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Analysis of pollutant removal effect using innovative ridge-shaped constructed wetland

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Abstract: In this paper, a new type of ridge-shaped constructed wetland which combines surface flow and horizontal subsurface flow was proposed. The proposed wetland had simple structure, low construction and operating cost, less human interference and good pollution removal effect. The combination of surface flow and subsurface flow provided an aerobic and anaerobic alternating environment for the entire wetland. The performance of the proposed wetland was compared with a traditional horizontal subsurface flow wetland. The comparison results showed that the removal rates of BOD (biochemical oxygen demand), TN (total nitrogen), and TP (total phosphorus) in the ridge-shaped wetland increased up to 20.3%, 17.0%, and 9.1%, respectively. The proposed wetland structure could be widely applied for treatment of rural and urban domestic sewage pollution or agricultural point and nonpoint source water pollution.

Key words: ridge-shaped; wetland; surface-flow; horizontal subsurface flow

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1 Introduction

With the increase in water pollution and the shortage of water resources, the reuse of water resources had been of great concern. Water treatment technology had become an important research area of environmental protection[1-2]. As a new emerging wastewater treatment technology, constructed wetlands had become a research hotspot[3-6].

The traditional constructed wetland could be divided into two categories based on the location of flow such as surface flow constructed wetland and subsurface flow constructed wetland. Each category had its own advantages and disadvantages. The water flow of the surface flow constructed wetland (SFCW) mainly flow above the substrate, which was similar to natural wetlands. This category had the characteristics of less investment, simple operation, low operating cost, and obvious landscape benefit. However, the wetland required a large area and had a limited decontamination capacity. Thus, the SFCW was mostly used to treat river water bodies with low pollution levels. For example, in the previous studies such as: Dzakpasu et al. con-

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ducted a study on the removal characteristics of nitrogen and phosphorus in the surface-flow constructed wetland of Zaohe River[7]. Liao et al. used the constructed wetland of Zhoushan Chengbei Reservoir as an example to study the treatment of domestic sewage by surface flow constructed wetland, and proposed that the surface-flow constructed wetlands are suitable for construction in rural areas with abundant land resources[8]. Zhang and Wang studied the purification effect of surface-flow constructed wetland on polluted river water, which showed that such wetlands had a stable removal effect on the polluted water of the Fuyang River[9].

The subsurface-flow constructed wetland (SSFCW) was widely studied and applied in China and abroad. In this type of wetland, the water body flows under the surface of the earth, and the sewage was purified through the joint action of plant roots, fillers, and biofilm. Coban et al. studied the nitrification and denitrification in horizontal SSFCW[10]. Abdelhakeem et al. conducted research on the removal efficiency of vertical SSFCW under different operating conditions[11]. The effect of SSFCW removal was limited by the dissolved oxygen concentration because the water body flows under the surface[12]. Therefore, the research on SSFCW had focused more on studying the effect of aeration on their ability to remove effluents. Jia et al. studied the effects of intermittent aeration on pollutant removal and plant growth in vertical flow constructed wetlands[13]. Ilyas and Masih conducted a study on the effects of different aeration methods on the phosphorus removal performance of constructed wetlands[14]. Many studies had shown that aeration can improve the removal of pollutants from constructed wetlands, which meanwhile increased the operating costs of constructed wetlands[12,14].

At present, the research on constructed wetlands focused on the combination of traditional surface and subsurface flow constructed wetlands to obtain higher removal efficiencies of pollutants. Pelissari et al. studied the transformation of nitrogen in composite horizontal subsurface flow and vertical subsurface flow constructed wetland[15]. Hernández-Crespo et al. studied the removal effect of eutrophic water by using a combination of surface flow and subsurface flow constructed wetland[16]. Molle et al. conducted a study on the total nitrogen removal potential of constructed wetlands combining horizontal and vertical subsurface flows[17]. Most research results showed that combined constructed wetlands had better removal effects than individual types of constructed wetlands. In this paper, through the research on combined artificial wetland.

