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Research on Greenhouse Gas Emission Reduction Methods of SBR and Anoxic Oxic Urban Sewage Treatment System

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Abstract: With the rising awareness of environmental protection, more sewage treatment plants have been built. However, this is also one of the main sources of greenhouse gas emissions. This study carried out a series of sewage treatment experiments to analyze the factors affecting the greenhouse gas emissions of the two commonly used treatment processes in the current urban sewage treatment: the A/O and SBR methods. The experimental results showed that the total amount of greenhouse gases emitted by the A/O method was 415.63 gCO_2-eq/m^3, and the total amount of greenhouse gases emitted by the SBR method was 879.51 gCO_2-eq/m^3. The N_2O emission factor in the A/O method experimental group was 0.76% of the nitrogen content in the influent. In the aerobic section, when the content of dissolved oxygen was in the range of 1.30~2.10 mg/L, and the content of dissolved oxygen was 1.90 mg/L, the minimum N_2O emission factor was reduced to 0.29% of the nitrogen content of the influent. In the SBR experimental group, the ammonia oxidation rate of sewage decreased rapidly as the temperature decreased, thus affecting the discharge rate of N_2O. At 25 °C, the biological enzyme activity of nitrifying bacteria was higher, thus promoting denitrification and generating more greenhouse gases. The research results provide reference for strengthening the management of sewage treatment plants and reducing greenhouse gas emissions from sewage treatment plants.

Keywords: SBR; anoxic oxic; sewage treatment; greenhouse gases; emission reduction

Citation: Bai, M.; Li, W.; Xu, J. Research on Greenhouse Gas Emission Reduction Methods of SBR and Anoxic Oxic Urban Sewage Treatment System. *Sustainability* **2023**, *15*, 7234. https://doi.org/10.3390/su15097234

Academic Editor: Agostina Chiavola

Received: 22 March 2023
Revised: 18 April 2023
Accepted: 21 April 2023
Published: 26 April 2023

1. Introduction

With the rapid growth of China's economy, the total amount of domestic sewage and industrial sewage produced by cities has increased year by year. However, the current domestic environmental conditions no longer allow China to directly discharge sewage according to the previous energy-intensive development model [1]. With the demand for urban sewage treatment soaring in recent years, new sewage treatment plants have also emerged [2,3]. China pays attention to improving the total treatment rate of urban sewage and strengthening the implementation and supervision of effluent standards of treatment plants. In general, the effluent quality of most of our sewage treatment plants still lags behind that of developed countries [4]. Even for the few domestic sewage treatment plants that can reach the emission quality of their European and American counterparts, their greenhouse gas emissions in the sewage treatment process are far higher. At present, with the global greenhouse effect gradually becoming more harmful, the greenhouse gas emissions in China have attracted more and more public attention. Since the beginning of the 21st century, China has encouraged and guided the construction of sewage treatment plants with low additional emissions. In foreign countries, the issue of greenhouse gas emissions from sewage treatment is equally serious. The rapid development of India's population and industry has brought a large amount of wastewater, including domestic wastewater and 27 types of industrial wastewater. The toxicity and discharge rate of harmful components in these wastewaters have far exceeded the limits of self-purification of the ecological environment. Moreover, poor management systems can generate a large amount of greenhouse gases, which will have a negative impact on the daily lives of urban residents [5,6]. On the other hand, it is necessary to find alternative renewable energy sources that can play an important role in alleviating energy demand. Greenhouse gas emission standards and sewage treatment standards of urban sewage treatment plants are also becoming increasingly strict. In this context, how to master the greenhouse gas emission rules of sewage treatment plants, and how to design control strategies and operation parameters that can reduce emissions on this basis have become increasingly important. At present, N_2O, CO_2, and CH_4S are the three main greenhouse gases emitted by sewage treatment plants. There are many studies on emission reduction strategies for CO_2 and CH_4S. However, the research on N_2O is relatively limited, and quantitative research based on experiments is particularly rare. This study attempts to take sewage treatment plants with common anoxic oxic (A/O) and sequencing batch reactor (SBR) activated sludge processes in the industry as the research object, analyze the N_2O gas emission rules, and summarize the strategies and operating parameters conducive to reducing N_2O emissions.

2. Related Works

Greenhouse gases emitted by units including sewage treatment tanks are an important reason for the serious global greenhouse effect. To reduce greenhouse gas emissions, many scholars have carried out various studies. Zhu and others found that the greenhouse gas produced by sewage treatment plants in large cities was an important reason for the energy waste of the whole system. Therefore, this team developed nine different sewage treatment processes based on several different types of sewage treatment plants in Hong Kong. The experimental results showed that the sewage treatment process proposed in the study significantly increased the greenhouse gas produced in the sewage treatment process. It also reduced the operating energy consumption of the sewage treatment plant compared with the traditional process [7]. Kim developed effective emission reduction strategies for the large amount of greenhouse gases produced by cogeneration plants and boilers in the working stage. The team selected two South Korean wastewater treatment plants as the research objects to carry out the experiment. The experimental results showed that the greenhouse gases emitted by the boiler in the whole life cycle were higher than those of the cogeneration plant. Therefore, the service time of the boiler should be reduced as much as possible [8]. Zaborowska believed that modern sewage treatment plants should balance energy performance, sewage quality, and greenhouse gas emissions to provide support for auxiliary sewage treatment. A comprehensive model of a sewage treatment plant was designed for experimental analysis. The analysis results showed that the model produced less greenhouse gases and consumed less energy to treat unit mass sewage discharge, which had certain application potential [9]. Jafri and others found that replacing fossil fuels with biofuels could reduce greenhouse gas emissions during transportation. Specifically, an improved pyrolysis bio-oil method was studied as the energy source of transport vehicles. Experiments showed that this method also provided sufficient power for transport vehicles, and the greenhouse gas emissions were lower [10]. Kyung's team believed that there was huge energy consumption and material consumption during the operation of the sewage treatment plant, which was one of the important sources of greenhouse gases. The team accurately estimated the greenhouse gas emissions of each treatment step of the sewage treatment plant and developed a process-based life cycle assessment method for the sewage treatment plant. Then, a sensitivity analysis tool was used to find out the core factors that affected the greenhouse gas emissions in the whole life cycle of the sewage treatment plant. On the basis of the research results, several strategies were proposed to reduce sewage discharge [11]. Lofty and others found that the greenhouse gas emissions of the sewage treatment plant were not consistent with the emission rate in a year. Therefore, the team selected a domestic sewage treatment plant as the research object to analyze the reasons for this phenomenon. The experimental results showed that properly reducing the operating ambient temperature of the sewage treatment plant could reduce the emission rate of greenhouse gases. However, too low ambient temperature reduced the quality of sewage treatment. Therefore, on the premise of controlling the cost of sewage treatment, the ambient temperature of the plant should be properly controlled to reduce the emission of greenhouse gases [12]. A summary of various literature reviews is shown in Table 1.

