EXPERIMENTAL STUDY ON PURIFICATION OF POLLUTED RIVER WATER WITH HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLANDS OF DIFFERENT FILLERS AND PLANTS

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Abstract. The Fuhe River in Baoding City is one of the rivers entering Baiyangdian Lake, but its pollution is serious, so improving the water quality of the Fuhe River can not be ignored. In this paper, the horizontal subsurface flow constructed wetland was used to purify the water of Fuhe River, and the pollutant removal effect of ceramsite, crushed stone filler, cyperus alternifolius, Reed and yellow iris plants was analyzed. The results showed that the cyperus alternifolius ceramsite constructed wetland has the best removal effect on COD and TP, its average removal rates are 56.18% and 61.97%, respectively, and its average effluent concentrations are 18.64 mg/L and 0.27 mg/L; the reed ceramsite constructed wetland has the best removal effect on NH_4^+-N, with a rate of 64.00%, respectively, and its average effluent concentration is 0.82 mg/L. The results can provide theoretical reference for improving the water quality of Fuhe River.
Keywords: *Baiyangdian, Fuhe River, horizontal subsurface, plant screening, purification effect, substrate*

Introduction

Xiong'an New Area will be built as an ecological city, in which the river is harmonious with the city. Baiyangdian Lake needs a good ecological environment to meet the requirements of Xiong'an New Area (Xia et al., 2017; Li et al., 2013). At present, the flow of water's environment of Baiyangdian Lake is poor, for which the main pollution source is the water from the Fuhe River into the Lake, so it is very important to control the water of Fuhe River. Currently, constructed wetlands are widely applied to the improvement of polluted water due to its high efficiency, ecology and low investment (Machado et al., 2017; Gagnon et al., 2012).

Fillers and plants play an important role in constructed wetland systems. More and more people begin to study the purification effect of different fillers and plants on constructed wetlands (Leto et al., 2013; Xiong et al., 2015). The constructed wetland designed by Tang et al. (2009) uses a combination of crushed stone and shale to study its purification effect on eutrophic water bodies. The horizontal free surface flow integrated constructed wetland (ICW) concept was proposed by Scholz et al. (2007) and combines that goal of purifying farmland water with the goal of incorporating wetland infrastructure into landscape, with good results achieved after commissioning. Ji et al. (2017) studied the filler and its purification mechanism of constructed wetland sewage treatment system. Hao et al. (2017) conducted a study on the purification efficiency of plant water in constructed wetlands.

Under the background of this study, constructed wetland is used to purify the water quality of Fuhe River, study the effect of wetland on the removal of pollutants in the

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river water and the effect of different fillers and plants on the purification effect. In this paper, the polluted river water is taken as the research object, and according to the combination type of different fillers (such as crushed stone and ceramsite) and different plants (cyperus alternifolius, reed and yellow iris), 8 horizontal subsurface constructed wetlands are constructed outdoors to study the purification effect of the river water.

Materials and methods

Raw water quality

The experimental water is taken from the section of Yonghua Bridge, Fuhe River, Baoding City. The water quality of the section for nearly one year is shown in *Table 1.*

Table 1. *Water quality of the section*

pH	DO (mg/L)	Turbidity (NTU)	COD (mg/L)	TP (mg/L)	NH_4^+-N (mg/L)
6-8	0.5-9.0	10-30	30-50	0.6-1.0	1.7-3.0

Construction of experimental device

8 horizontal subsurface flow constructed wetlands are constructed, with the size of the pond as 65 cm × 35 cm × 40 cm and the filling height as 23 cm. They are divided into two group according to the filler, one is ceramsite, other group is crushed stone, the particle diameter of the ceramsite is 10-20 mm, the particle diameter of the crushed stone is 5-10 mm (3 cm), 10-15 mm (10 cm), 15-20 mm (5 cm), and 20-30 mm (5 cm) from the top to the bottom, covering with 5 cm soil on the surface of the filler. According to the principle of strong purifying ability and fast growing to adapt to environment, three kinds of plants are preliminarily selected as wetland plants, such as cyperus alternifolius, reed and yellow iris, with a planting density of 18 plants/square trough. The schematic diagram is shown in *Figure 1*.

