Research status of low-temperature operation effect and strengthening measures of constructed wetlands

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Abstract: *Constructed wetlands are a new method of wastewater treatment, which has the advantages of low cost, ease of implementation, and high ecological benefits, and has been applied in many scenarios. However, this method also has certain limitations, manifested in reduced purification efficiency or even complete failure under low temperatures. This article analyzes the influencing factors of low-temperature operation of constructed wetlands, explores its operational effectiveness in low-temperature areas, and summarizes previous research experience, and then proposes some suggestions for the current situation. The research in this article can provide theoretical references for wetland wastewater treatment, and also provide references for subsequent similar research.*

Keywords: *constructed wetland, low temperature, sewage treatment*, strengthening measures

1 Foreword

The constructed wetland is an artificial wetland system. The elements included in this system are mainly artificial media, plants, microorganisms, etc., which will interact with each other through physical and chemical methods to achieve the treatment of sewage and sludge. Based on previous practical experience, this sewage treatment process has the advantages of easy management, high removal rate of nitrogen and phosphorus organic matter, low cost and high ecological and economic benefits. The constructed wetland can purify sewage into water that can be used for a second time through filtration, adsorption and sedimentation, ion exchange and other principles. The specific analysis shows that the constructed wetland can regulate the microclimate, improve the urban environment, and has good landscape effect and sustainable economic benefits. However, it should be noted that this ecosystem is susceptible to various factors. For example, during the operation, the purification effect will be reduced due to changes in environmental temperature, hydraulic and pollution load and other factors. The temperature has the most prominent impact on the system, especially in winter, wetland plants will enter a dormant state; and the metabolism of microorganisms will become slow or even stop. Therefore, low temperature has a significant impact on the efficiency of constructed wetland sewage treatment, and corresponding strengthening measures should be taken to give full play to the purification effect of water quality.

2 The impact of low temperature on artificial wetlands

2.1 Impact on wetland plants

Aquatic plants in constructed wetland systems typically purify water quality through physical processes, absorption mechanisms, and synergistic effects. They not only directly remove pollutants but also influence the filtration efficiency of the wetland matrix and microbial growth, indirectly affecting pollutant removal in water. Additionally, harvested plants can provide insulation on the ice surface during low temperatures to aid in heat preservation. Generally, plant root activity decreases during winter, impeding normal photosynthesis and disrupting the aerobic-anaerobic environment [1]. The interactive nature of various elements within the wetland system further complicates this process. When plants enter a dormant period, substance exchange between root microorganisms is inhibited, thereby impacting the entire wetland system and significantly reducing sewage purification effectiveness [2].

2.2 Impact on wetland matrix

The matrix is the main site for pollutant removal and plays a very important role in wetland systems. At present, the widely used substrates include slag, gravel, zeolite, limestone, coal ash slag and activated carbon.The analysis shows that the sewage purification principle of substrate includes precipitation, filtration, adsorption, etc. It is also an element for plant roots to survive, and is the main place for nitrogen and phosphorus adsorption and transformation in wetland ecosystem.In the low temperature season, the microbial activity in the matrix decreases, which affects the degradation and transformation of particles, increases the viscosity of water, and reduces the gap, resulting in a large accumulation of organic solid particles in the filler, which leads to the blockage of the matrix, the decrease of oxygen transfer rate, and the weakening of microbial activity, making it difficult for the wetland to fully play the role of sewage purification [3].

2.3 Impact on wetland microorganisms

Under low temperature conditions in winter, the metabolism of microorganisms is affected, and their number and activity decrease. Denitrification microorganisms are greatly affected by low temperature. The study of FAULWETTER et al. showed that nitrification in constructed wetlands is beneficial when the temperature ranges from 28℃to 36℃, and nitrification is almost completely inhibited when the temperature is lower than 6℃or higher than 40℃. Similarly, at low temperatures, the denitrification rate slows down[4]. Zhang Rongxin et al. conducted a long-term study on the microbial growth rule at different temperatures, and found that the microbial growth of wetland was inhibited at low temperatures. Then, a comparison analysis was conducted between groups, and the results showed that the removal rates of various pollutants in the experimental group were significantly lower at 5℃than those in the experimental group at 15℃[5].

