N₂O emission from full-scale urban wastewater treatment plants: a comparison between A²O and SBR

Shichang Sun, Xiang Cheng, Sha Li, Fei Qi, Yan Liu and Dezhi Sun

ABSTRACT

The emission of nitrous oxide (N₂O) from full-scale anoxic/anaerobic/oxic (A²O) and sequencing batch reactor (SBR) processes was measured to evaluate N₂O emission from urban wastewater treatment plants (WWTPs). The results showed that N₂O flux in the A²O WWTP followed an order of A²O-oxic zone > aerated grit tank > A²O-anaerobic zone > A²O-anoxic zone > final clarifier > primary clarifier, while in the SBR WWTP the order was SBR tank > swirl grit tank > wastewater distribution tank and within the SBR tank an order of SBR-feeding period > SBR-aeration period > SBR-settling period > SBR-decanting period. N₂O emission from the A²O WWTP was approximately 486.61 kg d⁻¹, 96.9% of which was from the A²O-oxic zone. In the SBR WWTP, the emission of N₂O was 339.24 kg d⁻¹ with 99.9% of the total emission coming from periods of feeding and aeration.

INTRODUCTION

Nitrous oxide (N₂O) is a significant greenhouse gas with a lifetime of 114 years. It has a 296-fold stronger effect of global warming than carbon dioxide, and is responsible for ozone depletion in the stratosphere (Ravishankara et al. 2009). The concentration of N₂O in the atmosphere is increasing at a rate of 0.2–0.3% per year (Osada et al. 1995). It is therefore of great importance to develop methods and technologies for the measurement and control of its emission.

Wastewater treatment facilities are anthropogenic sources of N₂O to the atmosphere, taking account of 3.2–10% of the total emission (Law et al. 2012). Large amounts of N₂O have been demonstrated to be produced during nitrogen removal reactions, e.g. nitrification and denitrification (Itokawa et al. 2001; Tallec et al. 2006). Previous studies revealed that N₂O could be produced as an intermediate during biological denitrification with inhibition from high levels of oxygen (Kampschreur et al. 2009). Nitrosation and nitrifier denitrification by ammonia oxidizing bacteria (AOB) were reported as two important pathways of N₂O production, which occur with oxygen limitation or nitrite accumulation (Tallec et al. 2006). In the last two decades, the relationship between emission of N₂O and many operational parameters, e.g. dissolved oxygen (DO), chemical oxygen demand/nitrogen (COD/N), pH, nitrite level, salinity and sludge retention time, were widely investigated (Hanaki et al. 1992; Schulthess et al. 1995; Park et al. 2000; Tsuneda et al. 2005; Lemaire et al. 2006; Kampschreur et al. 2008a; Rassamee et al. 2011). However, most of these studies were performed through laboratory-scale experiments using synthetic wastewaters.

The emission factor of N₂O recommended by the Intergovernmental Panel on Climate Change (IPCC) was 0.035% of N-load in influent, which has been shown to be not always accurate. This is because the study in New Hampshire wastewater treatment plants (WWTP) was not sufficient to determine the factor of N₂O emission from both nitrification and denitrification (Czepiel et al. 1995). Later research on N₂O emission from full-scale WWTPs suggested that both a smaller and a greater percentage of N-load in influent could possibly be transformed into N₂O and be emitted during biological nutrient removal processes, e.g. 0.001% (Sümer et al. 1995), 0.02% (Sommer et al. 1998), 0.01–0.08% (Kimochi et al. 1998), 0.47% (Peu et al. 2006), 2.3–4% (Kampschreur et al. 2008b); 0.6–25% (Foley et al. 2009).
Large differences in the emission of N$_2$O were thus observed based on monitoring results. Currently, there is still an apparent lack of studies on N$_2$O emission from WWTPs to make it more objective to estimate the total emission of N$_2$O and illustrate N$_2$O emission characteristics in different treating processes.