Table 1. Summary of literature reviews.

Reference Number	Author	Title	Contribution
[7]	Zhuang, H., Guan, J., Leu, S.Y., Wang, Y., Wang, H	Carbon footprint analysis of chemical-enhanced primary treatment and sludge incineration for sewage treatment in Hong Kong	Developed nine different sewage treatment processes, some of which can reduce greenhouse gas emissions from sewage treatment
[8]	Kim, D., Kim, K.T., Park, Y.K	A comparative study on the reduction effect in greenhouse gas emissions between the combined heat and power plant and boiler	An experiment was conducted, and it was found that boilers emit higher greenhouse gases throughout their entire lifecycle than cogeneration plants
[9]	Zaborowska, E., Czerwionka, K., Mkinia, J	Integrated plant-wide modeling for evaluation of the energy balance and greenhouse gas footprint in large wastewater treatment plants	Designed a comprehensive model of the entire sewage treatment plant
[10]	Jafri, Y., Wetterlund, E., Mesfun, S., Radberg, H., Mossberg, J., Hulteberg, C., Furusjo, E	Combining expansion in pulp capacity with production of sustainable biofuels—techno-economic and greenhouse gas emissions assessment of drop-in fuels from black liquor part-streams	An improved pyrolysis bio-oil method was analyzed as an energy source for transportation vehicles; experiments showed that this method can also provide sufficient power for transportation vehicles and lower greenhouse gas emissions
[11]	Kyung, D., Jung, D.Y., Lim, S.R	Estimation of greenhouse gas emissions from an underground wastewater treatment plant	Several strategies have been proposed to help reduce wastewater discharge
[12]	Lofty, J., Muhawenimana, V., Wilson, C., Ouro, P	Microplastics removal from a primary settler tank in a wastewater treatment plant and estimations of contamination onto European agricultural land via sewage sludge recycling	Research has found that appropriately reducing the operating environment temperature of sewage treatment plants can help reduce the rate of greenhouse gas emissions, but too low an environmental temperature can lead to a decrease in the quality of sewage treatment

To sum up, to reduce the greenhouse gas emissions of sewage treatment plants and other nonresidential buildings, relevant scholars have carried out extensive relevant research. Various strategies and improved processes conducive to emission reduction have been proposed. However, most of these studies have not been implemented into the current sewage treatment processes on the market. Therefore, this study attempts to take the sewage treatment plants adopting A/O and SBR processes as the object, exploring strategies conducive to reducing greenhouse gas emissions in the sewage treatment process.

3. Experimental Methods and Materials

3.1. Environmental Setting of Sewage Treatment Plant

The research object was two sewage treatment plants of the same scale and type in a certain area in China, which adopt A/O and SBR as the sewage treatment processes. The specific parameters of each constituent unit of the sewage treatment plant using the A/O process are shown in Table 2. HRT in Table 2 represents the hydraulic retention time.

Table 2. Specific parameters of each constituent unit of A/O process sewage treatment plant.

Module Number	Modular	Module Abbreviation	Volume (m^3)	Surface Area (m^2)	HRT (h)
1	Aerated grit chambers	AGT	2256	498	0.02
2	Primary sedimentation tank	PST	149,709	24,910	/
3	Anoxic pool	AT	31,988	5279	1.55
4	Aerobic tank	OT	159,624	27,061	7.68
5	Secondary sedimentation tank	FC	93,785	24,073	2.50–4.10

The sampling points of each module in Table 1 are shown in Figure 1. Due to the blow-off effect of the aerobic tank, the front section of the aerobic tank needs to be set with denser sampling clusters to reduce the error of the collected data. However, the hydraulic retention times of the aerated sedimentation tank and primary sedimentation tank are relatively short, and only one sampling point needs to be set.

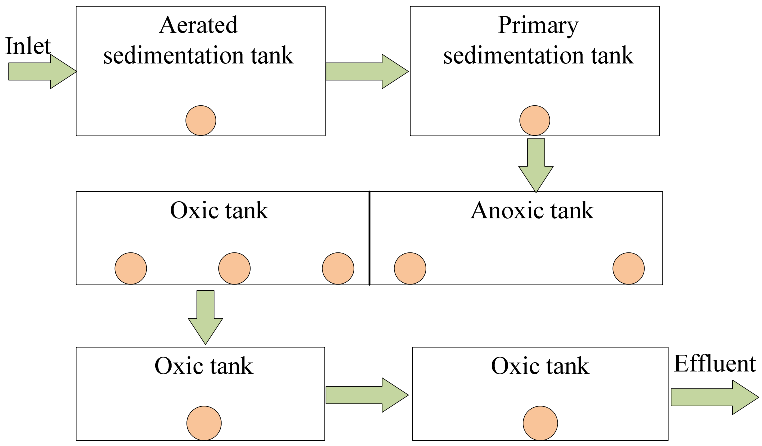

Figure 1. Layout of sampling points in A/O process sewage treatment scheme.

