Purification Efficiency under the Combined Function of 4 Plants on Domestic Sewage

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Abstract: Constructed wetlands have been successfully applied to the removal of various pollutants in recent decades. The treatment effect of constructed wetlands on domestic sewage is affected by the type of wetland, plant species, temperature, pollutant concentration and environmental factors. The seasonal variation of the removal rate of domestic sewage and the removal rate of main pollutants (TN, TP, COD, NH₄⁺-N) were studied under the mixed conditions of four plants, and the degradation effect of pollutants along the course was explored. Clarifying the comprehensive purification ability of various wetland plants on domestic sewage and defining the effect of temperature on removal rate. The results showed that temperature had a great influence on the removal efficiency, which was significantly higher in summer than in winter. Temperature had the greatest effect on TP removal, ranging from 88.1% to 42.4%, and COD was the lowest, ranging from 57.11% to 44.47%. The degradation rate increased gradually along the path in summer and winter, and the closer to the intake, the more obvious the degradation effect was, and the degradation rate was much higher in summer than in winter. Compared with other pollutants, TP had a higher removal effect in the middle and tail positions of the wetland.

1.Introduction
With the rapid development of Chinese economy and industrialization, the demand for water resource is increasing, and a large amount of industrial wastewater and domestic sewage are directly discharged into the water without treatment, which aggravates the pollution of the water environment. According to statistics, 80% of the water is directly discharged into the water without treatment, resulting in about one-third of the country's river sections being polluted to different degrees. In recent years, as a new type of ecological wastewater treatment technology, constructed wetland (CWs) has the characteristics of remarkable purification effect, low construction and operation cost, simple management and good landscape ecological effects [1-3], and is widely used to treat domestic sewage [4], river sewage [5], industrial wastewater [6], and aquaculture wastewater [7]. The constructed wetland can promote the growth of green plants and increase the yield through the circulation of water and nutrients in the water, and realize the resource utilization and harmless utilization of wastewater. Wetland can not only be used for the treatment of general pollutants in water, but for the treatment of pesticides, heavy metals and pharmaceuticals [8].
Constructed wetlands are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. They are designed to take advantage of many of the processes that occur in natural wetlands, but do so within a more controlled environment. As an important part of constructed wetlands, plants participate in the cyclical transformation of pollutants, play a role in sewage purification, rationally and effectively configure plants, and effectively improve the efficiency of artificial wetland purification. Studies have shown that\(^9\), plants play an important role in nitrogen and phosphorus removal, heavy metal enrichment and adsorption. Higher plants such as Phragmites australis and Canna indica are suitable for growth in surface wetlands, increasing the oxygen transfer process in the rhizosphere, promoting the growth of microorganisms in the deep matrix and facilitating the degradation process of pollutants.

The constructed wetland can promote the growth of green plants and increase the yield through the circulation of water and nutrients in the water, and realize the resource utilization and harmless utilization of wastewater. Surface flow constructed wetland is a free-surface wetland state, composing of saturated matrix, emergent plants and submerged plants, microorganisms and water by simulating natural wetlands, artificially designed and constructed\(^{10}\). Surface constructed wetland near-water surface is divided into aerobic layer, and the deeper part and bottom are usually anaerobic layer\(^{11}\). The purification mechanism is the triple synergy of physical, chemical and biological using matrix + aquatic plants + microorganisms in the system. Efficient purification of sewage by matrix filtration, adsorption, precipitation, ion exchange, plant absorption and microbial decomposition to achieve\(^{12}\). The constructed wetland sewage treatment technology is a sewage treatment system compared with China's national conditions. It has wide application prospects in rural areas and small and medium-sized cities. It is an effective alternative way to traditional sewage treatment technology, and has a significant role in water conservation and ecological restoration.

