Emission reduction technologies for different N2O sources in various ways: Industry, aquaculture and agriculture.

Chutian Shu*

School of Huamei international, Guangdong, China

*Corresponding author: 746100234shuchutian@gmail.com

Abstract. Nitrous oxide (N_2O) is a powerful greenhouse gas and is a key reason that causes the depletion of the ozone layer. Global emissions are rising constantly. This article systematically analyzes the principle of N_2O discharge in three major fields: In wastewater treatment plants (WWTPs), the nitrification and denitrification processes, and chemical reactions in biological denitrification produce N_2O, as well as the aerobic zone is the main diffusion area. In aquaculture, emissions are caused by several factors, including feed conversion rates. In agriculture, nitrogen fertilizer application and straw returning to the field release N_2O through nitrification and denitrification processes. Emission reduction plans are proposed for various fields: In WWTPs, emission reduction is achieved by regulating the ammonia oxidation rate and optimizing the denitrification conditions. The aquaculture industry focuses on improving feed utilization efficiency. Agriculture adopts scientific fertilization, straw management, and others. At the same time, it points out the technical limitations, such as the risk of increased discharge of glycogen-accumulating bacteria (GAO) in WWTPs, the constraints of species characteristics on emission reduction in aquaculture, and the influence of the environment on irrigation methods and the effectiveness of improvers in agriculture, providing a reference for the precise prevention and control of N_2O pollution.

Keywords: Wastewater treatment plants (WWTPs); aquaculture, agriculture; Nitrous oxide(N_2O).

1. Introduction

Nitrous oxide (N_2O) is a colorless and non-toxic gas, often called “laughing gas”. It is composed of two nitrogen atoms and one oxygen atom. In our daily life, it has many uses such as medicine, the food industry, alchemy, and so on, and its presence can be found in numerous fields because its nature is beneficial to our life.

However, since the 21st century, the problem of global warming has been receiving increasing attention from societies. Now, the world is facing serious challenges. N_2O exists in various chemical forms such as air, water, soil, and so on. In addition, N_2O is a potent greenhouse gas, which has an average lifetime of 114 years in the atmosphere. Even if N_2O just accounts for 0.03 per cent in the total emission of greenhouse gases, its radiation capacity is very strong [1]. For instance, compared with the common greenhouse gas: carbon dioxide (CO2), N_2O s global warming potential (GWP) is more than 300 times that of it [2].

Furthermore, N_2O is the main cause of ozone layer depletion[1]. In the stratosphere, ultraviolet photochemical action oxidizes NOx, which leads to the stratosphere being the main absorption sink for N_2O, and the ozone layer will impact the climate. Thus, it causes a lot of problems in the environment [1].

In the global environment, there are many sources of N_2O. While agricultural activities such as the use of nitrogen fertilizers, livestock farming, and so on, are one of the major contributors, it causes a big amount of damage to the environment. In order to solve this problem, researchers investigate various data; there are also some approaches to deal with it. For example, changing the irrigation way in agriculture can reduce nitrogen leaching in the root zone[3]. The biochar can directly reduce the N_2O emission[3]. Also changing some of the types of feeding in aquaculture or the types of fertilization way [4]. These ways can reduce the emission of N_2O in an effective way. Therefore, the aim of this study to explore the source of N_2O and how to solve it.

2. Industry wastewater

The complexity of water environments renders the N_2O emission scenarios of wastewater treatment plants uncertain. During the wastewater treatment process, nitrous oxide may be produced [5]. Nitrous oxide is mainly produced from the nitrification and denitrification processes in estuaries and rivers, and in this process, it does not generally remove nitrogen elements [5]. Nitrogen elements usually exist in the form of reduced ammonium salts. In traditional sewage treatment, the nitrification process converts ammonia into nitrite or nitrate, and the denitrification process then reduces it back to nitrogen gas. Both processes may lead to the emission of nitrogen oxides[5] .

