the total oxygen supply. [Each aerator in ditch 2 had a lower depth of submergence, and therefore, injected less oxygen than an aerator in ditch 1.] The maximum D.O. level, as measured after aerator 2-3 in ditch 2, was 0.6 mg/L during normal operation. Therefore, it was difficult to use dissolved oxygen concentration as a process control parameter.

The actual detention time in the anaerobic cell was used as a control parameter to maintain a satisfactory biological phosphorus removal. The process was operated with an average of 40 percent of the raw influent flow entering the anaerobic cell. The rest of the influent was bypassed to the first oxidation ditch. The mixed liquor recycle rate was maintained at 35 percent of plant influent flow. Typically, the detention time was increased in cold weather because the influent contained higher levels of dissolved oxygen.

Figure 1. Schematic of the VT2
Biological Nutrient Removal Process,
Bowie WWTP

Figure 2. Schematic of the Barrier
Oxidation Ditch Process (INOVA TECH™)
Patuxent WRF
Process Operation, Patuxent Water Reclamation Facility

The Patuxent WRF was designed as a barrier oxidation ditch system with one draft tube aerator (DTA) in each ditch (Figure 2). Compared to the Bowie WWTP, the plant has a relatively longer flow path in each ditch. The internal recycle rate is 100 times the influent flow. The circulation time for the flow to circulate once around each oxidation ditch is 15 minutes, as compared to 10 minutes at Bowie.

Operation with a single point of aeration and lower internal recycle rates results in a difference in D.O. in excess of 2 mg/L across the draft tube aerator. At these D.O. levels, aeration can be controlled with an automated system using D.O. probes on a PLC loop. Two Zulich D.O. probes are located at the 25 percent point in each ditch (Figure 2). The D.O. set point can be adjusted in steps of 0.05 mg/L. Typical set point measures 1.3 mg/L at a nominal HRT of 40 hours with two ditches in operation in parallel.

The original DTA installed at the Patuxent WRF did not have the capacity to inject an adequate amount of oxygen for nitrification while treating an influent flow of 8.3 megalitres per day in one oxidation ditch only. During the upgrade, attempts were made to operate the plant at the minimum MCRT required for nitrification to help reduce the oxygen demand and measure several factors, included amongst which was the temperature sensitivity of nitrification.

PERFORMANCE AND CONTROL

Bowie WWTP

Biological phosphorus and nitrogen removal were implemented in phases at the Bowie WWTP. The raw influent BOD, COD, TKN and TP averaged 160, 400, 35 and 5.5 mg/L, respectively. The recycle from the solids handling units (gravity thickeners and belt filter presses) increased influent phosphorus concentration to 7 mg/L after excess biological phosphorus removal was established. The effluent phosphorus and nitrogen concentrations are shown in Figures 3 and 4. The process has been operated for biological phosphorus and nitrogen removal since June, 1989. The plant has maintained effluent phosphorus averages of 0.5 mg/L in warm weather and 0.7 mg/L in cold weather. Phosphorus concentrations in the biomass averaged 5 percent on a volatile suspended solids basis. The effluent ammonia-N and total nitrogen averaged less than 1 mg/L and 4 mg/L, respectively.

Control Parameters

Secondary effluent alkalinity was the principal process control parameter for aeration at the Bowie WWTP. The operating range for effluent alkalinity was between 72 and 75 mg/L. The oxygen supply was increased when the effluent alkalinity increased above the range and reduced when it dropped below the range. The secondary effluent alkalinity was measured two times each day.

The "available" influent alkalinity is the sum total of the alkalinity measured on the influent and the alkalinity from the deamination of organic-N in the influent sample (Table 1a). At the Bowie WWTP, the available influent alkalinity increased with the influent TKN (Figure 5), since the alkalinity consumed per mg/L of nitrogen removed through biomass production is the same as that removed through nitrification and denitrification (3.57 mg/L). Because of the proportionality of the available influent alkalinity and the TKN, the effluent alkalinity was not affected by changes in the influent TKN. Table 1a shows that the change in effluent alkalinity could be related to the changes in effluent ammonia or nitrate. The effluent alkalinity is independent of MCRT if it is adequate for nitrogen removal (Table 1b). The expression for effluent alkalinity can be summarized as follows:
Effluent Alkalinity = Available Influent Alk - 3.57 (Influent TKN - Influent Non-biodegradable N) + Effluent N effect

Available Influent Alk = Measured Influent Alk + 3.57 (Biodegradable Influent Organic N)
Effluent N Effect = 3.57 (Effluent Ammonia-N) - 3.57 (Effl Nitrite-N + Effluent Nitrate-N)

Alkalinity control fails when the effluent ammonia and nitrates increase simultaneously (Table 2b). This would indicate a loss of anaerobic conditions because of a prevalence of nitrates across the entire system, and would be reflected in an increase in secondary effluent ortho-phosphorus and turbidity.