Anaerobic/anoxic/oxic (A$^3$O) and sequencing batch reactor (SBR) processes are the two most used technologies for the treatment of urban wastewaters. The processes include both nitrification and denitrification reactions, during which N$_2$O can be produced and emitted under certain conditions. In an A$^3$O process, a favorable condition for N$_2$O production is the presence of oxygen during denitrification in anoxic tanks. This could occur when water recirculation brings a certain amount of dissolved oxygen from oxic tanks to anoxic tanks. Another possibility of N$_2$O production is oxygen-limited nitrification in oxic tanks, which occurs when the wastewater contains high concentrations of COD and ammonium. In SBR processes, ammonium is transformed into N$_2$ as a by-product during the period of aeration, oxygen inhibition or insufficient carbon resource during denitrification in the periods of settling and decanting. Thus, there is a great need to better understand the production and emission of N$_2$O in A$^3$O and SBR processes to develop an effective method for the control of N$_2$O emission.

This work aimed to obtain a basic understanding of total emissions of N$_2$O from A$^3$O and SBR WWTPs. Characteristics of N$_2$O emission were investigated and the emission of N$_2$O from the two processes and each treatment unit was calculated and compared. Measures for controlling the emission of N$_2$O from A$^3$O and SBR processes were also discussed.

**METHODS**

Three reduplicative experiments of N$_2$O monitoring were completed respectively in an A$^3$O WWTP and an SBR WWTP, and the average results of N$_2$O emission from the two WWTPs were shown and compared in this work.

**Field sites**

The A$^3$O and SBR WWTPs for the field site experiment were located in Beijing, China. The two plants had capacities of wastewater treatment of 5 x 10$^5$ and 8.0 x 10$^4$ m$^3$ wastewater per day, respectively. The influents were sewage from local areas. The organic load, average levels of COD and total nitrogen (TN) in the influents were 0.14 kg biochemical oxygen demand (BOD) (kg mixed liquor volatile suspended solids (MLVSS) d$^{-1}$), 350 and 50 mg L$^{-1}$ in the A$^3$O plant and 0.15 kg BOD (kg MLVSS d$^{-1}$), 400 and 65 mg L$^{-1}$ in the SBR plant during the sampling periods (data from the plants). Emission of N$_2$O from all units for treatment and distribution of wastewater/sludge in the two processes were measured, namely, aerated grit tank, primary clarifier, A$^3$O-anoxic zone, A$^3$O-anaerobic zone, A$^3$O-oxic zone and final clarifier tank in the A$^3$O plant and swirl grit tank, wastewater distribution tank and SBR tank in the SBR plant. The SBR system was operated by six continuous 4-h cycles each day. The cycle consisted of feeding (with aeration), aeration, settling and decanting periods with a duration of 1 h for each period.

**Gas sampling in biological units**

The schematic diagram of the biological treatment unit in the A$^3$O process is shown in Figure 1. The anoxic and anaerobic zones occupied two-ninths of the area of each tank (2,678.2 m$^2$), and the oxic zone the other seven-ninths. Considering continuous consumption of substrates and the resulting reduction in oxygen demand as the water flowed through the oxic zone, emission of N$_2$O and the concentration of dissolved N$_2$O were measured at six locations along the oxic zone. The flux of N$_2$O from the whole oxic zone ($E_{\text{average, oxic}}$ g m$^{-2}$ d$^{-1}$) was calculated by

$$E_{\text{average, oxic}} = \frac{1}{9} S_{\text{oxic}} (E_1 + E_2 + E_3)/3 + \frac{1}{3} S_{\text{oxic}} (E_3 + E_4 + E_5)/3 + \frac{1}{3} S_{\text{oxic}} (E_5 + E_6)/2 / S_{\text{oxic}}$$

where $E_{\text{average, oxic}}$ was the average flux of N$_2$O in the oxic zone, $S_{\text{oxic}}$ (m$^2$) was the total area of the oxic zone, $E_1$ to $E_6$ (g m$^{-2}$ d$^{-1}$) was the flux of N$_2$O at the six locations along the aeration zone.