In this paper, a new kind of ridge-shaped constructed wetland was proposed. In the surface flow part, the concentration of dissolved oxygen in the water body was increased by water surface reoxygenation, and the aeration cost of the subsurface flow wetland was reduced. Through the precipitation of the surface flow, the concentration of suspended particulate matter in the water body was reduced, the blockage of the horizontal subsurface flow constructed wetland filler was prevented, and the removal of the pollutant was promoted. The ridge-shaped constructed wetland could be widely used to purification for rural and urban domestic wastewater, agricultural point source and non-point source pollution.

2 Materials and Methods

2.1 Proposed Wetland Structure

The proposed wetland was an enhanced ridge-shaped constructed wetland which combined surface flow and horizontal subsurface flow, as shown in Fig. 1a. The length and width of the experimental device was 0.9 m, 0.4 m, respectively. The wetland size was shown in Tab. 1. The wetland consisted of five parts in series. Parts 1, 3, and 5 were surface flow constructed wetlands with the water level keeping at around 0.25 m. Parts 2 and 4 are horizontal subsurface flow constructed wetlands. To provide hydraulic head pressure, the left side of the two wetlands (inlet position) was raised by 0.1 m.

In the proposed wetland, the wastewater first flowed into the surface wetland (Part 1) from the water inlet, and the concentration of particulate matter in the water was reduced by the precipitation filtration in the surface wetland, which reduced the risk of blockage of the subsurface flow constructed wetland due to the excessive concentration of the particulate matter. In additional, the aerobic environment was provided by the reoxygenation of surface water (parts 1, 3, and 5), which promoted the removal of BOD and the progress of nitrification. Nitrification can convert ammonia nitrogen into nitrate nitrogen. Then the wastewater flowed from the surface wetland (Part 1) into the subsurface wetland (Part 2), entering the anaerobic environment to convert the nitrate nitrogen into nitrogen through denitrification, which promoted the removal of nitrogen. The wastewater flowed into the surface wetland (Part 3), and the untreated ammonia nitrogen was converted into nitrate nitrogen in an aerobic environment to provide nitrate nitrogen for denitrification in the subsurface wetland (Part 4), which greatly improved nitrogen removal. Finally, the tail water was treated through the surface wetland (Part 5) to further remove the BOD in the wastewater. In this process, the increase of dissolved oxygen concentration promoted the removal of BOD. The alternation of aerobic and anaerobic environment promoted the conversion of nitrogen, as well as the adsorption of precipitation and the adsorption of matrix promotes the removal of phosphorus, result in the treatment effect of sewage better improved[18].

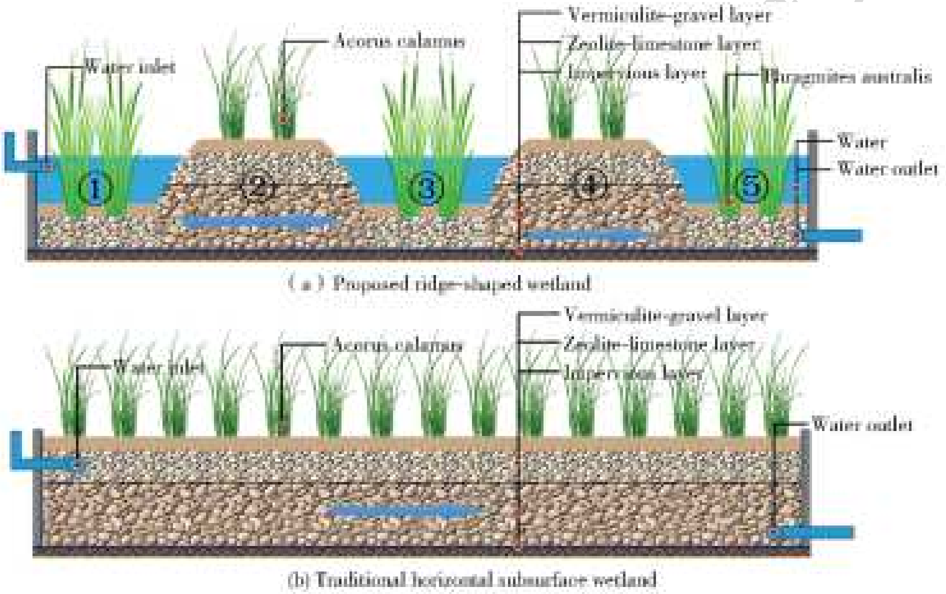

Fig. 1　Structure of proposed and traditional constructed wetlands

Tab. 1　Sizes of proposed and traditional wetlands

Wetland Type	Length/m	Width/m	Filler Height/m
Proposed (Parts 1,3,5)	0. 1	0. 4	0. 1
Proposed (Parts 2,4)	0. 3	0. 4	0. 3
Traditional	0. 9	0. 4	0. 3