2.1. The Emissions Mechanism of N2O in Wastewater Treatment Plants (WWTPs)

N2O is an inevitable by-product of both biological and abiotic reactions during the biological denitrification (BNR) process In this process, it also produces other reactions[5]. In the nitrification process, N2O is a by-product of ammonia-oxidizing bacteria (AOB) oxidizing hydroxylamine (NH2OH) and denitrification by nitrifying bacteria. Etc [5].

In terms of Nitrification, which is accomplished by 3 types of microbes: ammonium-oxidizing archaea(AOA), nitrate-oxidizing bacteria (NOB), and ammonium-oxidizing bacteria(AOB). These way use different ways to convert into nitrate. In traditional WWTPs, nitrification is mainly dominated by autotrophic AOB and NOB (with ammonia or nitrite as energy sources and carbon dioxide as carbon sources . Although N_2O is not an intermediate product of the main nitrification catabolic pathway, AOB is mainly associated with nitrifier denitrification, which is a process to produces N_2O. Also, N_2O has likely been emitted by unstable biological intermediates. Therefore, the studies showed that N_2O produced by heterotrophic nitrification may be more than that by autotrophic nitrification [5].

Besides, in the context of denitrification. It is based on a diverse group of microorganisms (bacteria and archaea), which gradually reduce the NO_2, NO, nitrite, and nitrate by oxidizing organic and inorganic substances. N_2O is an intermediate product of the denitrification process, so it will emit N_2O if it is not completely reacted [5].

In addition, the chemical pathways in the process of WWTPs may generate N_2O, including: the reaction of nitrite with hydroxylamine to form NO and N_2O, and the reduction reaction of nitrite with organic or inorganic compounds. Among them, the first reaction needs AOB to produce the intermediate product hydroxylamine, which makes it complicated to distinguish between chemical and biological [5].

Additionally, since N_2O is emitted in gas form, the aeration zone (nitrification zone) is the main emission area. However, it occurs not only in the aeration zone but also likely in the anoxic zone [6].

2.2. Solution

The N_2O in the aerobic zone of WWTP is mainly discharged through the NH2OH oxidization path and the denitrification or nitrification pathway [7]. The reduction emission strategies will focus on regulating AOR in the aerobic zone. There are some ways for AOR to reduce the emission of N_2O, which refer to the maximum growth rate, growth yield, pH, ammonium concentration, and dissolved oxygen (DO) concentration [7]. First, adjusting the feeding method (from dump-feed to step-feed or intermittent feed), maintaining a low ammonium ion concentration in the reactor, laboratory tests show that N_2O emissions can be reduced up to 66% [7] . Second, because AOB is related to AOR, control the PH of the reactor within the nonoptimal range (6-7) for AOB by adjusting the feeding rate and supply of alkalinity, and reducing emissions by decreasing AOR [7]. Third, reduce the DO set point, allowing the WWTPs to achieve a 35% reduction in emissions [7].

Moreover, to reduce the N_2O generated by the heterotrophic denitrification pathway. In this process, N_2O is produced by the reduction of nitric oxide and is further reduced to nitrogen. [7] However, both of their different rate will lead to the accumulation of N_2O. The emission reduction measures include:

First, reduce or avoid unnecessary anoxic periods in the nitridation reactor to inhibit the formation of N_2O in heterotrophic denitrification [7]. Second, influent with a low carbon-nitrogen ratio (COD/N) can avoid the incomplete denitrification pathway [7].

Also, decentralized systems can be classified into 2 types one is natural systems (such as constructed wetland, waste stabilization ponds), and another one is mechanical systems (activated sludge wastewater, treatment plants (WWTPs)). Among them, the mechanical sludge wastewater treatment is the key force for N_2O reduction in decentralized systems [7]. In terms of decentralized natural systems with a relatively low degree of mechanization, the N_2O emission per unit of nitrogen removal in constructed wetlands are much lower than that in the water treatment field [7].