Measurements of N$_2$O in the SBR tank were carried out in the four operational periods. Based on the dynamics of
the SBR system during the periods of feeding and aeration, the measurement of N\(_2\)O emission and dissolved N\(_2\)O in the water phase in these two periods were performed every 0.5 h. The flux of N\(_2\)O from the periods of feeding and aeration and the emission of N\(_2\)O in each period of the SBR were calculated by

\[
E_{\text{average, feeding}} = \frac{(E_{90 \text{-} 30 \text{min}} + E_{30 \text{-} 60 \text{min}}) \cdot S_{\text{SBR}}}{2}
\]

\[
E_{\text{average, aeration}} = \frac{(E_{60 \text{-} 90 \text{min}} + E_{90 \text{-} 120 \text{min}}) \cdot S_{\text{SBR}}}{2}
\]

\[
N_2O_{\text{emission}} = S_{\text{SBR}} \cdot E \cdot \frac{24}{T} \cdot \frac{1}{1,000}
\]

where \(E_{\text{average, feeding}}\) was the average flux of N\(_2\)O in the SBR-feeding period, \(E_{\text{average, aeration}}\) was the average flux of N\(_2\)O in the SBR-aeration period, \(E_{30 \text{-} 60 \text{min}}\), \(E_{90 \text{-} 120 \text{min}}\), \(E_{60 \text{-} 90 \text{min}}\) and \(E_{90 \text{-} 120 \text{min}}\) were N\(_2\)O flux during 0-30, 30-60, 90-90 and 90-120 min of SBR cycle, \(S_{\text{SBR}}\) (m\(^2\)) is the area of water surface in the SBR tank, \(T\) (h) is the duration of an SBR cycle. The concentration of DO was examined every 5 min for the whole cycle (4 h) using an on-line DO meter (WTW 3420, WTW Company, Germany).

**N\(_2\)O sampling apparatus**

**Aerated areas**

A cubic polyethylene bag with a volume of 90 L was used for air sampling from the water surface of the aerated units during the period of aeration (Czepiel et al. 1995). The sampling bag was fixed on a foam board by steel hoops to cover an area of 0.09 m\(^2\). Air samples were then taken by a pump through a silicone tube connecting to a sampling port on the top of the gas bag when it was fully blown up. Flux of N\(_2\)O (g m\(^{-2}\) d\(^{-1}\)) from aerated areas was then calculated by

\[
E = Qc\rho/A
\]

where \(Q\) (m\(^3\) d\(^{-1}\)) was the air flow rate, \(c\) (10\(^{-6}\) m\(^3\) m\(^{-3}\)) was the concentration of N\(_2\)O in the samples, \(\rho\) (g m\(^{-3}\)) was the density of the gas at the temperature recorded and \(A\) (m\(^2\)) was the sampling area.

**Non-aerated areas**

When sampling in non-aerated units, a static chamber technique was used to grab the gas samples diffused from the wastewater surface. The cylindrical hood was 0.6 m in height and 0.125 m\(^2\) in surface area of the bottom. A foam board was employed to stabilize the hood on the water surface. The bottom edge of the hood entered 0.3 m below the water surface to prevent any air exchange with outside space. Air samples were collected by a pump through a silicone tube connecting to the hood. The sampling was done every 10 min in replicates for a period of 40 min. The temperature of the gas inside the chamber was recorded by digital thermometer (M293423, KEGE Company, China). N\(_2\)O flux (g m\(^{-2}\) d\(^{-1}\)) from non-aerated periods was then calculated by

\[
E = 24 \cdot 60 \cdot (dc/dt)\rho (V/A)
\]

where \(c\) (10\(^{-6}\) m\(^3\) m\(^{-3}\)) is the concentration of N\(_2\)O, \(t\) (min) is time, \(dc/dt\) was the linear increase of the gas concentration during the sampling procedure, \(\rho\) (g m\(^{-3}\)) was the density of the gas at the temperature recorded, \(V\) (m\(^3\)) was the volume of the flux hood, \(A\) (m\(^2\)) was the enclosed surface area.

**Measurement of dissolved N\(_2\)O**

A headspace gas technique was adopted to analyze the concentration of dissolved N\(_2\)O in the water (Kimochi et al. 1998). Water samples were collected from each unit into 300-mL airtight serum bottles using a 2.5 L water collection device. The sample was gently added down the side of the bottle to avoid agitation or bubbles, which could strip dissolved gases. The bottle was completely filled and 1 mL H\(_2\)SO\(_4\) (1 mol L\(^{-1}\)) was injected to restrain the microbial activities. A headspace was then generated by replacing 100 mL of water with high-purity N\(_2\). The serum bottle was then shaken vigorously with the use of hands to allow the gas to equilibrate between the headspace and the liquid. Approximately 50 mL of gas was collected from the headspace by quickly injecting the same volume of de-ionized water into the bottle. The dissolved N\(_2\)O concentration could be calculated based on Henry's Law using equilibrated headspace N\(_2\)O concentration, as recommended by Noda et al. (2003).

