Overview of Nitrogen Removal in Constructed Wetland and Its Influencing Factors

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Abstract. Nitrogen, as a common substance in water pollution, can easily cause eutrophication of water when it is excessive. Constructed wetland, as a water treatment method that combines the common actions of plants, microorganisms, and substrates, has positive significance for the removal of nitrogen. This article reviews the nitrogen removal mechanism of each component in constructed wetlands, and the effects of temperature, carbon-nitrogen ratio, dissolved oxygen, pH, and HRT on denitrification, and proposes existing problems and research directions in constructed wetlands.

1. Introduction
As a common component of sewage, nitrogen is one of the main elements that cause eutrophication of water bodies [1], and the content of ammonia nitrogen and total nitrogen in water bodies are important indicators for environmental monitoring. Excessive nitrogen content in water can easily cause algae and plankton to multiply, and insufficient dissolved oxygen in the water will eventually deteriorate water quality, cause serious harm to aquatic organisms, and cause great damage and loss to the aquaculture industry [2]. There are a large number of nitrogen elements in domestic sewage, industrial waste water, agricultural sewage and other water bodies, which are dispersed in the water environment in the form of organic nitrogen, ammonia nitrogen, nitrate nitrogen and other organic and inorganic forms [3]. They can interact with each other under certain conditions, convert and finally achieve the purpose of denitrification. Therefore, finding efficient and economical denitrification methods has been the focus of long-term research.

As a relatively complete ecosystem, constructed wetland is mainly composed of plants, microorganisms, and substrates [4]. Sewage flows through the constructed wetland. After a series of physical, chemical, and biological actions, the pollutants are filtered, adsorbed, absorbed, degraded, etc., and finally the water body is purified. Constructed wetlands can be divided into surface flow constructed wetlands and subsurface flow constructed wetlands. According to the direction of water flow, subsurface flow constructed wetlands can be divided into horizontal flow constructed wetlands and vertical flow constructed wetlands [5]. The constructed wetland has a rich redox environment and meets the conditions required for nitrogen removal. The vertical flow constructed wetland has an anaerobic environment at the bottom of the bed and anoxic/aerobic environment near the water surface. After the organic nitrogen is ammonified, under the action of nitrifying bacteria and denitrifying bacteria, inorganic carbon and organic carbon in the water are used as carbon sources. It can carry out
nitrification and denitrification reactions, so that the ammonia nitrogen in the water is converted into nitrate nitrogen, and finally reduced to nitrogen, so that it escapes into the atmosphere and finally denitrifies [6]. In addition to the effects of microorganisms, the entire process is inseparable from the synergistic effect of the components in the wetland. Therefore, it is of practical significance to study the nitrogen removal mechanism and the corresponding influencing factors of the components in the wetland.

2. Nitrogen removal approach in constructed wetland

2.1. Substrate removal of nitrogen
As the most basic component of the constructed wetland, the substrate is the carrier for the growth of microorganisms and plants, and it also provides the most basic living space for tiny aquatic organisms. Generally, the substrate of constructed wetland is mainly soil, gravel, river sand, etc. [7]. These matrix fillers are generally used for filtration, to intercept coarse particles in the sewage, for the adhesion and growth of biofilms, etc., the removal efficiency of nitrogen is not high, and the adsorbed pollutants are easily saturated. The adsorption of ammonia nitrogen by the substrate includes ion exchange and physical adsorption. Studies have shown that the adsorption capacity of the four substrates for ammonia nitrogen is zeolite > red mud > slag > washed sand. The adsorption capacity of zeolite for ammonia nitrogen is significantly higher than that of the other three substrates [8]. Wang et al. [9] selected five substrates in the experiment: zeolite, peat, vermiculite, shale, and sand to study the removal of nitrogen in domestic sewage. The results showed that the difference between several substrates was not big, such as zeolite, shale. The effect of vermiculite is slightly better. Li et al. [10] used ceramsite and pebbles as substrates for comparative experiments, and the results showed that the clay ceramsite constructed wetland has the highest total nitrogen removal efficiency, reaching 84.0% - 96.3%, which is suitable for treating eutrophic wastewater. Research shows that the removal rate is the result of the joint action of the wetland components, not a single substrate, but a substrate with better effects can also be selected from it.