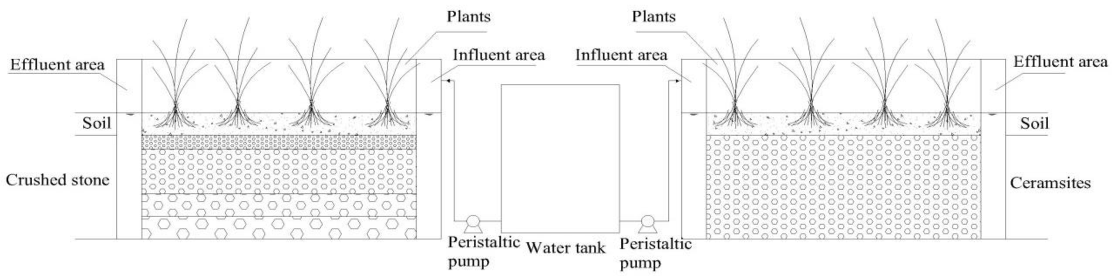

Figure 1. *Schematic diagram of experimental device*

Operation of experimental system

The experimental device adopts continuous water inflow, the hydraulic load is controlled at 0.2-0.4 $m^3/(m^2 \cdot d)$, the hydraulic retention time is 1.5-2.5 d, and the operating water level is located on the soil surface. In order to ensure the stability of water inflow, peristaltic pump is used to quantitatively and constantly supply water to the constructed wetland system. The experimental system lasted 7 months from the

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construction of trial operation to the end of operation, and stably ran 3 months after the plant is mature.

Sample collection and testing

Sample collection includes influent and effluent of each wetland. The sample collection frequency is once every three days, and the detection indicators include temperature (T), dissolved oxygen (DO), pH, turbidity, chemical oxygen demand (COD), total phosphorus (TP), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), nitrite nitrogen (NO_2^--N), and nitrate nitrogen (NO_3^--N). The temperature and dissolved oxygen are measured by a dissolved oxygen meter at the sampling site, and the pH is measured by a PH meter. The determination methods of TN and TP are potassium persulfate oxidation-ultraviolet spectrophotometry and anti-spectrophotometric method of potassium persulfate molybdenum antimony oxidation, respectively. Other indicators are measured in the laboratory by the method of national standard.

Results

Removal effect of COD

Figure 2 is a diagram of removal effect of COD by the horizontal subsurface flow constructed wetland system, in which COD concentration of the influent fluctuates little and COD removal is stable. It can be seen from *Figure 2* that the wetland system with plants is better than the blank wetland system in the removal of COD in the water, and among three plants, cyperus alternifolius has the best removal effect on COD, followed by yellow iris and reed. The average effluent COD concentration of cyperus alternifolius ceramsite-bed wetland is 18.64 mg/L, which reaches Class Ⅲ standard of surface water. The average effluent COD concentration of reed, yellow iris and blank ceramisite-bed wetland is 20.86 mg/L, 21.12 mg/L and 24.98 mg/L, and the average effluent COD concentration of cyperus alternifolius, reed, yellow iris and blank crushed stone-bed wetlands is 21.35 mg/L, 23.39 mg/L, 23.73 mg/L and 27.48 mg/L, all of which reach the class IV standard of surface water.

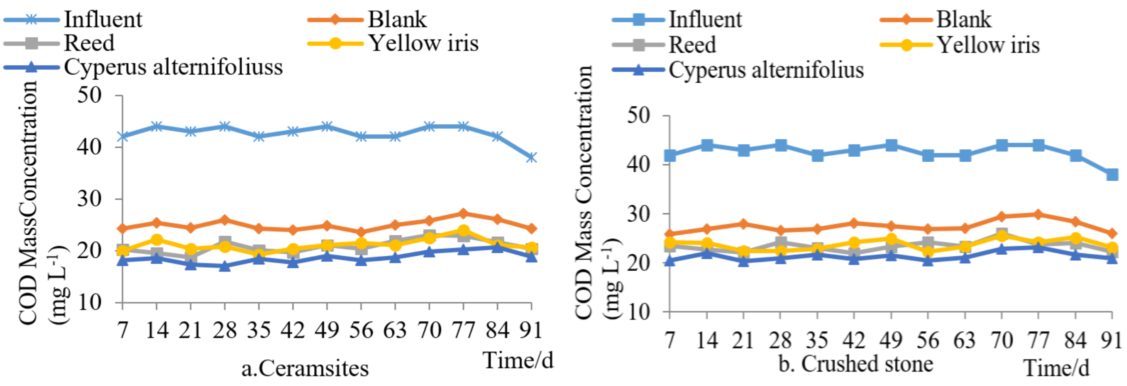

Figure 2. *Removal effect of COD by ceramsite and crushed stone*

In the constructed wetland system, the removal of COD is mainly accomplished by the filtration of substrate and the decomposition of microorganisms. As can be seen from *Figure 2,* compared with the blank wetland group, the removal effect of COD in