The sewage treatment plant using the SBR process contains four parallel principal tanks. Each principal tank needs to run six complete processing cycles every day. During this process, there are sewage distribution wells, the influent aeration stage, aeration without influent stage, sedimentation stage, and drainage stage, which are defined as SDT, AF, ANF, SP, and DP, respectively. The surface area, volume, and HRT data are 11,924 m^2, 65,400 m^3, and 4 h for the independent SBR tanks, and 30 m^2, 140 m^3, and <0.1 h for the swirling sedimentation tanks, respectively. Figure 2 displays the sampling layout of each module in the sewage treatment system.

3.2. Experimental Scheme

In the A/O process, the more advanced anoxic anaerobic oxic method (A^2/O) is selected to treat sewage. This method has a processing capacity of 150,000 tons/day and contains multiple components. Table 3 shows more specific information. In this way, it takes 6 months for sewage to detect and collect N_2O. The sludge needs to stay in the secondary biological treatment module for 15–25 days.

N_2O is the main greenhouse gas emitted in urban sewage treatment. In the A^2/O process, the aerobic tank is the main source of N_2O release. This study attempts to analyze the relationship between the aeration condition DO of the sewage treatment plant adopting the A^2/O process and N_2O emission in the front of aerobic tank. This can allow identifying strategies conducive to reducing greenhouse gas emissions. Considering that the water temperature of sewage causes differences in N_2O emissions, temperature was the main research factor. SBR was selected as the sewage treatment equipment in the experiment.

NO is the prophase product of N_2O in sewage nitrification reaction; hence, it was also included in the research scope. The water quality of the corresponding sewage treatment plant using the A^2/O process in the study is shown in Table 4. TN, SS, COD, and BOD respectively represent total nitrogen, suspended solids, chemical oxygen demand, and biological oxygen demand.

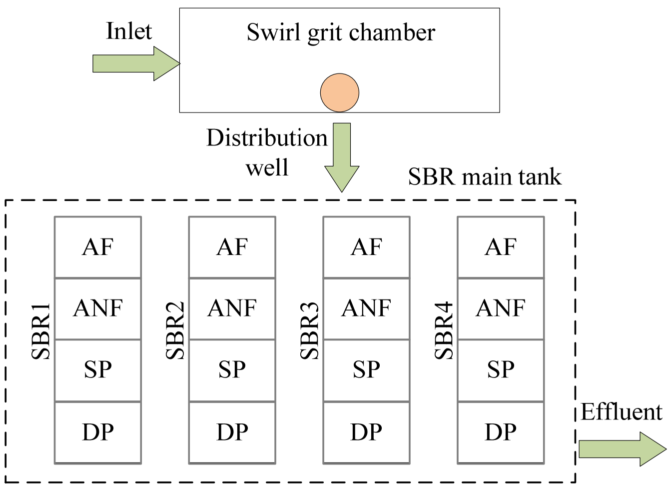

Figure 2. Layout of sampling points in SBR process sewage treatment scheme.

Table 3. Parameter statistics of each module of A^2/O process sewage treatment plant.

Module Number	Modular	Module Abbreviation	HRT (h)	Total Surface Area
1	Grit chamber	GT	0.12	119.6
2	Anaerobic tank	AnT	1.10	1120.0
3	Anoxic pool	AT	1.10	1120.0
4	Aerobic tank	OT	5.97	6500.0
5	Secondary sedimentation tank	FC	3.14	1910.0

Table 4. Water quality data of sewage treatment plant corresponding to A^2/O process.

Index No	Evaluating Indicator	Index Value (mg/L)	Index No	Evaluating Indicator	Index Value (mg/L)
1	Inlet water TN	33.8 ± 3.5	07	Outlet water TN	15.26 ± 1.88
2	Inlet water SS	98.4 ± 14.2	08	Outlet water TSS	12.98 ± 4.10
3	Inlet water COD/N	5.91 ± 0.97 L	09	Temperature	25.8 ± 2.5
4	COD of inlet water	189.7 ± 25.1	10	COD of outlet water	22.4 ± 4.1
5	Inlet water BOD	76.2 ± 10.3 L	11	Outlet water BOD	11.62 ± 2.40
6	Inlet water NH_4^+-N	22.5 ± 4.1	12	Outlet water NH_4^+-N	0.81 ± 0.13

To study the effect of different DO on N_2O emission under this process, a treatment tank group (Figure 3) was constructed in the experiment. Figure 3 shows the location of sampling points. The A^2/O process pilot sludge was obtained from the on-site A^2/O aeration tank. After 15 days of aeration treatment in the sedimentation tank, the experiment lasted for 6 months [13–15].

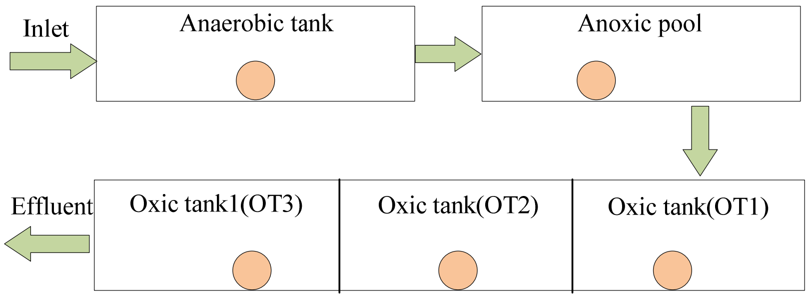

Figure 3. Schematic diagram of treatment tank group and N_2O sampling point corresponding to A^2/O process.