2. Materials and Methods

2.1 Simulated CWs Characterization

A free water surface flow wetland reactor (as shown in Figure 1) with a length× width× height = 3.10m × 1.2m × 0.7m synthesized from 304 stainless steel, with a total length of 12.00m, a width of 0.3m, and a height of 0.7m. The corridor-type surface wetland has a discharge channel length of 0.1m. The water is directly injected by the peristaltic pump, the water load is 0.05m\(^3\) (m\(^2\)·d)\(^{-1}\), the sediment depth is 0.35m, and the water depth is 0.3m. The selection of local dominant plants to construct CWs is a key measure to improve the purification effect of constructed wetlands. In this experiment, four plants with growth advantages in Huixian Wetland were selected as research objects. The four plants are, Phragmites australis, Cladium chinense, Vallisneria natans and Canna indica, the plants and sediments are taken from the Huixian Karst National Park Wetland in Guilin, Guangxi. The simulated surface wetland system was officially started after two months of trial operation. The system inlet water is taken from the sewage discharge port of the Huixian Qixing Wharf.

![Fig.1 Simulated free water surface flow CWs](image-url)
2.2 Water Samples Collection and Processing
The domestic sewage and aquaculture wastewater are the mainly pollution in Huixian wetland and this study is mainly aimed at domestic sewage. The removal effects of total nitrogen, total phosphorus, ammonia nitrogen and dissolved organic carbon (COD) in simulated surface flow system were measured. The experiment lasted about 2 months (in July and December), and 10 days were used as a cycle to determine the water quality indicators of the influent and effluent. Each index was measured in 3 replicates, and the removal effect of the compared group without plants was also measured. The water sample was collected in high-density polyethylene bottles, sampling bottle was washed once, then placed under 10 cm water surface with the cap. Open the cap to avoid suspended substances entering the bottle. Ensure there is no bubbles in the bottle after collection. Then send it back to the laboratory and store it at 4℃. Measure the water quality index as soon as possible. PH, temperature, dissolved oxygen were measured on-site using a portable water quality detector.

2.3 Statistical Analysis
The experimental data was analyzed by Spass19 and Excel, and plotted with Origin.Pro9.0. Setting up 3 parallel tests for each sample, a quarterly data takes the average of nine experimental results as the final result to make the data more reliable and realistic.

3. Results and Discussion
3.1 The Total Removal Efficiency of Main Pollutants in Simulated CWs
The water temperature in sampling was 30℃, the dissolved oxygen content in water was 4 mg.L⁻¹, and the pH was 8.03 in July. The water temperature in the reactor was 12℃ during the sampling in December, the dissolved oxygen content was 5.0 mg.L⁻¹ and the pH was 7.86. Fig 2 shows that the simulated surface flow constructed wetland composed of four plants which has good removal efficiency for TP, TN, NH₄⁺-N, COD and TSS in domestic sewage. In July (summer), the removal efficiency of TN, TP, COD, NH₄⁺-N and TSS respectively was 80.98%, 88.10%, 57.11%, 76.51%, 86.81% and in December (winter) was 55.90%, 42.4%, 44.47%, 61.76%, 73.72%. The purification effect in summer was better than that in winter, which showed that temperature had a great influence on the removal rate, and the removal rate of TP and TN was the most significant, while the removal rate of COD changed slightly. Plants grow vigorously and microbial activities are strong in summer, which can promote the removal of pollutants. In comparison, Bosak[13] stated that the removal efficiencies above 80% can be for TP, TN, TSS and BOD₅ in water surface flow (FWS) systems. In the present study, removal of NH₄⁺-N, TP, TN is quite reliable. Vymazal[14] stated that nutrient removal in FWs CWs is variable and is largely dependent on both hydraulic loading rate (HLR) and sizes of systems.

Studies have shown that[15], the FWs CWs composed of a single plant has a significantly lower removal effect than the mixed mode. For example, the removal effect of Phragmites australis on TP, TN, NH₄⁺-N and COD is 40%, 30.6%, 29.3%, 25.6%, respectively. Indicating that the mixed planting mode can improve the purification efficiency of the constructed wetland system. The upper layer of the surface flow constructed wetland is an aerobic layer, and the lower layer is an anaerobic layer, which has a good reoxygenation capacity and can promote the treatment rate of COD. Some researches show[16] that the main pathway for organic removal in FWS CWs is microbial degradation and settling of colloidal particles, and suspended solids are effectively removed via settling and filtration through the dense vegetation. In the case of plant, which rhizosphere microorganisms can promote the decomposition of organic pollutants and improve the purification ability of COD in wetlands. The number and diversity of bacteria in the rhizosphere soil of plants had a great influence on the removal of COD and NH₄⁺-N, and they were positively correlated, indicating that the number and diversity of bacteria in summer rhizosphere were higher than those in winter. In addition, the low temperature in winter, the plant growth is withered, the microorganisms play a major role in degradation, the environment is prone to hypoxia, and the number and activity of rhizosphere...
microorganisms are significantly reduced, which is not conducive to the removal of pollution.  