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the constructed wetland group with plants differs slightly, for which the filtration of the substrate is the main way to remove COD in the constructed wetland system and the proportion of plant absorption and microbial decomposition is relatively small (Kjellin et al., 2007; Albuquerque et al., 2010). From the above results, it can be seen that compared among the three plants, the removal effect of COD in cyperus alternifolius wetland is better than that of the reed wetland and the yellow iris wetland, for which the root system of cyperus alternifolius is stronger than that of the other two wetland plants, its stem and leaf are lush, and its ability to absorb organic pollutants is stronger.

Figure 3 shows the change trend and removal rate of effluent COD of ceramsite-bed and crushed stone-bed constructed wetland systems. It can be seen from *Figure 3* that when the plants are the same, the removal effect of COD by the ceramsite-bed constructed wetland system is better than that of the crushed stone-bed constructed wetland system, for which the surface areas of ceramsite is greater, and under the same hydraulic load, the contact surface between water and ceramsite is more, which increases the absorption of COD by ceramsite and makes the removal rate of COD in ceramsite-bed higher.

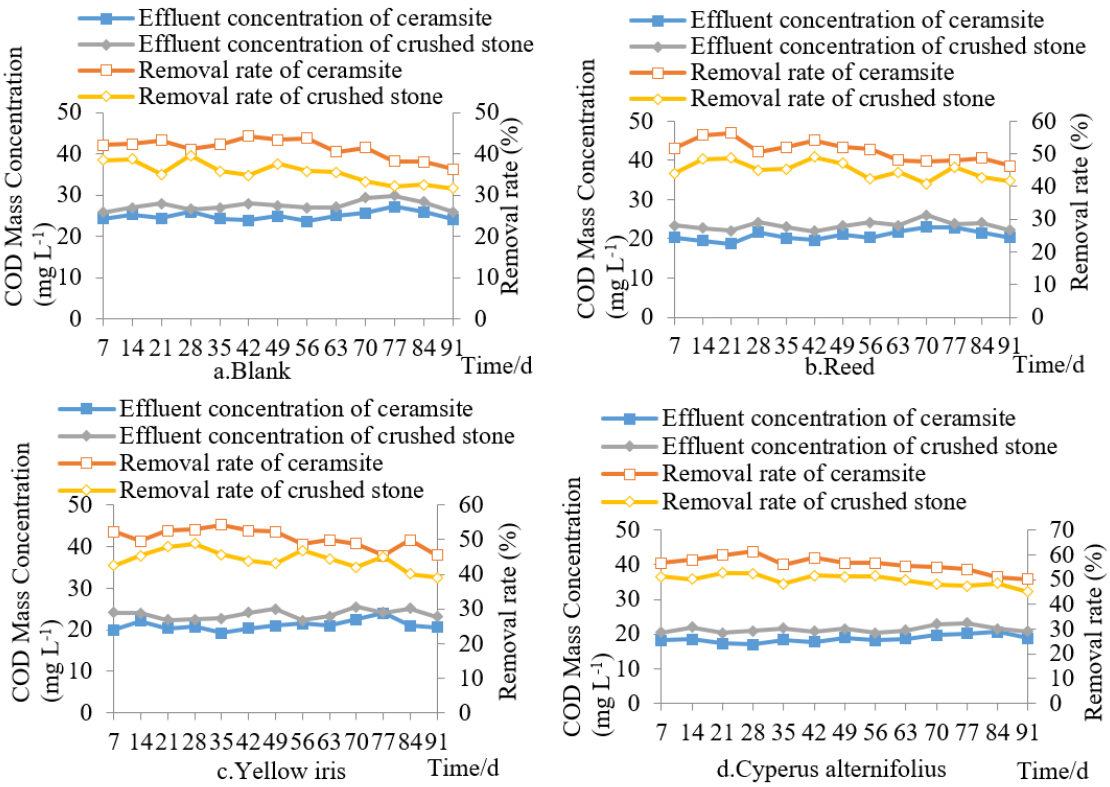

Figure 3. *Comparison of COD removal rate between ceramsite and crushed stone*

It can be seen from *Figure 3* that the removal of COD by the constructed wetland system is relatively uniform and less fluctuating during the operation of the experiment, and the removal rate of the ceramsite-bed wetland and the crushed stone-bed wetland at the later stage of the experiment shows a slow decreasing trend. The reason may be that the plant grows slowly, begins to wither and absorbs less COD, and as the temperature decreases, the activity of microorganisms declines. Meanwhile, with the operation of the experiment, the adsorption of the filler tends to the saturation state, and the