2.2. Nitrogen removal by plants
As the uppermost life body of the wetland ecosystem, plants are an essential part of sewage treatment. As a nutrient that plants can directly absorb, inorganic nitrogen in sewage can be enriched in plant roots, stems, leaves and other organs, and be removed by harvesting plants [11], and plants are regenerative and can continue Absorbing pollutants has a strong economic applicability. Guo [12] and others studied the nitrogen accumulation ability of three plants and their organs, and the results showed that the N accumulation ability was in the order of Zaili Mosaic > Mosaic Reed leaf > Vetiver > Zaili Flower Stem > On the stems of reed reeds, the average enrichment coefficients were 18.063, 16.117, 8.858, 7.747 and 7.083. Yu et al. [13] constructed artificial wetlands with five plant types, in which reeds, cattails and changpus have the effect of removing single Better, the removal rates of ammonia nitrogen, nitrate nitrogen and total nitrogen are higher than 76.53%, 78.61%, and 58.44%, respectively. However, the effect of plants on nitrogen removal is limited and cannot be used as the main nitrogen removal measure. In the study of surface flow constructed wetlands, Pan et al. [14] indicated that microbial action (34.84% ~ 45.44%) is the main way of nitrogen removal in constructed wetlands.

2.3. Nitrogen removal by microorganisms
As the main undertaker of nitrogen and phosphorus removal in water, microorganisms play a major role in the removal of nitrogen in constructed wetlands. Under the combined action of anaerobic bacteria, aerobic bacteria and facultative aerobic microorganisms, most of the nitrogen-containing pollutants in the water are removed through related reactions such as ammonification, nitrification, and denitrification. Wang et al. [15] studied the law of nitrogen transfer in subsurface flow constructed wetlands and showed that the degradation of nitrogen by microorganisms accounts for half of the total
nitrogen in the influent. Studies have reported that microorganisms can remove 60% to 90% of nitrogen in water through related denitrification reactions [16]. The type, quantity, community structure, and distribution of microorganisms are also key factors that determine the nitrogen removal effect. Only through the synergy of these factors can a better purification effect be obtained.

3. Factors affecting nitrogen removal in constructed wetlands

3.1. Temperature
Temperature, as an important control parameter for denitrification treatment, has varying degrees of impact on substrates, plants, and microorganisms, with the greatest impact on microorganisms. Under low temperature conditions, the activity of microorganisms in water is generally low, and the life activities of microorganisms are inhibited. However, as the temperature increases, the activity gradually increases, and the degradation efficiency of pollutants also increases. Studies have shown that when the temperature is less than 10°C, the nitrification reaction of microorganisms becomes slower [17]. When the temperature is lower, the activity of microorganisms is reduced, the content of dissolved oxygen and carbon source is less, and the efficiency of nitrogen removal is low [18]. Qian et al. [19] mentioned in the research that when the temperature is less than 20°C, the activity and abundance of anammox bacteria will decrease. In a low temperature environment, plants will grow slowly, and their absorption of inorganic nitrogen will be reduced. The oxygen secreted by roots will also be reduced accordingly, which simultaneously affects microbial activity. The research of Bao et al. [20] showed that Sargassum has good nitrogen removal effect at high temperature. The main effect of temperature on the substrate is that it is prone to blockage at low temperatures [21], which causes the water to be blocked and aggravates the deterioration of water quality.

3.2. Carbon to nitrogen ratio
The carbon-nitrogen ratio is a key factor affecting nitrogen removal [22], and it is of great significance to control the proportion of influent water. The carbon-nitrogen ratio can have a great impact on the nitrification of microorganisms [23]. Zhang et al. [24] found through research that the higher the C/N, the higher the nitrate removal rate, and the lower the C/N. The higher the removal rate of ammonia nitrogen and total nitrogen, the low carbon to nitrogen ratio limits the nitrification reaction to a certain extent. Zhang et al. [25] reported that good results can be achieved when C/N is 10, and the removal rates of ammonia nitrogen and nitrate nitrogen are (75.36±10.55) % and (86.34±9.23)%, respectively. Meng et al. [26] mentioned that when the C/N is 6.5, the total nitrogen removal rate below 130cm of the filler layer can reach more than 95%. Controlling the carbon-nitrogen ratio in an appropriate range and achieving a better denitrification effect is the key to continued research.