3. Aquaculture

In Aquaculture, there is also a significant emission of nitrous oxide. Generally, varieties with a higher feed conversion rate emit more N_2O because the feed conversion rate has a significant impact on the total emissions [4]

3.1. Aquaculture: Influencing Factors of Nitrous Oxide Production

Nitrogen is beneficial for fish growth, the feed contains a high level of nitrogen. Its conversion pathways: most of it is ingested by fish and converted into biomass, and some is partially excreted as feces and un-ionized ammonia, and the remaining feed sinks to the bottom of the water. Thus, this unused nitrogen is nitrified and denitrified by microorganisms to produce N_2O [4].

EFs were determined to calculate NO_2 emissions, the higher the EF of an animal, the higher its N_2O emissions will be [4].

The most popular species for aquaculture are herbivorous and omnivorous fish (such as grass carp, crucian carp, Leiocassis longirostris…) [4]. These fish have a relatively low EF because they can easily convert artificial feed into biomass [4]. However, in recent years, some of the high economic value and high feed conversion rate animals (such as crayfish, river crabs, yellow catfish, river bass…) have become more popular to breed [5]. For example, the Leiocassis longirostris its EF is more than 0.92, but the river crab's EF is more than 2.32 [4]. Therefore, the concentration of N_2O is increasing constantly [4].

3.2. Solution

In this case, improving feed utilization and enhancing management will help reduce emission factors. Non-oxide promotes the formation of N_2O dominated by denitrification; otherwise, the high dissolved oxygen inhibits this process. Therefore, the appropriate use of aerators and regular water changes can be effective ways to control N_2O emissions. The optimal temperature range for nitrification and denitrification to produce N_2O is 25 degrees to 30 degrees, but the production can be inhibited below 10 degrees. As a result, cold-water fish(such as Salmonidae) should be encouraged to reduce emissions [4]. Also, through suitable feeding and improving the feed technology to increase utilization, reducing the emission of N_2O [4].

4. Agriculture

Agriculture is the most significant factor of N_2O emissions, which occupy more than 60% in total emission of N_2O. There are a diversity of reason producing N_2O in the field of agriculture. For instance: N fetilizer, crop straw and other crops residues(CR).

4.1. The Application of N Fertilizers

As the human population increases, food requirements are also growing constantly, and thus the application of N fertilizers is rising. Due to N fertilizer's strong mobility, it undergoes various

reactions after application, leading to nitrogen leaching, immobilization, volatilization, and DNF [3]. Also available, ammonium and nitrate are the main sources of soil N_2O emissions [3].

Also, the different types of fertilizer affect the emission of N_2O., In the corn-wheat rotation, the application of urea, slurry increased the N_2O emissions by 33% and 46% respectively compared with the control plots [3]. In the wheat planting system, the emissions of N_2O increased simultaneously with the application rate of urea(urea emissions increased by 174% for every additional 100kg of N/ha, and the emissions of 400kg/ha calcium ammonium nitrate (CAN) treatment were also significantly higher than those of the 200kg/ha treatment [3].

The different types of fertilizers, application method, and timing can cause some differences in N_2O emissions. For example, sideband application can emit less N_2O than the broadcasting method [6]. Plus, N fertilizers somewhat provide directly these 2 forms (shallow fertilization and deep fertilization) of nitrogen and are largely involved in the generation and emission of N_2O, the plant roots tend to proliferate around the fertilized area. Therefore, the deep fertilization significantly increased the root density of various grains, and the nitrogen and water absorbed from the deep layers. Additionally, when deep fertilization is used, the diffusion of N_2O must pass through thicker soil layers, which prolongs its staying time and is beneficial to reduce the N_2O to N_2 in the upper layers of soil where no fertilizer has been applied [3].

Moreover, the amount of nitrogen fertilizer has a significant impact on greenhouse gas emissions. For instance, the studies showed that the N_2O emissions of rice increase is related to the increase of N fertilizer rate. When the nitrogen application is reduced by 33%, its N_2O emission can be reduced by 28% [3].