In the SBR process, the relatively advanced long cylindrical short-pass nitrification SBR (PN-SBR) reactor is selected to treat sewage. To simulate the real sewage composition, $ZnSO_4 \cdot 7H_2O$, $CoCl_2 \cdot 6H_2O$, $MnCl_2 \cdot 4H_2O$, $CuSO_4 \cdot 5H_2O$, $Na_2MoO_4 \cdot 2H_2O$, and $CaCl_2 \cdot 2H_2O$ are added to the sewage to achieve concentrations of 0.5, 0.42, 1.28, 0.41, 0.06, and 1.38 g/L, respectively. Before studying the emission characteristics of N_2O and NO gas under different temperature conditions, PN-SBR is required to simulate the treatment of sewage with 30 °C and the same water quality. It operates for 4 cycles every day, and each cycle lasts for 6 h [15–17]. In the experiment of exploring the effect of temperature change on PN-SBR greenhouse gas emissions, the temperature conditions set were 30, 25, 20, 15, and 10 °C. Under each temperature condition, the sewage treatment plant needed to operate stably for more than 4 weeks before measuring data. According to the existing research experience, the reaction time of the PN-SBR reactor in the aeration stage at the temperatures of 0, 25, 20, 15, and 10 °C was set as 105 min, 110 min, 120 min, 180 min, and 300 min, respectively. The relative content of AOB in the reactor was determined by fluorescence in situ hybridization. AOB abundance in the reactor was detected by FISH.

3.3. Experimental Sampling Method

In the experiment, N_2O produced on site was collected by an aluminum foil sampling bag, the gas flux data of each module in the A^2/O process was monitored using the static box sampling method, A^2/O greenhouse gas was collected using the air bag method, and dissolved greenhouse gas data were measured using the headspace test method. As the above methods are common, the specific processes are not explained in detail.The overall execution of the experiment designed for this study is shown in Figure 4.

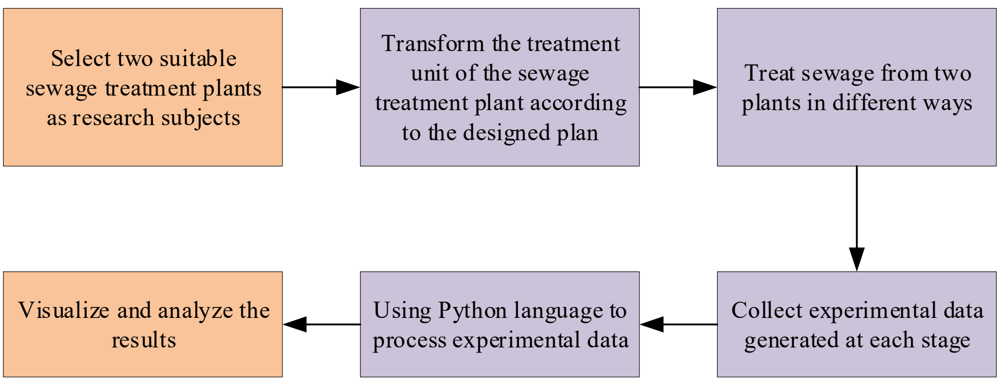

Figure 4. Overall execution flow chart of the experiment.

3.4. Experimental Instruments and Reagents

The instruments and equipment to be used in this study were as follows: DO fast tester, pH fast tester, DO fast tester, ORP fast tester, greenhouse gas sampling bag (50, 200, and 500 mL), static box (40 L), electronic balance, aeration zone sampling bag (0.09 m^3), gas chromatograph, magnetic stirrer, gas flow meter, N_2O online monitor, NO online monitor, COD fast tester, centrifuge, pH meter, peristaltic pump, water bath device, muffle furnace, ultraviolet visible spectrophotometer, visible spectrophotometer, multiparameter PLC, TOC analyzer, and ion chromatograph.

The drugs used in the experiment included CH_4, high-purity nitrogen, concentrated sulfuric acid, concentrated hydrochloric acid, a special catalyst and oxidant for COD rapid tester, $ZnSO_4 \cdot 7H_2O$, $CoCl_2 \cdot 6H_2O$, $MnCl_2 \cdot 4H_2O$, $CuSO_4 \cdot 5H_2O$, $Na_2MoO_4 \cdot 2H_2O$, $CaCl_2 \cdot 2H_2O$, NH_4HCO_3, K_2HPO_4, KH_2PO_4, and NaOH.

3.5. Calculation Method of Experimental Indices

In the experiment, the specific ammonia oxidation rate (sAOR) was used to measure the conversion rate of ammonia nitrogen in the reactor. Equation (1) shows the calculation method.

$$sAOR = dC_{NH_4^+-con}/(dt\ MLVSS), \tag{1}$$

where $C_{NH_4^+-con}$ is the concentration of NH_4^+ (mg/L), $MLVSS$ is the total solid concentration (g/L), and $MLVSS$ is the time interval required for aeration reaction (min). The relationship between sAOR and the temperature index is described in Equation (2).

$$r_T = r_{T293} \cdot \theta^{(T-293)}, \tag{2}$$

where r_T is the reaction rate, T represents the Kelvin temperature of the system, and θ is the temperature coefficient in the specified temperature condition.