To evaluate the performance of the proposed wetland, a traditional horizontal constructed subsurface flow wetland having same length, width and construction materials as proposed constructed wetland was also constructed and then used for comparison purposes. The geometry, water inlet and inlet of the traditional wetland were shown in Fig. 1(b) and Tab. 1.

2.2　Wetland Filler

The filler of horizontal subsurface flow wetland consisted of two layers. The upper layer was 0. 1 m vermiculite-gravel mixed layer. Vermiculite could fix plant roots better, but its permeability was poor. Therefore, vermiculite was mixed with gravel at a volume ratio of 2 ∶ 1. Mixing vermiculite with gravel could improve the permeability and provide a good attachment environment for microorganisms[19]. The lower layer was 0. 2 m zeolite-limestone mixture layer, and the zeolite-limestone mixture was 1 ∶ 1 in volume ratio. The combination of zeolite and limestone could improve the removal efficiency of TN and TP[20-21]. In the proposed wetland, the filler in surface flow part was vermiculite-gravel mixture with 0. 1 m, and the filler in subsurface flow part was the same as that in the traditional wetland.

2.3 Wetland Plant

Plants were an important part of constructed wetlands[22]. The selection of wetland plants should first consider the adaptability and purification ability of the plants[23-24]. There were many kinds of wetland plants, and the purification effects of different plants on pollutants were quite different. Through review of literature, this paper selected *Phragmites australis and Acorus calamus* as wetland plants[25]. The roots of *Phragmites australis and Acorus calamus* were well developed and had strong oxygen secretion capacity, which could increase the dissolved oxygen concentration in the wetland system, improved the activity of root microorganisms, and promoted the removal of pollutants. *Acorus calamus* was planted in the traditional horizontal subsurface flow constructed wetland. In the proposed wetland, the surface flow part planted *Phragmites australis*, horizontal subsurface flow part planted *Acorus calamus*. The planting density was 18 plants/m^2.

2.4 Wetland Operation

This experiment was an indoor experiment. In order to keep the inlet concentration stable, the synthetic sewage was used in the test water. The inlet water quality was shown in Tab. 2. The experiment adopted continuous water inlet mode; the hydraulic load was 0.12～0.2 m^3/(m^2·d), the average water level of the surface flow section of the proposed wetland was maintained about 0.25 m above the surface of filler. The proposed and traditional wetlands ran simultaneously. After the operation of the wetland was stabilized, water samples were taken every three days at the outlets of the proposed constructed wetland and traditional constructed wetland. Now, BOD, TN, and TP were become a major concern to research about the effects of constructed wetlands. Lots of studies were published[8,20,26]. Here, BOD, TN, and TP were chosen as the main indicators too. The international standards were used for the determination[27].

Tab. 2 Inlet Water Quality

Property	BOD	TN	TP
Concentration/(mg·L^{-1})	110.6～129.5	46.1～53.6	3.4～4.5
Average concentration/(mg·L^{-1})	119.5	49.7	3.9

3 Results and Comparative Analysis

3.1 BOD Removal Effect

Fig. 2 presented the comparison of BOD removal effect. The influent concentration of BOD ranged between 110.6 mg/L to 129.5 mg/L and the average influent concentration was 119.5 mg/L. In the traditional horizontal subsurface flow wetland (1#), the effluent concentration of BOD ranged between 40.2 mg/L to 57.8 mg/L, the average effluent concentration was 47.1 mg/L. The removal rate ranged between 55.4% to 65.8%, and the average removal rate was 60.5%. In the proposed wetland (2#), the effluent concentration of BOD ranged between 20.0 mg/L to 25.0 mg/L, the average effluent concentration was 22.9 mg/L. The removal rate ranged between 78.8% to 82.9%, and the average removal rate was 80.8%.