Plus, changing the fertilization time is essential. Fertilizing several weeks after sowing can increase the possibility of N entering the crop tissues instead of being lost to the atmosphere [3].

In addition, Nitrification inhibitors (NI) reduce emissions through both direct and indirect actions: direct inhibit nitrification (NF) contain some compounds that can inactivate the critical enzyme, prolonging the reaction time of NH^{4+} in the soil, and reducing the NF, which reduces the production of NO_3 indirectly and decreases the availability of DNF, and thus it reduce the diffusion of N_2O [3].

The Slow-release nitrogen fertilizers are an effective way, which represents controlled-release fertilizer (CRF) and uses the way of slow nutrient release to reduce the emission of N2O by delaying the initial nitrogen supply and gradually providing nutrients to crops. It not only improves nutrient absorption efficiency but also reduces nitrogen loss (converted to N_2O). Taking rice as an example, it can significantly reduce N_2O by CRF, which can reduce nitrogen loss and replace urea [3].

Furthermore, the feasibility of achieving self-nitrogen fixation through crop modification to reduce fertilizer dependence. Firstly, to establish a symbiotic relationship of root nodules in grains, it is necessary to modify the bacteria to enable them to recognize and infect the root cells of grains, while allowing plants to form a low-oxygen environment. Second, using nitrogen-fixing endophytic bacteria as fertilizer . The third approach is to introduce nitrogen as a system into plant organelles . It can integrate the complete biosynthetic pathways of multiple components of negronis into grains and keep it in a low-oxygen area [1].

Another study showed that the N2O reduction ability of crops: expressing the Nos operon protein of Pseudomonas stutter in transgenic plants to assemble reductase (N_2OR), which aims that reduce the N_2O to N_2 [1].

4.2. Crop Straw and Other Crop Residues (CR)

The addition of crop straw and other crop residues provides easily accessible sources of nitrogen and carbon for the environment, and nitrogen produced by mineralization in CR can easily diffuse into the environment in the form of N_2O.

Besides, many else factors affect CR, which allow CR to emit more N_2O in the environment, such as PH in the soil, moisture extent [3].

During the period of mineralization, the carbon-nitrogen ratio (C: N) depends on the residue itself, and thus the DNF (denitrification)rate is related to the amount of carbon in denitrification. To be

specific, when straw with a low C: N is added, the emission of N_2O is relatively high. In contrast, when the straw with a high C: N is added, the emission of N_2O is relatively low [3].

In addition, in terms of moisture extent, it is critical to change the way of irrigation, which is a key process of denitrification (DNF)and nitrification(NF) in the nitrogen cycle. Therefore, sprinkler irrigation (SI) and drip irrigation (DI) can efficiently reduce N_2O. These two kinds of methods can reduce nitrogen leaching root zone, which makes nitrogen more easily absorbed by cro ps. [3]

Furthermore, the pH is also a critical factor affecting CR [6]. Alkaline PH may affect the activity of microorganisms, which increases the process rate of NF and DNF, thereby directly influencing the emission of N_2O [3]. Biochar is a good tool to solve it, which is a carbon-rich product; it has a large surface area that it can better adsorb anions and cations, and absorb greenhouse gases CO_2 and N_2O. Biochar can enhance the growth and activity of bacteria and fungi, thereby participating in the mineralization of N, and can achieve carbon sequestration, thereby affecting the formation of N_2O [3, 8]. Due to its slow degradation (plant biomass biochar can sequester carbon in soil for an average of 2000 years), it can reduce the greenhouse gas emissions, including N_2O. Also, biochar can improve the soil PH, promoting the complete reduction of N_2O to N_2. Additionally, Biochar can alter the soil's aeration and water-holding capacity, thereby increasing O2 availability. Third, it can absorb the N_2O directly [3].