In the study, Equations (3) and (4) were used to calculate the greenhouse gas emissions E_n and E_a in the non-aeration zone and the aeration zone, respectively.

$$E_n = 273\rho(dc/dt)A_t V(273+T)^{-1}Q_w^{-1}A_S^{-1}, \tag{3}$$

where dc/dt represents the slope of the linear fitting equation between the cumulative concentration of greenhouse gases in the static box and time, V is the volume of space above the static box, and its unit is m^3, ρ is the gas density (g/m^3), V is the volume of space above the static box, T is the temperature (°C), Q_w is the flow of sewage (m^3/min), and A_s is the total surface area of each sampling point.

$$E_a = 273c\rho A_t Q_a A_g^{-1} Q_w^{-1}(273+T)^{-1}, \tag{4}$$

where Q_a and c are the fluxes of greenhouse gases ($m^3 air/m^2/d$), and A_g is the module surface area. The average emission flux X of the aerobic section was calculated according to Equation (5).

$$E_{average} = \frac{1}{3(E_1+E_2+E_3)}, \tag{5}$$

where $E_1 \sim E_3$ represents the emission flux of greenhouse gases at different sampling points in the aerobic tank ($g/m^2/d$). The real-time volume mass fraction of greenhouse gas was used to calculate the gas output. Equations (6) and (7) were used to calculate the output of N_2O and NO, respectively.

$$C_{N_2O} = \frac{28 \times 10^{-6}}{RT}, \tag{6}$$

$$C_{NO} = \frac{14 \times 10^{-6}}{RT}, \tag{7}$$

where $1/RT$ represents the molar volume of N_2O or NO.

4. Results

4.1. Impact of DO Concentration in A/O Sewage Treatment Method on Greenhouse Gas Emissions

After the experiment, the N_2O emission flux of each treatment unit of the sewage treatment plant was measured. Figure 5 shows the statistical results. The horizontal axis represents the components of the sewage treatment plant corresponding to the A^2/O process. Figure 5a–c represent the N_2O flux concentration, dissolved N_2Oconcentration, and N_2O emission concentration, respectively. According to Figure 5, the N_2O flux concentration and N_2O emission concentration in OT of the sewage treatment plant were significantly higher than those in other parts. The dissolved N_2O concentration was significantly lower than that of other parts. The specific values were 5.32 $gN/m^2/day$, 0.2315 $gN_2O\text{-}N/m^3$, and 0.13 mgN/L respectively. The N_2O emission fluxes of GT and FC parts were 0.12 $gN/m^2/day$ and 0.14 $gN/m^2/day$, respectively, which were the smallest of all parts. N_2O in these two parts of the water surface was more stable, and the corresponding dissolution concentration was also higher. This is because internal circulation in FC part could return sludge to anaerobic tank, which may have increased dissolved N_2O concentration.

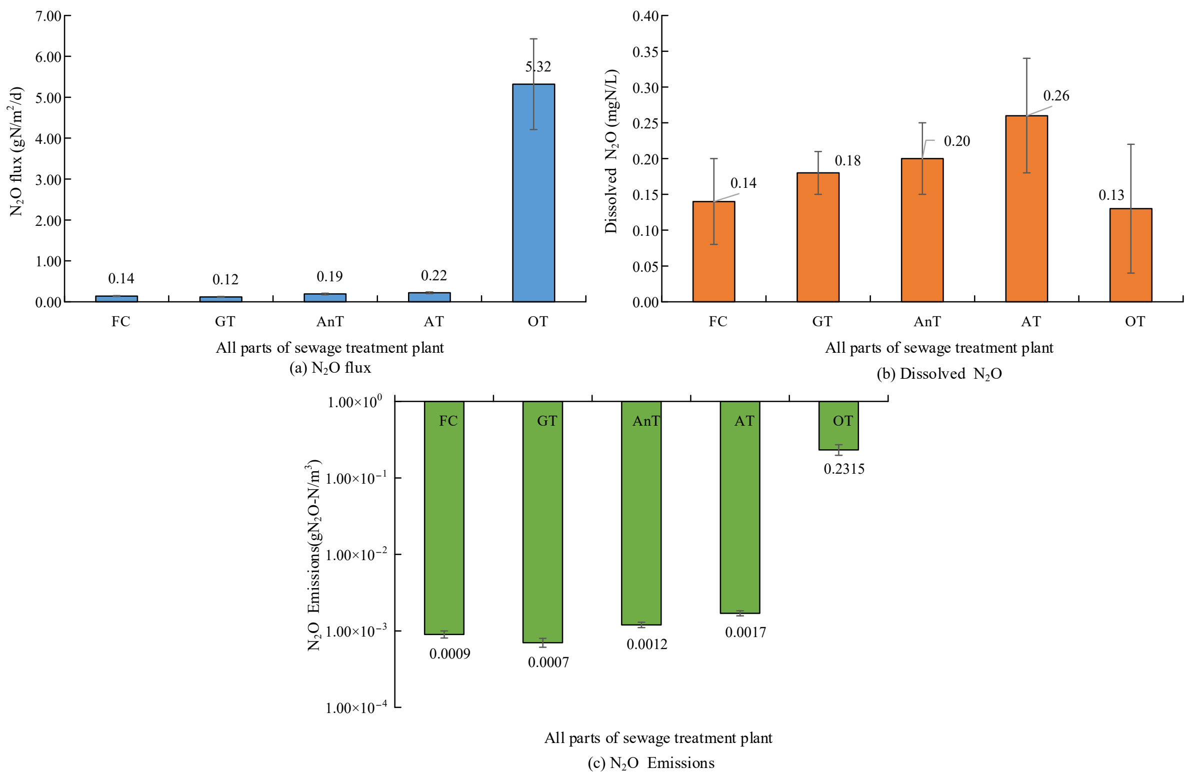

Figure 5. N_2O emission flux statistics of different units of sewage treatment plant.