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adsorption capacity decreases, resulting in the slowly decreasing trend in the removal rate of COD in wetland system.

Removal effect of TP

Figure 4 shows the removal effect of TP by the wetland system. It can be seen from the figure that the TP concentration of the influent decreases slowly in the later period of the experimental operation, and the TP concentration of effluent in the wetland with plants is lower than the TP concentration of effluent in the blank wetland. Cyperus alternifolius has the best effect on TP removal. The average TP concentration of effluent in cyperus alternifolius ceramsite-bed wetland and cyperus alternifolius crushed stone-bed wetland is 0.27 mg/L and 0.32 mg/L, respectively. Reed and yellow iris has less effect on TP removal. The average TP concentration of effluent in reed ceramsite-bed wetland, yellow iris ceramsite-bed wetland, reed crushed stone-bed wetland and crushed stone-bed wetland is0.30 mg/L, 0.31 mg/L, 0.35 mg/L and 0.34 mg/L, respectively. The blank wetland system also has a certain removal effect on TP. The average TP concentration of effluent is 0.36 mg/L and 0.40 mg/L in the blank ceramsite wetland and the blank crushed stone wetland, respectively.

The removal of phosphorus in constructed wetlands mainly depends on the interaction of plant absorption, adsorption and filtration of substrate and microbial transformation. As can be seen from *Figure 4,* the difference between wetland with plants and blank wetland in removal of TP in water is slight, for which the content of phosphorus absorbed by plant growth accounts for less proportion to the phosphorus removal, and the adsorption and filtration of substrate, which is combined with its Ca, Al, Fe, and others to form precipitates for removal, which accounts for a large proportion (Kotti et al., 2016).

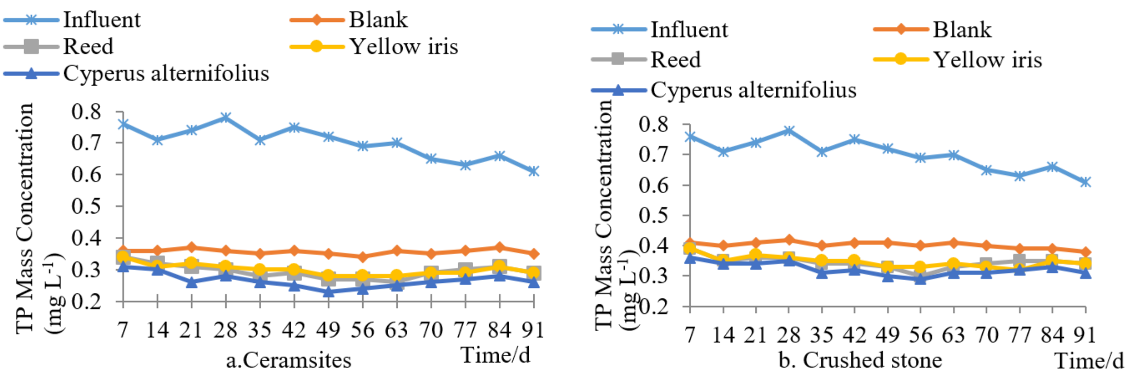

Figure 4. *Removal effect of TP by ceramsite and crushed stone*

Figure 5 shows the change trend and removal rate of effluent TP of ceramsite-bed and crushed stone-bed constructed wetland systems. It can be seen from *Figure 5* that when the plants are the same, the removal effect of TP by the ceramsite-bed constructed wetland system is better than that of the crushed stone-bed constructed wetland system, for which ceramsite is better than crushed stone since its coarse surface is good for the growth of plants and microorganism, and under the same hydraulic load, the contact method between water and ceramsite significantly affects the absorption of TP.