3.2 Removal Efficiency along Intake Distance

According to Fig 3 and Fig 4, the removal rates of TN, TP, NH$_4^+$-N and COD in summer are significantly higher than those in winter, and the removal rates increase gradually along the way. The removal rate of TP in winter was the most obvious, ranging from 43.81% to 64.43%. Plants need to take up phosphorus during the growth process, higher total phosphorus load is beneficial to the rapid growth of plants, therefore, plant growth can improve the removal rate of total phosphorus. A large number of studies have shown that phosphorus degradation is the fastest degradation in the middle and tail of wetlands. Which is consistent with the results of this study. The closer the position of the water inlet is, the more obvious the change of degradation is. For the surface flow wetland, there is a certain removal effect along the way, but it is obviously lower than the dilution effect at the inlet. The removal rates of TP in summer were 78.25% - 84.6%, while that was 43.8% - 64.43% in winter. The removal rates of TN were 65.53% - 76.98% in summer and 39.39% - 53.81% in winter. The removal rates of NH$_4^+$-N were 82.82% - 87.51% in summer and 56.45% - 66.01% in winter, COD removal rate was 41.94% - 46.99% in summer and it was 16.67% - 37.47% in winter. The removal rate of COD is the least affected by temperature, and the changes of TP and TN are obvious, indicating that temperature has a great influence on pollutant removal.

In this study, there was no significant diversification in the removal rate of COD in summer and winter, the reason may be that temperature is not the most important factor in organic matter removal, while soil microorganisms play an important role in organic compound removal. Temperature interacted strongly in controlling dynamics of COD and the COD removal efficiency declined. Garfii[17] stated that BOD$_5$ removal seemed to be affected by temperature and higher BOD$_5$ mass removal rate efficiencies concurred with the higher temperature observed in summer. Conversely, some studies indicated that the temperature dependence was not so significant to the removal of organic matters. Gorra[18] stated that treatment performance for BOD$_5$ reached an average mass removal efficiency of 96% during the winter season, and the treatment performance resulted rather stable over winter time and did not show any declining tendency. These findings imply that although removal of the organic matter is mostly a result of the microbial activity, soil microbes still function and have the capacity to decompose organic contaminants even at low temperatures.

The mechanisms involved in nitrogen removal in CWs are manifold and include volatilization, ammonification, matrix adsorption, plant uptake, nitrification, denitrification. The temperature dependence of the mechanisms involved in nitrogen transformation process has been widely reported, the influence of temperature on plant eco-physiology and nitrogen removal effect in a SSF CW and the dissolved organic nitrogen, NH$_4^+$-N and TN were significantly temperature-dependent. Nitrogen removal was largely dependent on microbial activity in root-zones, thus the dependence of removal
efficiency on temperature was much more significant. Phosphorus has a good removal rate in this study, the summer removal rate is far superior to the winter. Phosphorus removal in CWs is a result of bacteria activity, plant uptake, microbial immobilization, aeration of wetland soils, adsorption by the porous media, and precipitation in the water column. The seasonal variations in phosphorus removals could be explained by the fact that during winter litter and microbial biomass are decomposed, and phosphorus is released from the precipitates, resulting in phosphorus solubilization in water. The TP removal efficiency were 50.7% and 41.8% at temperature below 15°C, respectively; while the values above 15°C were 79.2% and 70.1%, respectively[19]. Similarly, the results are consistent with this study, because the removal effect of 4 plant mixed planting modes is adopted in this study, the result is better.

4.Conclusions
Under mixed plant conditions, the removal effect of pollutants is significantly higher than that of single plant. The temperature is higher, which is conducive to the removal of pollutants, namely, the degradation pollutants are more effective in the summer. The removal effect along the water flow direction increases gradually and the changes are more pronounced in winter. The degradation of TP occurs mainly in the middle and tail of wetland. However, compared with other pollutants, the removal rate of COD changed least in the two seasons, and temperature had less impact on COD removal than other pollutants.

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