Secondary effluent ortho-phosphorus and turbidity were utilized as secondary control parameters at the Bowie WWTP (Sen et al., 1990c). In an excess biological phosphorus removal system, the increase in effluent ortho-phosphorus concentrations can be the result of a loss of anaerobic conditions (as caused by an increase in nitrates or dissolved oxygen), or from a lack of oxygen for BOD removal and phosphorus uptake under aerobic conditions. In an activated sludge system operating with a low nitrate recycle, a small deficit in the amount of air supplied is reflected primarily in the loss of complete nitrification. However, in a system with a high nitrate recycle rate, the influent BOD is diluted several times by the nitrate recycle stream. This allows nitrification to occur simultaneously with BOD removal at any point in the flow train where the biomass is aerated. Therefore, the short-term effect of a drop in oxygen supply is reflected simultaneously in a partial loss nitrification and phosphorus removal. However, if the disturbance persists, the population of nitrifiers will gradually be depleted. Phosphorus removal may be restored to satisfactory levels when the available air supply is adequate for BOD removal but not for complete nitrification.
The Patuxent WRF recovered nitrification during cold weather in February, 1990 after installation of an upgraded DTA. In June, 1990, the treatment plant lost nitrification in warm weather following an increase in sludge wasting. The limiting MCRTs for nitrification at the temperatures in February and June are shown in Table 3.

The pH of the mixed liquor in the oxidation ditch was depressed because carbon dioxide generated during respiration was entrained in the liquid. At the relatively high oxygen transfer efficiencies observed with the DTA's (dirty water efficiencies of 22 to 26 percent), a smaller volume of air escaped to the atmosphere. Therefore, comparatively lower fractions of carbon dioxide were stripped out of solution in the oxidation ditch. However, the carbon dioxide was stripped out of solution during reaeration of the secondary effluent which increased the pH by an average of 1.0 unit.

### Table 3. Limiting Aerobic MCRT for Nitrification at Patuxent WRF

<table>
<thead>
<tr>
<th>Temperature Celsius</th>
<th>Aerobic MCRT days</th>
<th>Anoxic MCRT days</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.5</td>
<td>6.0</td>
<td>4.0</td>
<td>6.1</td>
</tr>
<tr>
<td>24.0</td>
<td>3.5</td>
<td>7.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>
The temperature sensitivity of nitrification can be calculated from growth rates. The growth rate ($\mu$) was calculated using the following equation:

$$\mu = \frac{1}{\text{aerobic MCRT}} + k_d$$  \hspace{1cm} (1)

where the decay rate under aerobic conditions, $k_d$ \textit{aerobic} was 0.04 day$^{-1}$.

The growth rate for nitrifiers was 0.207 day$^{-1}$ at 15 Celsius and 0.325 day$^{-1}$ at 24 Celsius. The temperature sensitivity factor ($\Theta$) was calculated using the growth rates as follows:

$$\mu_{T_2} = \mu_{T_1} [ \Theta^{(T_2-T_1)} ]$$  \hspace{1cm} (2)

where $T_1$ and $T_2$ were 15 and 24 Celsius, respectively.

The growth and decay rate coefficients were verified separately by simulating the loss of nitrification when the MCRT was decreased in November, 1990, and comparing the simulated results to the observed trend (Sen \textit{et al.}, 1990b).

Figure 5. Influent Available Alkalinity versus Influent TKN, Bowie WWTP

Figure 6. Effluent Nitrogen trends in February and June, 1990 at Patuxent WRF
The temperature sensitivity factor, as calculated from the aerobic MCRTs and corresponding temperatures in Table 3, was 1.066. The calculation is conservative because the system was gradually recovering nitrification at the lower temperature in February, and losing at the upper temperature in June (Figure 6). At steady state, the computed value would have been lower.