3 Measures to solve the low efficiency of artificial wetland operation at low temperatures

3.1 Improve the treatment effect in winter by using insulation measures

Adding mulch to wetland surfaces is undoubtedly a good reinforcement measure. Using the mulch as a barrier between the wetland and the external low temperature environment can significantly improve the internal temperature of the constructed wetland, so that the constructed wetland can still maintain a certain processing capacity in winter. Xiong Changlong et al. analyzed and tested the treatment effect of vertical subsurface flow constructed wetland in winter operation after strengthening measures in a sewage treatment plant in Chengdu. The results showed that the decontamination effect was improved significantly by using activated sludge membrane hanging and surface mulching process. Before using the above process, the removal rates of COD, TN and TP were 25%, 27% and 29% respectively, and after using the above measures, the removal rates were increased to 49%, 45% and 51% respectively [6]. Chen Tao et al. conducted a study on the treatment of micro-polluted rivers by subsurface flow constructed wetlands in autumn and winter. It was found that the method of covering the surface of subsurface flow wetland with plant residues and films could increase the water temperature in the wetland bed by 3 ~ 7℃, and more importantly, the TN removal rate could be maintained at 32% ~ 42%. In the process of wetland operation, the appropriate amount of corn cob can provide carbon source for denitrifying bacteria. The combined use of various methods makes the nitrogen removal rate of micro-polluted water reach 64% in low temperature season [7].

3.2 Improve the treatment effect in winter by using combined processes

In the application of constructed wetlands in cold areas, most studies focus on the design of thermal insulation measures. Optimizing the operation mode of constructed wetlands or combining sewage treatment processes can also improve the purification effect of wetlands. On the basis of summarizing the previous research experience, Yao Dong et al. proposed a sewage treatment method combining physical and chemical pretreatment with constructed wetland. Among them, the physical and chemical pretreatment is mainly completed by using high efficiency sedimentation tank, and the constructed wetland includes subsurface flow wetland and surface flow wetland. The effect of this process on water purification of Longhe River was analyzed. The research results show that the constructed wetland still has a good sewage purification capacity under winter conditions, and the removal rates of COD and NH reached 49.06% and 77.72%, respectively, and TP and SS were 57.95% and 38.73% [8]. In addition, timely harvest of wetland plants in winter and then implementation of ice insulation can control the temperature of the wetland within a suitable range, and the above measures have positive significance for the effective removal of pollutants. Liu Maolin et al. proposed a bio-ecological combination process (coupled biological turntable + surface flow constructed wetland method), and analyzed the treatment effect of this method on polluted river water in low temperature season. The results showed that the combined process had the highest removal rate of ammonia nitrogen (83.83%), and the total nitrogen, total phosphorus and chemical oxygen demand were 3.32%, 11.09% and 20.52%, respectively. The effluent ammonia nitrogen concentration reached the "surface water environmental quality Standard". The oxygenation and heat preservation effect of RBCs turntable is suitable for the survival of Nitrospira and provides guarantee for the effective removal of ammonia nitrogen and COD [9].

3.3 Improve the effect of winter treatment by selecting cold-resistant organisms

In winter low temperature areas, wetland plants with good decontamination effect and strong cold resistance should be selected according to the local actual situation. Wan Lei et al. constructed a new constructed wetland with hardy plants, and then conducted an in-depth analysis of the removal rates of total nitrogen, total phosphorus and organic matter by such wastewater treatment processes. The results showed that in winter, the water purification effect of Iris sibirica and Othiopogon japanicus was the most stable, and the sewage removal rate of both exceeded 30%. Moreover, under different temperature conditions, the removal rates of the above three pollutants in the Yingwei wetland of Siberia were significantly better than that of Othiopogon japanicus [10]. In the case of low temperature in winter, the effect of plants on pollutant removal depends more on the adsorption and interception of roots, so plants with more developed roots and large adsorption capacity should be selected. Chen Yonghua et al. used ten indexes, including root length, vitality, and leaf malondialdehyde, to evaluate plant purification capacity, and screened out Oenanthe javanica, Brassica campestris L., Juncus effusus L., Saxifraga stolonifera Curt., Iris germanica L., Osmanthus fragrans and Iris ensata var.hortensis, which were suitable for the growth of constructed wetlands at low temperatures [11].