N_2O emissions of the sedimentation tank, anaerobic tank, anoxic tank, aerobic tank, secondary sedimentation tank, and all modules corresponding to the A^2/O process were $0.091 \times 10^{-3} \pm 0.021 \times 10^{-3}$, $0.938 \times 10^{-3} \pm 0.181 \times 10^{-3}$, $1.604 \times 10^{-3} \pm 0.308 \times 10^{-3}$, 0.235 ± 0.05, $0.521 \times 10^{-3} \pm 0.130 \times 10^{-3}$, and 0.235 ± 0.05 N_2O/m^3, respectively. The amount of N_2O discharged by the aerobic tank was significantly higher than that of other modules. Therefore, controlling N_2O emission in aerobic tank is the key to reducing N_2O emission in the A^2/O process. The corresponding N_2O flux and dissolved N_2O for DO in the front section of aerobic cells of different modules under different aeration rates are shown in Figure 6. In Figure 6, the horizontal axis represents the DO concentration and sewage tank module of aerobic tank 1, the main vertical axis represents N_2O flux, and the secondary vertical axis represents N_2O dissolved concentration. According to

Figure 6, the dissolved N_2O concentration of the AT module was the highest, showing a continuous increasing trend with the increase in DO concentration in OT1. The dissolved N_2O concentration in other parts changed slightly. The N_2O flux concentration of OT1 was also higher than that of other parts. The aeration rate was the only variable in the aerobic tank on the premise when other operating parameters were consistent. Therefore, the change in N_2O emission flux and dissolved concentration was due to the stripping effect caused by aeration.

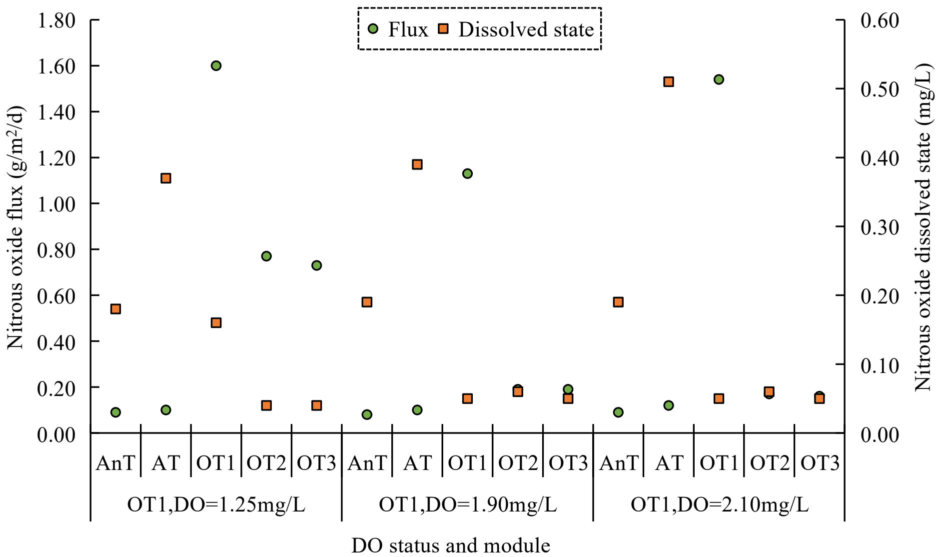

Figure 6. N_2O flux and dissolved N_2O corresponding to DO in front of each aerobic cell at different exposure rates.

The changes in DO and NO_2-N concentrations in the A^2/O tank under different aeration rates are discussed below. Figure 6 shows the statistical results. The horizontal axes in Figure 7 represent the constituent modules of the structure of theA^2/O tank. The vertical axes of the subgraphs in Figure 7a,b represent DO and NO_2-N concentrations, respectively. According to Figure 7, under the DO concentration conditions of different OT1 structures, the DO concentration of each OT tank was significantly higher than that of other structure tanks. For example, when the DO concentration of OT1 was 1.90 mg/L, the DO concentrations of AnT, AT, and OT2 were 0.16 mg/L, 0.19 mg/L, and 4.17 mg/L, respectively. The NO_2-N concentration value of the AT module under all DO concentrations was significantly higher than that of other structural modules, followed by the OT1 module. Therefore, the aeration intensity and time did not influence the nitrite oxidation effect. After the chemical reaction in the front of the aerobic tank is completed, more aeration operations can increase the relative energy consumption.

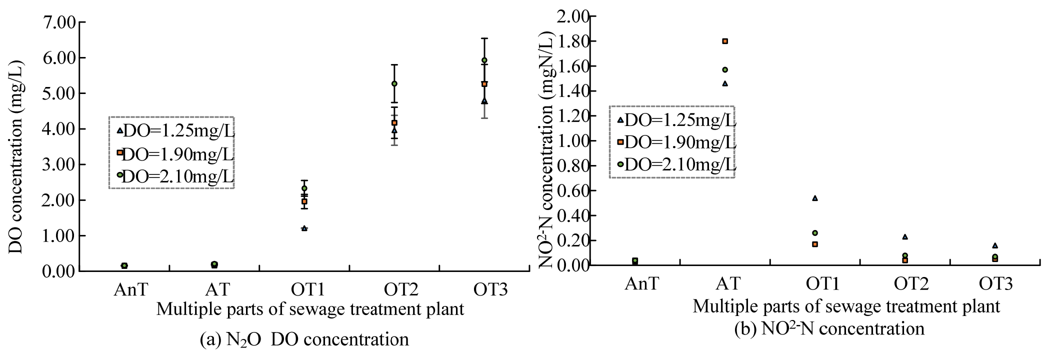

Figure 7. DO and NO_2-N concentration curves of A^2/O tank under different exposure rates.