Unlike the Bowie WWTP, the Patuxent WRF was operated with D.O. as the primary control parameter. The plant could consistently maintain effluent ammonia-N levels below 0.5 mg/L and oxidized-N less than 3 mg/L during normal operations with two oxidation ditches. At the same time, the effluent ammonia-N and oxidized-N were monitored once every day to make adjustments to the D.O. set point. Two D.O. probes were used at the location where the D.O. was monitored in each ditch. The system was operated off the higher D.O. reading to eliminate errors which could occur if one of the two probes were clogged and measured artificially low values.

A software was developed by the plant personnel to reduce the D.O. set point temporarily when the instantaneous oxygen demand exceeded the capacity of the draft tube aerators. The software was keyed to three parameters. These included an increase in the D.O. concentration as measured at the probes, an increase in back-pressure on the blowers, and an increase in vibration monitored at the DTA mount. The D.O. measured at the probes increased for a short interval when the draft tube started to "flood". "Flooding" occurs when the quantity of air supplied by the blowers exceeds that which can be transferred across the J tube by the mixer. As a result, an "air bubble" begins to accumulate on the upstream side of the DTA. This decreases the quantity of liquid flowing across the draft tube and increases the amount of oxygen transferred per unit volume of liquid flowing across it, and therefore, increasing the D.O. measured at the probes. Details of the software and control will be presented separately.

**DISCUSSION**

At the high internal recycle rates observed in oxidation ditches, the oxygen and nitrate uptake rates decrease significantly because of dilution of the influent BOD with the recycle flow. Therefore, a small increase in the operating D.O. or the nitrate concentration can result in a significant increase in the aerobic or anoxic volumes, and in the loss of anaerobic or anoxic volumes, respectively. Therefore, to maintain excess biological phosphorus and nitrogen removal, it is necessary to have a strict control over the process control parameters.

A loss of aerobic or anaerobic volume as a result of a change in the oxygen supply can cause an increase in the population of filamentous bacteria. While the former reduces D.O. levels in the aerobic zones where BOD is to be stabilized, the latter creates low D.O. conditions in the anaerobic zone. Figure 7 shows the result of fluctuations in the amount of oxygen supplied (as reflected in the change in secondary effluent alkalinity) on the population of filamentous bacteria (reflected in changes in Sludge Volume Index) at the Bowie WWTP. The effect of short term disturbances was magnified at higher liquid temperatures (Sen et al., 1990a).

The temperature sensitivity coefficient of 1.066 for nitrification, computed for a range between 15 and 25 C, is lower than values computed for South African plants (Marais et al., 1984). Two factors may be responsible for the lower coefficient. Firstly, the influent BOD levels in wastewaters in eastern U.S. measure 100 to 200 mg/L. These are lower than those observed in South Africa. Secondly, influent BOD levels are diluted by the high rates of internal recycle in oxidation ditches. Low BOD levels reduce the rate of uptake of oxygen by heterotrophs. This can provide nitrifiers with an advantage in competing for oxygen and ammonia against the heterotrophs. Observations of complete nitrification in cold weather at aerobic MCRTs of seven days at 12 to 14 Celsius at activated sludge plants at UOSA, Virginia, and Annapolis WRF, Maryland, whose influent wastewaters strengths are typical of eastern U.S. have provided additional information that the temperature sensitivity for nitrification is similar to that observed at the Patuxent WRF (UOSA WWTP and Annapolis WRF, 1991).
CONCLUSIONS

1. Simultaneous excess biological phosphorus and nitrogen removal were implemented in a modified oxidation ditch process to maintain an average of 0.6 mg/L total phosphorus and 4 mg/L of total nitrogen in the effluent.

2. An anaerobic cell may be incorporated in front of the oxidation ditches to receive a fraction of the influent flow. The influent flow entering the anaerobic cell may be adjusted to compensate for an increase in oxygen and nitrates entering the anaerobic cell. At the Bowie WWTP, only 40 to 50 percent of the influent entered the anaerobic cell.

3. A multi-parameter control approach using D.O., secondary effluent alkalinity or nitrogen forms, turbidity and percent VSS were used to maintain a satisfactory level of process control. Secondary effluent alkalinity, ortho-phosphorus and turbidity were satisfactory alternative control parameters to D.O.

4. The temperature sensitivity of nitrification was $1.066^{\circ}/\text{Celsius}$ in the oxidation ditch system at the Patuxent WRF in temperature range between 15 and 25 Celsius.

REFERENCES