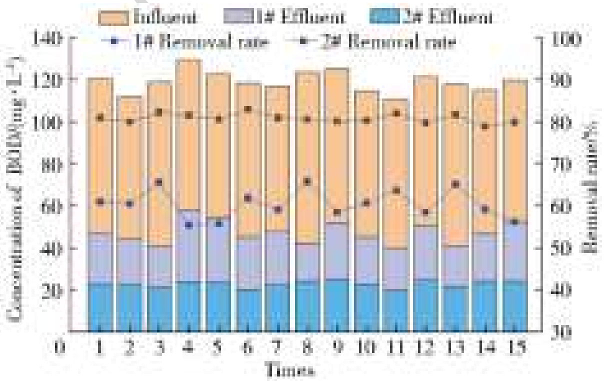

Fig. 2 BOD removal effect and comparison with traditional horizontal subsurface constructed wetlands

In constructed wetlands, the removal of BOD was mainly through the adsorption and metabolism of microorganisms. The subsurface flow constructed wetland had good removal effect on organic matter. Soluble organic matter could be removed by the adsorption of biofilm and metabolism of microorganisms, while insoluble organic matter could be removed by precipitation and filtration. However, the subsurface flow constructed wetland had been submerged for a long time, and the oxygen released by the plant root system alone was not enough to improve the internal anoxic environment of the wetland and satisfy the removal of organic matter. Compared with the traditional wetland, the proposed wetland increased the surface flow part in the water inlet, middle part, and water outlet. The dissolved oxygen concentration in the water was increased by surface reoxygenation and plant root oxygen secretion, which greatly improved the removal of organic matter. The average effluent concentration of BOD in the proposed wetland decreased by 24.3 mg/L compared with that in the traditional wetland, and the average removal rate increased by 20.3%.

3.2　TN Removal Effect

Fig. 3 showed the TN removal effect comparison, the influent concentration of TN ranged between 46.1 mg/L to 53.6 mg/L, the average influent concentration was 49.7 mg/L. In the traditional horizontal subsurface flow wetland (1#), the effluent concentration of TN ranged between 15.2 mg/L to 18.2 mg/L, the average effluent concentration was 16.7 mg/L. The removal rate ranged between 64.0% to 68.4%, and the average removal rate was 66.5%. In the proposed enhanced constructed wetland (2#), the effluent concentration of TN ranged between 6.1 mg/L to 10.3 mg/L, the average effluent concentration was 8.2 mg/L. The removal rate ranged between 78.2% to 87.6%, and the average removal rate was 83.5%.

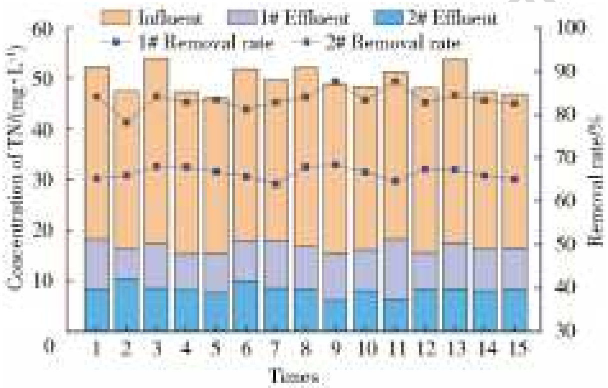

Fig. 3　TN removal effect and comparison with traditional horizontal subsurface constructed wetlands

There were three main ways to remove TN in constructed wetland systems: plant uptake, nitrogen volatilization, and microbial nitrification and denitrification. Plants could absorb and utilize inorganic nitrogen in water, but only 8% to 16% of total nitrogen was absorbed by plants. The removal of TN in constructed wetlands mainly depended on the nitrification and denitrification of microorganisms. Nitrification required an aerobic environment, while denitrification required an anaerobic environment. The traditional horizontal subsurface flow constructed wetland was conducive to denitrification because of its low dissolved oxygen concentration, but it inhibited nitrification and had a low removal rate of TN. The proposed wetland combined surface flow with subsurface flow. The dissolved oxygen concentration in surface flow was high, which promoted nitrification. Subsurface flow constructed wetland provided anaerobic environment, which improved denitrification. The combination of the surface flow and subsurface flow increased the removal rate of TN. The experimental results showed that the average effluent concentration of TN in the proposed wetland decreased by 8.5 mg/L compared with that in the traditional wetland, and the average removal rate increased by 17.0%.