**Gas samples analysis**

Concentrations of N\(_2\)O in gas samples were analyzed within 12 h after sampling by an Agilent 7890A Gas Chromatograph (GC) equipped with an electron capture detector (ECD). Nitrogen gas was used as the carrier gas and the equilibrium gas was a 90% Ar/10% CH\(_4\) mixture.
RESULTS AND DISCUSSION

N₂O emission in the A²O WWTP

Flux of N₂O emission and levels of dissolved N₂O in different units in the A²O WWTP are shown in Table 1. Large gaps in N₂O flux were observed among different units of wastewater treatment. The flux followed a descending order of A²O tank >> aerated grit tank > final clarifier > primary clarifier and within the A²O tank the order was oxic zone >> anaerobic zone > anoxic zone. The flux of N₂O from the aerated grit tank was as high as 10.93 g m⁻² d⁻¹ due to the high concentration of dissolved N₂O in influent as well as the stripping effect (Diaz-Valbuena et al. 2011). Very low values of N₂O flux (averagely 0.37 g m⁻² d⁻¹) were seen from the anoxic zone. When wastewater entered the anaerobic zone, a certain growth of N₂O flux to 2.13 g m⁻² d⁻¹ was found. In the non-aerated areas with small emission of N₂O, the level of N₂O received a continuous accumulation during denitrification under the anoxic conditions, i.e. 0.26 mg L⁻¹ in the anoxic zone and then rose to 0.60 mg L⁻¹ in the anaerobic zone, which was the highest in the whole system. The concentration of dissolved N₂O in the oxic zone reduced to 0.08 mg L⁻¹, indicating that most of the dissolved N₂O accumulated via anaerobic denitrification was stripped out as the wastewater passing through the oxic zone for carbon removal and nitrification. As a result, the peak of N₂O flux of 18.91 g m⁻² d⁻¹ was observed in the oxic zone.

With the same strength of aeration in the oxic zone, N₂O flux showed a gradual descending trend from 58.42 to 3.15 g m⁻² d⁻¹ along the water flow (Figure 2). At the same time the concentration of DO increased from 0.79 mg L⁻¹ at the starting location of the oxic zone to 7.00 mg L⁻¹ at the exit. This was because the demands of oxygen reduced as organic matters degraded. In the oxic zone near the entrance when low levels of DO and considerable organics remained, large production of N₂O could occur and be stripped out (Hu et al. 2010). However, most N₂O emission herein could still result from the dissolved N₂O produced during denitrification in the anoxic and anaerobic zones in the presence of oxygen (0.31–0.45 mg L⁻¹) from inner circulation (Wunderlin et al. 2012). Therefore, to decrease the emission of N₂O from the oxic zone in A²O processes, it was critical to adjust aeration rates at the rear of the oxic zones properly for a suitable concentration of DO in the anoxic and anaerobic zones after the water was returned.

N₂O emission in the SBR WWTP

The flux of N₂O and concentration of dissolved N₂O in different treatment units/periods in the SBR WWTP are shown in Table 2. High flux of N₂O was observed with big differences among different units/periods of water treatment. N₂O flux decreased in the order of SBR tank >> swirl grit tank > sewage distribution tank. In the SBR tank, the order was feeding period (with aeration) > aeration period >> settling period > decanting period. The differences in N₂O flux between feeding periods (60.26 g m⁻² d⁻¹) and aeration periods (53.96 g m⁻² d⁻¹) was small. The emission of N₂O in these two periods accounted for the majority of the total emission from the process. This was closely related to the vigorous stirring and relatively high concentration of dissolved N₂O (0.07–0.16 mg L⁻¹) during the feeding and aeration. The sources of high levels of dissolved N₂O could be: (1) denitrification during the previous cycle, (2) nitrification during the aeration, and (3) the influent wastewater. N₂O fluxes from other units/periods did not differentiate from others (0.01–0.05 g m⁻² d⁻¹) although the levels of dissolved N₂O in the periods of settling and

