Advance of Nitrogen Removal in Constructed Wetland

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Abstract. Based on current literature, the article reviewed the mechanism and route of nitrogen removal, discussed the microbial species associated with nitrogen metabolism in constructed wetlands. Key unresolved issues were concluded for classical and novel nitrogen removal routes.  

Keywords: Nitrogen removal; Constructed wetlands; Route

1. Introduction

In the last ten years, Constructed wetlands have been widely used due to low cost, simple operation and maintenance [1, 2]. Constructed wetlands are an artificial ecosystem consisting of plants, substrate and microbes [3]. The substrate can provide the necessary nutrients for the microorganisms and the larger attachment area. The plant has a certain effect on the removal of total nitrogen and suspended matter. Furthermore, Microbes often play a critical role in term of pollutant removal, especially nitrogen-containing contaminants. Because of excessive emissions of nitrogen aggravates eutrophication of rivers [4, 5].

2. The Form of Nitrogen in Constructed Wetland

Nitrogen is one of the major contaminants causing eutrophication, affecting the level of dissolved oxygen in the receiving water and may be toxic to aquatic organisms. There are organic and inorganic forms of nitrogen in the wastewater. Organic nitrogen can be represented by amino acids, urea, uric acid and purines and pyrimidine. The inorganic nitrogen includes ammonium (NH₄⁺), nitrite (NO₂⁻), nitrate (NO₃⁻), nitrous oxide (N₂O) and dissolved element nitrogen or nitrogen (N₂) [6].

3. Related Processes of Nitrogen Metabolism and Related Bacteria

In constructed wetland, the transformation and removal of nitrogen are accomplished by biological (ammonification, nitrification, denitrification, plant uptake, biomass assimilation, dissimilatory nitrate reduction), and physicochemical routes (e.g. ammonia volatilization, and adsorption) [7, 8]. Ammonification, nitrification and denitrification might constitute a nitrogen cycle in constructed wetland (classical route of nitrogen removal).
3.1. Ammonification
Ammonification is the first step of nitrogen transformation in constructed wetlands when influent is rich with organic nitrogen. The main reaction is as follows:
Amino acids $\rightarrow$ Imino acids $\rightarrow$ keto acid

3.2. Nitrification
The second step is Nitrification. Nitrification is carried out by ammonia-oxidizing archaea (AOA), ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) that are capable of transforming ammonia directly to nitrite and nitrate. The main reaction is as follows:

$$\text{NH}_4^+ + 1.5\text{O}_2 \rightarrow \text{H}^+ + \text{H}_2\text{O} + \text{NO}_2^-$$  (1)

$$\text{NO}_2^- + 0.5\text{O}_2 \rightarrow \text{NO}_3^-$$  (2)

$$6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$$  (3)

Involving in the reaction of the relevant chemolithotrophic bacteria contains Nitrosomonas, Nitrosospira, Nitrosococcus and Nitrosolobus et al., belonging to AOB, and Nitrobacter, Nitrococcus, and Nitrospira et al., belonging to NOB. In addition, heterotrophic nitrifiers (such as Actinomycetes, Arthrobacterglobiformis, Aerobacteraerogenes, Algae, Bacillus, Fungi, Mycobacterium phlei, Streptomyces griseus, Thiosphaera, and Pseudomonas) also contribute to nitrification [9]. Nevertheless, the nitrification rate is lower than autotrophic nitrifiers [10].

3.3. Denitrification
Denitrification consisting of reactions for transformation of nitrate or nitrite into gaseous forms by heterotrophic denitrification bacteria (HDB) and autotrophic denitrification bacteria (ADB) is an critical link in the removal of nitrogen in constructed wetlands [11, 12]. The main reaction is as follows:

$$\text{NO}_3^- + 0.833\text{CH}_3\text{OH} \rightarrow 0.5\text{N}_2 + 0.833\text{CO}_2 + 1.167\text{H}_2\text{O} + \text{OH}^-$$  (4)

$$\text{NO}_3^- + 1.08\text{CH}_3\text{OH} + 0.24\text{H}_2\text{CO}_3 \rightarrow 0.06\text{C}_6\text{H}_7\text{NO}_2 + 0.47\text{N}_2 + 1.68\text{H}_2\text{O} + \text{HCO}_3^-$$  (5)

Involving in the reaction of the relevant heterotrophic denitrification bacteria contains Denitratisoma, Thauera, Comamonas, Bacillus, Aerobacter and Paracoccus et al. [13, 14]. Others (such as Thiobacillus and Sulfurimonas et al.) were classified in ADB and living under strict anaerobic conditions [15].

Furthermore, the anammox bacteria, in the presence of planctomycete bacteria group under anaerobic conditions, capable of autotrophic ammonium oxidation with nitrite as the terminal electron acceptor were also proved to exist in constructed wetlands [16].

The knowledge particularly concerning nitrogen transforming bacteria in constructed wetlands had exhibited on some studies [17, 18]. Tietz et al. [19] evaluated the community of ammonia-oxidizing bacteria (AOB) in three VF beds (18 m², 0.50 m depth) treating municipal sewage after 2.5 years of operation and despite nitrification was stable, little AOB activity was identified. During the winter, nitrification decreased, however not affecting the spatial distribution of AOB, being Nitrosomonaseuropaea, Nitrosococcosmobilis and Nitrosospira the dominant AOB. Zhi and Ji [20] identified functional genes involved in nitrification and denitrification in a tidal flow CW showing nitrification activity performed by AOB and Anammox bacteria, as well as denitrification.

Fig. 1 shows a nitrogen cycle in constructed wetland.
4. Prospects
Overall, traditional nitrification-denitrification route widely distributed and play a crucial role for the removal of nitrogenin constructed wetlands. However, the nitrogen removal is limited due to the lack of organic carbon. Despite Partial nitrification-denitrification, an ammoxeliminated the necessity of organic carbon, identifying optimal environmental, operational parameters and microbes associated with nitrogen metabolism is still concerned, particularly in HF systems. This is of great significance to further optimize the design of constructed wetlands.

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6. References
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