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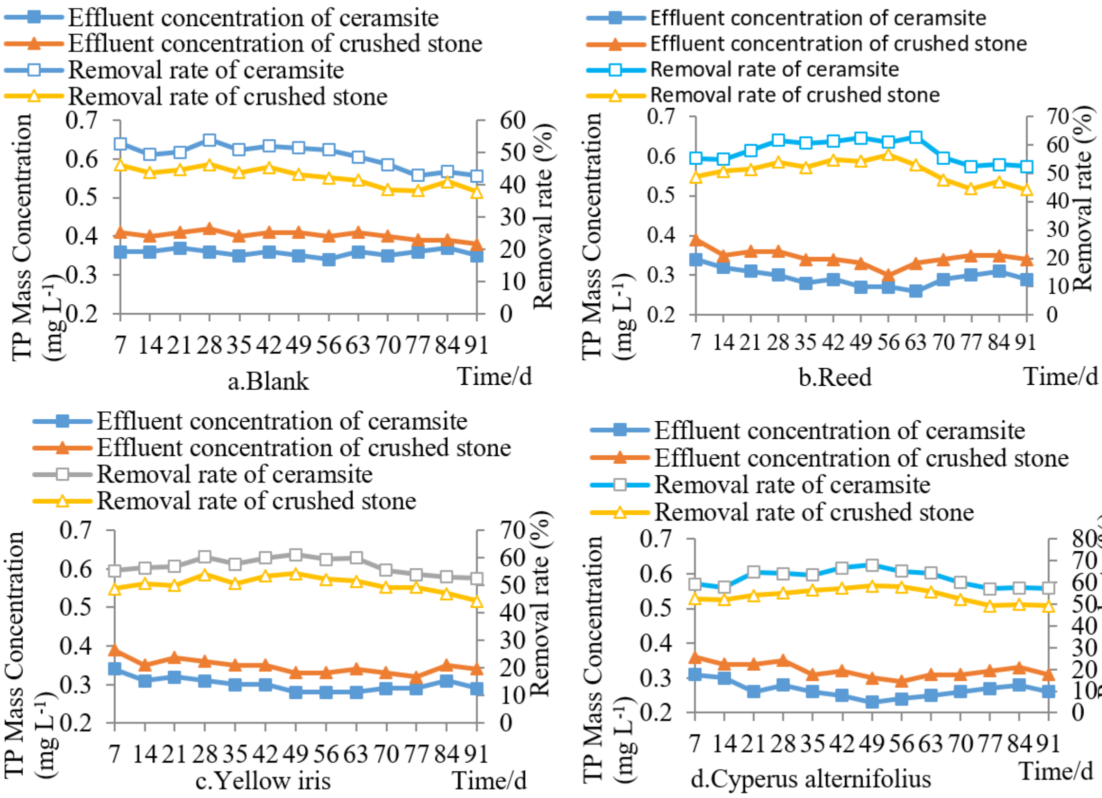

***Figure 5.** Comparison of removal rate of TP between ceramsite and crushed stone*

The removal of TP by the constructed wetland system is relatively uniform and less fluctuating during the operation of the experiment, and the removal rate of TP at the later stage of the experiment shows a slow decreasing trend. The reason may be that the plant grows rapidly at the beginning and absorbs more phosphorus, and as the experiments operates, plant grows slowly, begins to wither and absorbs less phosphorus, and even part of the phosphorus in plants is slowly decomposed by microorganisms and released, resulting in the decrease in the removal rate of TP.

Comparing the removal effect of TP between the ceramsite-bed and the crushed stone-bed in *Figure 5*, it is found that the difference between the effluent TP of the ceramsite-bed and the crushed stone-bed with plants is larger than the difference between the blank ceramsite-bed and the blank crushed stone bed. Among them, the difference of the TP concentration of the effluent in the cyperus alternifolius ceramsite-bed wetland and cyperus alternifolius crushed stone-bed wetland is greater than other three experiments, and the reason is that the strong root system of the plants in the wetland system enhances the porosity of the ceramisite, also increases the adsorption of the ceramsite to TP and thus exhibits a strong TP purification capability (Vohla et al., 2011).