Table 5 shows the removal rate of different pollutants and the N_2O emission coefficient under different DO conditions in the A^2/O process. According to Table 5, the NH_4^+ removal rate increased with the increase in aeration rate. For example, when the aeration rate was 33.00 m^3air/m^3water/h and 6.00 $m^3_{air}/m^3_{water}/h$, the NH_4^+ removal rates were 96.86% ± 0.77% and 98.95% ± 0.92%, respectively. However, there was no significant correlation between the other three indicators and the aeration rate. Therefore, properly increasing the aeration rate is beneficial to reducing N_2O. However, too high an aeration rate will consume more oxygen, thus increasing energy consumption and greenhouse gas emissions.

Table 5. Comparison of pollutant removal rate and N_2O emission coefficient under different DO conditions in A^2/O Process.

Scheme No	Aeration Rate $m^3_{air}/m^3_{water}/h$ (DO Concentration mg/L)	NH_4^+ Removal Rate %	TN Removal Rate %	COD Removal Rate %	N_2O Emission Coefficient % (Nitrogen Element of Influent Water)
1	2.00	96.37 ± 0.48	52.25 ± 4.42	87.54 ± 3.59	0.75 ± 0.20
2	3.00 (1.25)	96.86 ± 0.77	56.69 ± 3.67	88.51 ± 3.82	0.67 ± 0.14
3	4.00 (1.90)	97.52 ± 0.82	52.79 ± 4.09	87.07 ± 3.41	0.31 ± 0.07
4	5.00 (2.10)	97.54 ± 0.88	49.57 ± 4.08	87.86 ± 3.75	0.38 ± 0.05
5	6.00 (2.20)	98.95 ± 0.92	47.31 ± 3.77	87.51 ± 3.56	0.42 ± 0.06

4.2. Effect of Temperature on Greenhouse Gas Emissions in PN-SBR Sewage Treatment Process

The activity of microorganisms is affected by ambient temperature. The oxidation reaction of NH_4^+ is greatly affected by temperature. Relevant research results show that the activity of nitrifying microbial community is also affected by temperature. Therefore, the correlation between temperature and N_2O and NO emission factors in the PN-SBR reaction environment was statistically analyzed, and the results are shown in Table 5. Since Table 5 contains symmetric matrix data, all the data in the lower left corner are omitted. According to Table 5, the change in temperature had a direct impact on the AOR of AOB, and the AOR was also closely related to N_2O emission. In this study, the sAOR of the two aeration periods was significantly related to temperature ($p < 0.05$). However, there was no obvious correlation between temperature and total N_2O emissions (AERI + AER2). There was also a significant correlation between temperature and N_2O in AERI ($p < 0.05$). When the temperature dropped in the range of 25–100 °C, N_2O emissions also decreased, and the relationship between the two was obvious ($p < 0.05$). In addition, there was no obvious relationship between NO content and temperature, and the emission coefficient was much lower than N_2O.

The change in temperature changed the concentration of free ammonia (FA), which had a great impact on the performance of PN. After introducing sewage, at 30 °C and 10 °C, the content of FA was 11.22 and 3.98 mg FA/L, respectively, in which the average concentration of NH_4^+-N was 120–150 mg/L, and the pH was in the range of 7.8–8.2. However, when considering the relationship among N_2O, NO emissions, and TN, there was no significant difference in N_2O between AER2 and EF, indicating that the concentration range of FA had no significant impact on N_2O and NO emissions.

The decrease in temperature also increased the solubility of N_2O. In the PN-SBR system, the air/N_2 flow rate of the system was fixed at 5 L/min, and the aeration was discontinuous. N_2O and NO could be separated from the liquid phase by increasing the aeration volume. Under all temperature conditions, N_2O emission was stable at the end of the exposure stage, and the value was close to 0. The statistical results of the correlation between temperature and N_2O and NO emission factors in the PN-SBR reaction environment are shown in Table 6.

Table 6. Statistics of correlation between temperature and N_2O and NO emission factors in PN-SBR reaction environment.

/	/	AER1-N_2O	AER2-N_2O	AER1-NO	AER2-NO	sAOR
Temperature	Correlation coefficient	0.946	0.651	0.850	0.844	0.927
	P	0.0230	0.684	0.379	0.326	0.014
AER1-N_2O	Correlation coefficient	1	0.784	0.745	0.681	0.953
	P	/	0.602	0.559	0.513	0.012
AER2-N_2O	Correlation coefficient	/	1	0.158	0.159	0.792
	P	/	/	0.886	0.745	0.358
AER1-NO	Correlation coefficient	/	/	1	1.000	0.663
	P	/	/	/	0.000	0.485
AER2-NO	Correlation coefficient	/	/	/	1	0.715
	P	/	/	/	/	0.483
sAOR	Correlation coefficient	/	/	/	/	1
	P	/	/	/	/	/

5. Discussion

Greenhouse gases emitted by sewage treatment plants are among the reasons for global warming. This study focused on analyzing the emission laws of NO and N_2O greenhouse gases in A/O and SBR processes, aiming to find ways to reduce their greenhouse gas emissions [17–19].