Table 1 | N₂O flux and dissolved N₂O in different units in A²O plant

<table>
<thead>
<tr>
<th>Treating units</th>
<th>N₂O flux (g m⁻² d⁻¹)</th>
<th>Dissolved N₂O (mg L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerated grit tank</td>
<td>10.93</td>
<td>0.12</td>
</tr>
<tr>
<td>Primary clarifier</td>
<td>0.01</td>
<td>0.05</td>
</tr>
<tr>
<td>A²O-anoxic zone</td>
<td>0.37</td>
<td>0.26</td>
</tr>
<tr>
<td>A²O-an aerobic zone</td>
<td>2.13</td>
<td>0.60</td>
</tr>
<tr>
<td>A²O-oxic zone</td>
<td>18.91</td>
<td>0.08</td>
</tr>
<tr>
<td>Final clarifier</td>
<td>0.01</td>
<td>0.05</td>
</tr>
</tbody>
</table>
decanting were much higher. Dissolved N$_2$O during the periods of settling and decanting kept accumulating when denitrification proceeded with low levels of COD and also the stripping of N$_2$O reduced (Itokawa et al. 2001).

The variations of N$_2$O flux and DO level during the periods of feeding and aeration in the SBR tank are illustrated in Figure 3. N$_2$O flux increased from 40.89 to 79.63 g m$^{-2}$ d$^{-1}$ in the first hour, revealing that a large amount of N$_2$O was produced during the period. The concentration of DO increased rapidly to 3.17 mg L$^{-1}$ in the first 15 min and then dropped down to approximately 1.0 mg L$^{-1}$ by 40 min. Afterwards, DO values grew gradually to 4.37 mg L$^{-1}$ in the remaining period of aeration. During the first 0.5 h of feeding, the amount of organic matter entering the SBR tank was small. The low demand of oxygen for COD degradation led to a rapid increase in DO. Thus, N$_2$O emission during the period was mainly attributed to dissolved N$_2$O in the denitrified water from previous circles of the SBR. As feeding proceeded, the organic matter accumulated caused a sharp drop of DO value. The rapid growth of N$_2$O flux seen in this period suggested that incomplete nitrification would have occurred, resulting in a large production of N$_2$O, it was the greatest source of N$_2$O emission in the biological units. In the period of aeration, organics were consumed gradually and consequently DO values rose. The flux of N$_2$O in the first half hour of the aeration period remained at a high level, demonstrating that considerable N$_2$O was produced during the low DO nitrification (Liu et al. 2008). N$_2$O emitted during the second half hour of the aeration period was mainly due to the decreasing concentration of dissolved N$_2$O (from 0.11 to 0.04 mg L$^{-1}$) in the SBR tank. Although none of the N$_2$O would be produced during nitrification when DO exceeded 2 mg L$^{-1}$, the high DO (2.83–4.37 mg L$^{-1}$) might still cause big production of N$_2$O (from 0.04 to 0.10 mg L$^{-1}$) during denitrification in the settling period of the SBR (Hanaki et al. 1992). Therefore, increasing aeration rate during feeding periods and decreasing it to a proper value for nitrification in aeration periods were very important for the reduction of N$_2$O emission in SBR WWTPs.

Comparison of N$_2$O emission from A$^2$O and SBR WWTPs

As shown in Table 3, the total emission of N$_2$O from the A$^2$O system was 486.61 kg d$^{-1}$. The oxic zone in the A$^2$O tank was the largest contributor (>96.9%), followed by the A$^2$O-anaerobic zone, aerated grit tank and A$^2$O-anoxic zone, while the contributions of primary clarifier and final clarifier were negligible in the A$^2$O WWTP. The emission of N$_2$O from different units/periods in the SBR system is presented in Table 4. The total emission of N$_2$O was 339.24 kg d$^{-1}$. The periods of feeding and aeration contributed most (99.9%) to the total emission of N$_2$O.