Except to the biochar, the application of lime can affect the production of N_2O by altering the soil PH value and regulating the NF and DNF processes [9]. Lime can enhance the activity of N_2O reductase [9]. Within the PH range of 4 to 7, the emission of N_2O decreases when the PH value increases [3]. At this high PH, it accelerates the generation of NO^{3-}, may stimulate microorganisms to prioritize using the N_2O as an electron acceptor, promoting the complete process of DNF, which promotes N_2O converting to N_2, it can increase dissolved organic carbon to provide energy for microorganisms, and thus it reduces the N_2O emission [3].

5. Limitation

In the WWTPs, the denitrification of glycogen-accumulating bacteria (GAO) may increase the emission of N_2O, which means if GAO is multiplied in large quantities, there may be a risk of emission of N_2O [5]. This is because GAO and phosphorus-accumulating bacteria*PAO) have special mechanisms: they store organic carbon and finally degrade these carbon sources through the polyhydroxy butyric acid (PHB) pool in their bodies [5]. In the normal condition, it should prioritize the screening of PAO, but GAO is difficult to avoid in the relatively high temperatures [5].

Flood irrigation is the traditional method [6]. Although this way can make fertilizer absorb more easier, it may form anaerobic conditions, increasing the formation of N_2O and leaching of nitrate [3]. Plus, the alternating wet and dry (AWT) is a relatively precise watering method, it can save more than 97% water and reduce other greenhouse gas emission (CH4), but it is may enhance the substantial amount of N_2O because its moisture extend is so high and in this way, it will produce a soil fractures, enhancing aeration and promoting NF to provide substrates for N_2O emissions. Another irrigation method: sprinkler irrigation (SI) and drip irrigation (DI) are more beneficial to the NF; it is an efficient way to reduce the emission of N_2O, but it also has some emission shortcomings SI can reduce more N_2O, but the DI can control the emission risks [3].

What's more, Biochar is not omnipotent. The impact of carbon on N_2O emission is not absolute and suffers from some uncertain conditions, such as biochar extent, soil PH value, carbon-nitrogen ratio, organic carbon, moisture conditions, and microorganisms and enzyme activities. Also, the lime has similar problems. On the one hand, lime may provide more substrates for NF and DNF by increasing carbon and nitrogen mineralization and raising the extent of NH^{4+} and NO^{3-} thereby promoting N_2O emissions.[1].

6. Conclusion

This paper is talking about what is the source of √ and what the solution is, and how to solve it. N_2O is a greenhouse gas; its emission threatens the environmental security of the global. In terms of WWTPs, √ is produced during BNR. However, Emission reduction can be achieved by regulating the AOR in the aerobic zone, such as changing nitrification reactor, controlling reactor PH values, and reducing dissolved oxygen, avoiding anoxia in nitrification reactors and optimizing low carbon-nitrogen ratio influent to reduce denitrification. In decentralized systems, the N_2O emission od denitrification from contracted wetlands are lower than that from WWTPs. Mechanically activated sludge is the key to the reduction of emissions, but the denitrification by GAO may increase emissions. In aquaculture, species with high feed conversion rates emit more N_2O. Emissions can be reduced by promoting cold-water fish, using aerators properly, and optimizing feed and feeding methods.

What's more, the field of N_2O emission is in agriculture. The core of agricultural emission reduction lies in nitrogen fertilizers and crop straw management. It's critical to choose the types of fertilizer and control the fertilization time, because different methods and times will produce differences. Also, proposing three kinds of methods to reduce the dependence on the application of fertilizers.

In addition, PH, moisture extent may affect the emission of N_2O in the crop straw. In addition, Biochar can solve the emission of N_2O in various ways, such as adjusting PH, increasing oxygen availability, and so on. Lime is also a good tool; it can reduce the N_2O to N_2. However, the existing technologies have a lot of limitations. For instance, FI and AWT may increase drainage, SI and DI have shortcomings and the effects of biochar and lime are affected by factors such as soil characteristics.

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