3.3. Dissolved oxygen
As an important indicator, dissolved oxygen in constructed wetlands participates in various life activities in wetlands and is essential for the removal of nitrogen. The oxygen in the wetland mainly comes from the oxygen in the influent water, atmospheric reoxygenation, and oxygen supply by plants [27]. The oxygen in sewage is mainly used for the life activities of microorganisms. The nitrification of microorganisms requires the participation of oxygen, which affects the removal effect of ammonia nitrogen. The low dissolved oxygen environment in wetlands will also affect denitrification and anaerobic ammonia oxidation and other related reactions. In general, the dissolved oxygen in the nitrification process should be controlled above 2 mg/L [28], and the denitrification process should be strictly controlled below 0.5 mg/L [29]. Kuishan [30] found through research that the dissolved oxygen concentration is positively correlated with ammoniating bacteria and nitrosating bacteria, and negatively correlated with denitrifying bacteria, reflecting the relationship between dissolved oxygen and wetland microorganisms. Therefore, increasing the dissolved oxygen concentration can effectively remove ammonia nitrogen in water. The tower constructed wetland constructed by Ye et al. [31] enables wastewater to fall into the water and reoxygenate, which can improve the efficiency of
wastewater denitrification. At the same time, oxygen can be added to aeration device to get better nitrogen removal effect [32].

3.4. pH

pH can affect the growth and metabolism of microorganisms in wetlands, which in turn affects the removal of nitrogen. The optimum pH for ammoniating bacteria is between 6.5 and 8.5 [33], the optimum pH for nitrification is between 8.0 and 8.4, and the optimum pH range for denitrifying bacteria is between 7.0 and 8.0 [34]. The change of pH value will affect the population, quantity and distribution of microorganisms. Too high or low will inhibit their life activities. It is still very important to explore the appropriate pH range and study its influence mechanism.

3.5. HRT

The hydraulic retention time has a great influence on the progress of wetland denitrification. Generally, with the increase of HRT, pollutants in the water come into full contact with microorganisms, plants, substrates, etc. in the wetland, and they are more likely to be degraded, absorbed, and absorbed. Xu et al. [35] found through research that when the hydraulic retention time is 3 days, 2 days, 1 day, and 0.5 days, the removal rates of total nitrogen are 65.83%, 74.97%, 56.20% and 34.91%, respectively, indicating that HRT is the best treatment effect was achieved in two days. Wang et al. [36]'s research on subsurface flow constructed wetlands showed that when HRT was 1 to 3 days, the removal rate of ammonia nitrogen was 51.1%~56.0%, and the removal rate of ammonia nitrogen reached the maximum value of 65.3% at 5 days. But too long hydraulic retention time can also cause anaerobic water bodies and deterioration of water quality.

3.6. Other influencing factors

In addition to the above influencing factors, there are other factors that will affect the denitrification of constructed wetlands. For example, the types of constructed wetlands, surface flow, horizontal subsurface flow, vertical flow, and composite flow, etc., different water inlet methods cause different redox environments in water bodies, and the amount of nitrogen compounds removed is also different. (Table 1) There are different combinations of plants in wetlands. Combining plants with higher removal rates can improve the efficiency of nitrogen removal. Xiao et al. [37] combined several plants and found that the combination treatment of Cigu and Allium spp. had the best effect. The porosity, adsorption and structural energy of the matrix also have an impact on the removal of nitrogen in water. Ding et al. [38] mentioned in the research that the multi-layer matrix structure has the advantages of delaying blockage and improving decontamination ability compared with a single layer. Carbon source is also a related factor that restricts the ability of wetland to remove nitrogen. The lack of carbon source in wet underground layer inhibits the progress of denitrification [39]. For the operation of the entire constructed wetland, various influencing factors need to be considered, and the correlation between each factor on the nitrogen removal capacity should be studied.

| Wetland type                              | Main nitrogen compounds removed       |
|-------------------------------------------|---------------------------------------|
| Surface flow                              | Ammonia                               |
| Horizontal undercurrent                   | Nitrate                               |
| Vertical flow                             | Ammonia                               |
| Vertical flow-horizontal flow composite   | Ammonia nitrogen, nitrate nitrogen     |
4. Conclusion
As a water treatment method with less investment and simple operation and management, constructed wetland has good development prospects. The synergistic effect of various components in the wetland and related influencing factors can enhance the treatment effect of nitrogenous sewage. Through the mutual coupling of microorganisms, plants, substrates and related influencing conditions, it will still be a research hotspot to find the best operating conditions for nitrogen removal. Of course, there are still many problems in constructed wetlands, such as the clogging of wetlands. It is very important to find matrix fillers or matrix combinations that are not easy to be clogged; to couple constructed wetlands with other water treatment methods to strengthen the ability to treat sewage, and to study. When removing specific pollutants, the corresponding nitrogen removal effect is also a hot topic.

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