Emission factors of N$_2$O were evaluated by incorporating N loads in influent of the two WWPTs. N$_2$O emitted from the SBR plant accounted for 6.52% of its N load. The number was 3.4 times higher than the emission factor (1.95%) in the A$^2$O WWTP. Differences between operational modes (especially feeding and aeration) of A$^2$O

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**Table 2** | N$_2$O flux and dissolved N$_2$O in different units/periods in SBR WWTP

<table>
<thead>
<tr>
<th>Treating units/periods</th>
<th>N$_2$O flux (g m$^{-2}$ d$^{-1}$)</th>
<th>Dissolved N$_2$O (mg L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swirl grit tank</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Sewage distribution tank</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>SBR-feeding period</td>
<td>60.26</td>
<td>0.16</td>
</tr>
<tr>
<td>SBR-aeration period</td>
<td>53.96</td>
<td>0.07</td>
</tr>
<tr>
<td>SBR-settling period</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>SBR-decanting period</td>
<td>0.03</td>
<td>0.13</td>
</tr>
</tbody>
</table>

**Table 3** | N$_2$O emission from different units in A$^2$O WWTP

<table>
<thead>
<tr>
<th>Treating unit</th>
<th>Total area (m$^2$)</th>
<th>N$_2$O emission (kg d$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerated grit tank</td>
<td>504</td>
<td>5.51</td>
</tr>
<tr>
<td>Primary clarifier</td>
<td>25,200</td>
<td>0.25</td>
</tr>
<tr>
<td>A$^2$O-anoxic zone</td>
<td>3,564</td>
<td>1.32</td>
</tr>
<tr>
<td>A$^2$O-anaerobic zone</td>
<td>3,564</td>
<td>7.59</td>
</tr>
<tr>
<td>A$^2$O-oxic zone</td>
<td>24,945</td>
<td>471.70</td>
</tr>
<tr>
<td>Final clarifier</td>
<td>23,562</td>
<td>0.24</td>
</tr>
<tr>
<td>Total</td>
<td>–</td>
<td>486.61</td>
</tr>
</tbody>
</table>
and SBR processes were obviously the reason for the great differences in N\textsubscript{2}O emission. Compared with results from previous research (N\textsubscript{2}O emission factors: 0–25%), the results in the present study were at a medium level (Law et al. 2012).

**CONCLUSIONS**

Aeration units/periods were the most contributive to the emission of N\textsubscript{2}O in both A\textsuperscript{2}O and SBR WWTPs in this work. N\textsubscript{2}O from the oxic zone in the bio-treatment tank accounted for 96.9% of the total emission in the A\textsuperscript{2}O WWTP. In the SBR plant, 99.9% of the total emission of N\textsubscript{2}O occurred in the periods of feeding and aeration in the SBR tank. Approximately 6.52% of N load in the influent was transformed into the emitted N\textsubscript{2}O in the SBR WWTP, which was 3.35 times higher than the number in the A\textsuperscript{2}O system.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


**Table 4 | N\textsubscript{2}O emission from different units/periods in SBR WWTP**

<table>
<thead>
<tr>
<th>Treating units/period</th>
<th>Total area (m\textsuperscript{2})</th>
<th>N\textsubscript{2}O emission (kg d\textsuperscript{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swirl grit tank</td>
<td>28</td>
<td>0.0008</td>
</tr>
<tr>
<td>Sewage distribution tank</td>
<td>32</td>
<td>0.0003</td>
</tr>
<tr>
<td>SBR-aeration period</td>
<td>11,872</td>
<td>178.85</td>
</tr>
<tr>
<td>SBR-settling period</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>SBR-aeration period</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>SBR-decanting period</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>339.24</td>
</tr>
</tbody>
</table>

The table above shows the N\textsubscript{2}O emission from different units/periods in SBR WWTP. The data indicates that the aeration units/periods were the most contributive to the emission of N\textsubscript{2}O in both A\textsuperscript{2}O and SBR WWTPs. In the A\textsuperscript{2}O WWTP, the N\textsubscript{2}O from the oxic zone in the bio-treatment tank accounted for 96.9% of the total emission. In the SBR plant, 99.9% of the total emission of N\textsubscript{2}O occurred in the periods of feeding and aeration in the SBR tank. Approximately 6.52% of the N load in the influent was transformed into the emitted N\textsubscript{2}O in the SBR WWTP, which was 3.35 times higher than the number in the A\textsuperscript{2}O system.
wastewater treatment system with intermittent aeration. 


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