3.3　TP Removal Effect

Fig. 4 showed the TP removal effect comparison, the influent concentration of TP ranged between 3.3 mg/L to 4.5 mg/L, the average influent concentration was 3.9 mg/L. In the traditional horizontal subsurface flow wetland (1#), the effluent concentration of TP ranged between 0.9 mg/L to 1.4 mg/L, the average effluent concentration was 1.1 mg/L. The removal rate ranged between 66.8% to 74.6%, and the average removal rate was 71.2%. In the proposed wetland (2#), the effluent concentration of TP ranged between 0.51 mg/L to 0.92 mg/L, the average effluent concentration was 0.77 mg/L. The removal rate ranged between 76.2% to 85.3% and the average removal rate was 80.3%.

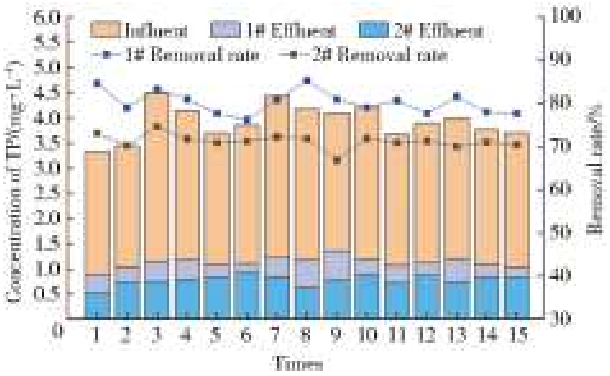

Fig. 4　TP removal effect and comparison with traditional horizontal subsurface constructed wetlands

Phosphorus removal in constructed wetlands was mainly through plant uptake, microbial transformation, the adsorption and precipitation of filler matrix. Among them, adsorption and precipitation of filler matrix was the main removal way. However, more particulate matter in water would cause the blockage of filler matrix and affect phosphorus removal in CWs. Compared with the traditional horizontal subsurface flow wetland, the proposed wetland added the surface flow part at the inlet, reducing the concentration of particulate matter in the water by sedimentation and adsorption, which could prevent the blockage of matrix in subsurface flow part. At the same time, the concentration of dissolved oxygen in the water was increased, which could promote the absorption of phosphorus by plant growth and the transformation of phosphorus by microorganisms. Therefore, the removal effect of phosphorus by constructed wetlands was greatly improved. The experimental results showed that the average effluent concentration of TP in the proposed wetland decreased by 0.33 mg/L compared with that of the traditional wetland, and the average removal rate increased by 9.1%.

4 Conclusions

This paper had presented a new type of ridge-shaped constructed wetland which was combined with surface flow and horizontal subsurface flow constructed wetlands. A traditional horizontal constructed subsurface flow wetland having same length and width was constructed. The test results of proposed ridge-shaped constructed wetland and outlet of traditional constructed wetland showed that the average removal percentages of BOD, TN, and TP in proposed (traditional) wetland were 80.8% (60.5%), 83.5% (66.5%), and 80.3% (71.2%), respectively. Compared with the traditional wetland which built in this paper, the removal rates of the proposed wetland were increased by 20.3%, 17.0%, and 9.1%, respectively.

The proposed wetland structure could be extended by increasing the number of surface wetlands in the middle part according to the length of the subsurface wetland. This modification would create a plurality of alternating aerobic and anaerobic environment and promote the removal of pollutants.

The proposed constructed wetland was similar to the farmland field and could be used for the cultivation of economic crops. For instance, rice could be planted in the surface flow part. Rice growth could better absorb nitrogen from wastewater. Planting rice in wastewater could meliorate the way of traditional irrigation and fertilization. Based on results and analysis, we suggest this innovative wetland has certain economic value and has the potential for good development prospects.

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