The research results showed that the aerobic tank was the main greenhouse gas emission module compared with the denitrification device. In this study, direct and indirect emissions from aerobic ponds were the main components of total greenhouse gas emissions. Therefore, process parameter optimization and strategy formulation are effective ways to reduce greenhouse gas emissions during the operation of sewage treatment plants [20–22]. The focus of reducing greenhouse gas emission is on the aerobic tank module. Because most of the existing research on wastewater treatment in China was at the laboratory level, the research results were greatly affected by the scale of the experiment, resulting in the research results mostly focused on reducing the emission of nitrogen-containing oxides [23].

In terms of sewage treatment, the prerequisite for reducing greenhouse gas emissions is to accurately assess the emissions of greenhouse gases. In the process and parameter optimization, the process parameters involved in the sewage treatment process need to be adjusted and controlled to optimize the technical strategy of greenhouse gas emission reduction [24]. In addition, corresponding emission reduction measures should be formulated from the aspects of reducing the energy consumption of wastewater treatment facilities and reducing the indirect emissions of greenhouse gases [25–27]. Various new greenhouse gas emission technologies have been combined to form a method with reference value for the overall planning and control of urban sewage system [28,29]. The results of this study showed that, from the process point of view, the A/O treatment process adopted by the sewage treatment plant could reduce the greenhouse gas emissions in wastewater treatment more than the SBR treatment process [30,31]. In the A/O process, controlling the aeration rate in the aeration zone and ensuring the DO at the front end of the nitrification section were the main measures to inhibit N_2O emissions [32–34]. In the established SBR treatment system, the CO_2 emission can be reduced by adjusting the control method of inlet and aeration section, increasing the frequency of inlet and aeration cycle, and reducing the aeration time under $NH4^+$ load [35–37]. SBR changes the process treatment mode before and after the operation of aerobic and anoxic methods. Therefore, the problems of insufficient denitrification caused by excessive consumption of the carbon source and N_2O accumulation caused by the electronic competition of elements Nar, Nir, and Nor vs. elements Nos are avoided, so as to reduce greenhouse gas emissions [38–40]. On this basis, DO concentration has an important impact on N_2O production, which is based on a biological mechanism (AOB is the main research objective) [41–43]. To ensure a low level of N_2O generation in the complete nitrification reaction, there must be a proper DO concentration (about 1.90 mg/L) [44–46].

In the A/O process, the aeration concentration at the front end of the aeration tank can be improved without changing the aeration mode by adjusting the ventilation layout in each area of the aeration tank [47–49]. Maintaining the original aeration rate in the middle and later stages of sewage treatment can ensure the effluent quality of the sewage treatment plant [50,51]. The total amount of greenhouse gases can also be reduced by accurately regulating the water quality and quantity of different wastewater treatment plants through A/O and homologous processes. SBR technology can reduce indirect discharge and sludge production by adjusting the aeration interval and the operation mode of inlet and outlet sections. In addition, if the research perspective is extended to the national level, the carbon dioxide removal method proposed by the Intergovernmental Panel on Climate Change (IPCC) and the national environmental opinions formulated under the United Nations Framework Convention on Climate Change (UNFCCC) initiative can also play a role in reducing greenhouse gas emissions. In particular, the "plant reactor" proposed by the IPCC, which selects plants with higher photosynthetic efficiency, can absorb a certain amount of greenhouse gases emitted near urban sewage treatment plants. Hence, it has high application value for environmental protection. This method based on factory reactors can neutralize greenhouse gas emissions and has good prospects. However, the main problem limiting its widespread application is the high cost of plant reactor layout and the lower efficiency of neutralizing greenhouse gases compared to industrial methods. In the future, plant reactor materials with lower layout costs and higher greenhouse gas neutralization efficiency can be cultivated through biological breeding technology. In addition, the application value of directly placing wastewater treatment bioreactors in enclosed spaces is relatively low at present. This method greatly restricts the exchange of substances between plants and the outside world, making it more prone to problems such as poor growth or abnormal death. Moreover, the greenhouse gas solidification efficiency of bioreactors is also low. It cannot meet the needs of some large-scale wastewater treatment plants.

6. Conclusions

The results of this study showed that, firstly, both the A/O and the SBR processes emit a large amount of greenhouse gases. While the total greenhouse gas emissions per unit of wastewater treated by the SBR process are higher than those of the A/O process. The increase in N_2O emissions is mainly due to the lower DO of aerobic pool water in the early stages, which limits the release of N_2O. Secondly, the DO of nitrifying solution returned to the hypoxia tank has a certain inhibitory effect on denitrification. When the DO concentration in the aerobic tank section ranges from 1.25 to 2.11 mg/L, appropriately increasing the DO concentration can effectively reduce the emission of N_2O gas. However, excessive aeration can slightly increase overall greenhouse gas emissions. This can have an impact on indirect emissions of N_2O and other greenhouse gases, leading to more gas pollution. Although there is a certain degree of NH_4^+-N oxidation during different aeration periods, the N_2O production of the first aeration is higher than that of the second aeration. The reason is that the N_2O gas emissions and AOB activity state will significantly change from the low activation stage (no water inflow, precipitation stage) to the high activation stage (with a certain concentration of $NH4^+$-N in the reactor). This leads to changes in the chemical reaction rate of nitrogen ions. These transient conditions are the most important during the first inflation stage. Specifically, N_2O emissions are highest at 25 °C. When the temperature is below 25 °C, the ammonia oxidation rate of the sewage treatment plant slows down. The amount of N_2O released during the first aeration cycle is also significantly reduced. In addition, the study revealed no significant correlation between the release of NO and temperature. Therefore, adjusting the temperature cannot significantly reduce the NO release from sewage treatment plants. The results of this study are of great significance for improving the management of waste gas emissions from sewage treatment plants.

Author Contributions: Investigation, M.B.; Writing—original draft, W.L.; Supervision, J.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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