The microbial activity decreased with the decrease of temperature, and the removal of nitrogen was most affected by temperature. Therefore, the operation capacity can be effectively improved by artificially selecting and screening low-temperature denitrification resistant bacteria and adding them to constructed wetlands. Wang Shuo et al. put cold ammoxidation resistant bacteria into wetlands, and the results showed that the treatment process had a good nitrogen removal effect. In the process, the researchers also analyzed the mechanism of action of the microbes. The results showed that under the condition of 5°C, after the enriched ammoxidation resistant bacteria were added to the wetland system, the microbial activity was significantly enhanced, and the ammonia nitrogen removal rate was increased from 69% to 89% [12].

3.4 Introducing benthic animals to improve the treatment effect in winter

At present, many scholars at home and abroad have pointed out that some benthos can play a role in water purification. Among them, Poulsen et al., after long-term investigation and analysis, found that midge larvae, a feed-collecting benthos, can greatly enhance the activity and diversity of denitrifying microorganisms in the ecosystem, thus enabling nature to effectively remove nitrogen [13]. In addition, the research results of foreign scholar Estragnat et al show that the scraped benthos field snail in nature can effectively reduce the body carbon and nitrogen content and inhibit the growth of algae [14].

In addition, relevant research results show that many benthos still maintain a certain metabolic capacity in winter. Therefore, introducing benthos into surface flow constructed wetlands can not only remove pollutants, but also reduce wetland management costs, and this method is also applicable in winter. Guo Ying et al. found that the addition of chironomid in winter can effectively remove pollutants in water, in which the average removal rate of NO3-N is 37.8%, TN and TP are 54.0% and 94.8%, respectively, increasing by 29.51%, 15.16% and 37.62% compared with the control group (no chironomid added) [15].

4 Outlook

Microbial activity directly affects the removal rate of pollutants. It has been found that the implementation of certain bioregulatory means in winter not only reduces the operational cost of wetland, but also leads to better ecological benefits. Currently, the main methods of biofortification are strengthening the roots in winter and adding cryoprotectants. Based on practical experience, it is appropriate to select aquatic plants that can overwinter through underground buds during the low-temperature season. Biosecurity needs to be fully considered in the process of adding cryoprotectants. In practice, aquatic plants with low-temperature tolerance, good growth and good water purification should be selected, and the allocation of plant diversity should also be emphasized to enhance ecological stability, which has positive implications for improving the treatment effect of wetlands.

As mentioned above, the pollution removal from the constructed wetland is poor at low temperatures. In practice, thermal insulation measures should be combined with combined technology to ensure good water purification capacity at any season. It should be noted that the most suitable aeration mode and location should be chosen based on the actual situation in the specific operation. In addition, methods that combine constructed wetlands with other processes can also be used to reduce the cost of wetland management and improve economic benefits.

Sewage treatment methods for wetlands with benthic fauna are also suitable for winter, but the dosage should be adjusted to the niche of different benthic fauna in order to give full play to its role. It should be noted that while the disturbance of such an animal promotes the adsorption of phosphorus in the substrate, it also leads to an increase in the concentration of phosphorus in the substrate and a reverse effect of the release of phosphorus in the excess water. Therefore, more research is needed to introduce benthic animals into the constructed wetlands.

In short, there are still bottlenecks in the promotion of artificial wetlands in low-temperature areas, and further exploration and research are needed in the future to find more effective water purification measures, better improve the structure of wetlands, and enhance their sewage treatment capacity.

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