Removal effect of NH_4^+-N

As can be seen from *Figure 6*, the NH_4^+-N concentration in the influent gradually increases at the later stage of the experiment. *Figure 6a* shows the removal effect of NH_4^+-N by the constructed wetland system of the ceramsite. As can be seen from the figure, the removal effect of NH_4^+-N by the ceramsite wetland system with plants is

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better than that of the blank group. The reed ceramsite-bed wetland has the best effect on NH_4^+-N removal, the average NH_4^+-N concentration of effluent is 0.82 mg/L, while the removal effect of NH_4^+-N by cyperus alternifolius ceramsite-bed wetland and yellow iris ceramsite-bed wetland is similar. The average NH_4^+-N concentration of effluent is 0.95 mg/L and 0.95 mg/L, respectively, while that of blank group is 1.28 mg/L. *Figure 6b* shows the removal effect of NH_4^+-N by the crushed stone-bed constructed wetland system. It can be seen that the removal effect of NH_4^+-N by the crushed stone-bed constructed wetland system with plants is better than that of the blank group; the reed crushed stone-bed constructed wetland has the best effect on NH_4^+-N removal, and its average NH_4^+-N concentration of effluent is 0.99 mg/L, while the removal effect of NH_4^+-N in cyperus alternifolius crushed stone-bed wetland and yellow iris crushed stone-bed wetland is similar with the average NH_4^+-N concentration of effluent as 1.10 mg/L and 1.11 mg/L respectively, while that of blank group is 1.39 mg/L.

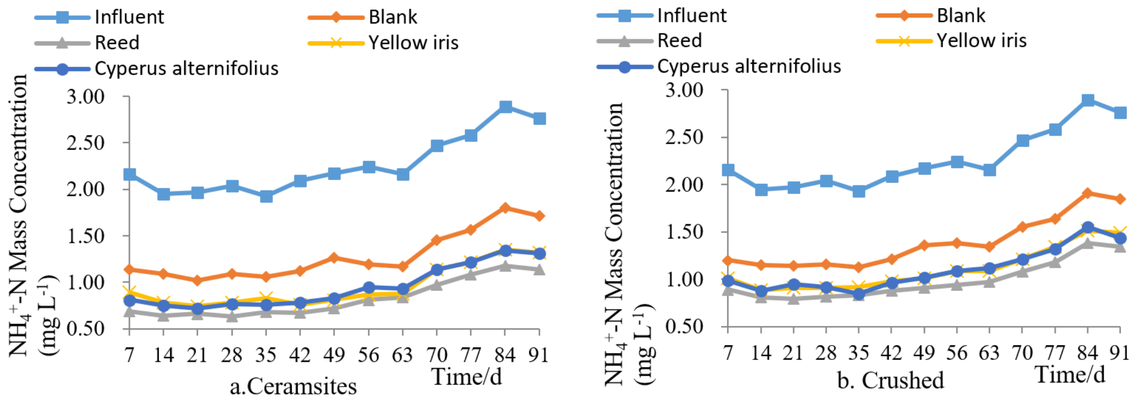

Figure 6. *Removal effect of NH_4^+-N by ceramsite-bed and crushed stone bed*

In the constructed wetland system, the removal of ammonia nitrogen is mainly through the filtration of substrate, the absorption of plants and the nitrification of microorganisms, where nitrification is the main mode, and oxygen supply is a restraint factor affecting nitrification in horizontal subsurface flow constructed wetlands (Vymazal et al., 2007; Saeed et al., 2012). In the experiment, the removal effect of NH_4^+-N by the wetland with plants is much better than that of the blank wetland, and the reason may be that the plants supply most of oxygen for the nitrification reaction through the transportation, release and diffusion of oxygen, strengthening nitrification.

In addition, the root system of the reeds is more developed and its oxygen transport ability is stronger than that of the two plants, so its removal effect of ammonia nitrogen is better.

Figure 7 shows the change trend and removal rate of effluent NH_4^+-N of ceramsite-bed and crushed stone-bed constructed wetland systems. It can be seen from *Figure 7* that the removal of NH_4^+-N by the constructed wetland system is relatively uniform and less fluctuating during the operation of the experiment, and the removal rate at the later stage of the experiment shows a slow decreasing trend. The reason may be that at the later stage the plant grows slowly and has less ability to transport oxygen. At the same time, when the temperature is lower, the activity of nitrifying bacteria and nitrobacteria in the water body will be inhibited to some extent, the nitrification capacity will be

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reduced, and the removal rate of NH4$^+$-N will be reduced. It is also possible that with the operation of the experiment, the nitrogen-containing organic matter retained by the filler decomposes in the anaerobic environment at the bottom of the wetland bed, resulting in an increase in the NH4$^+$-N content of the effluent water.

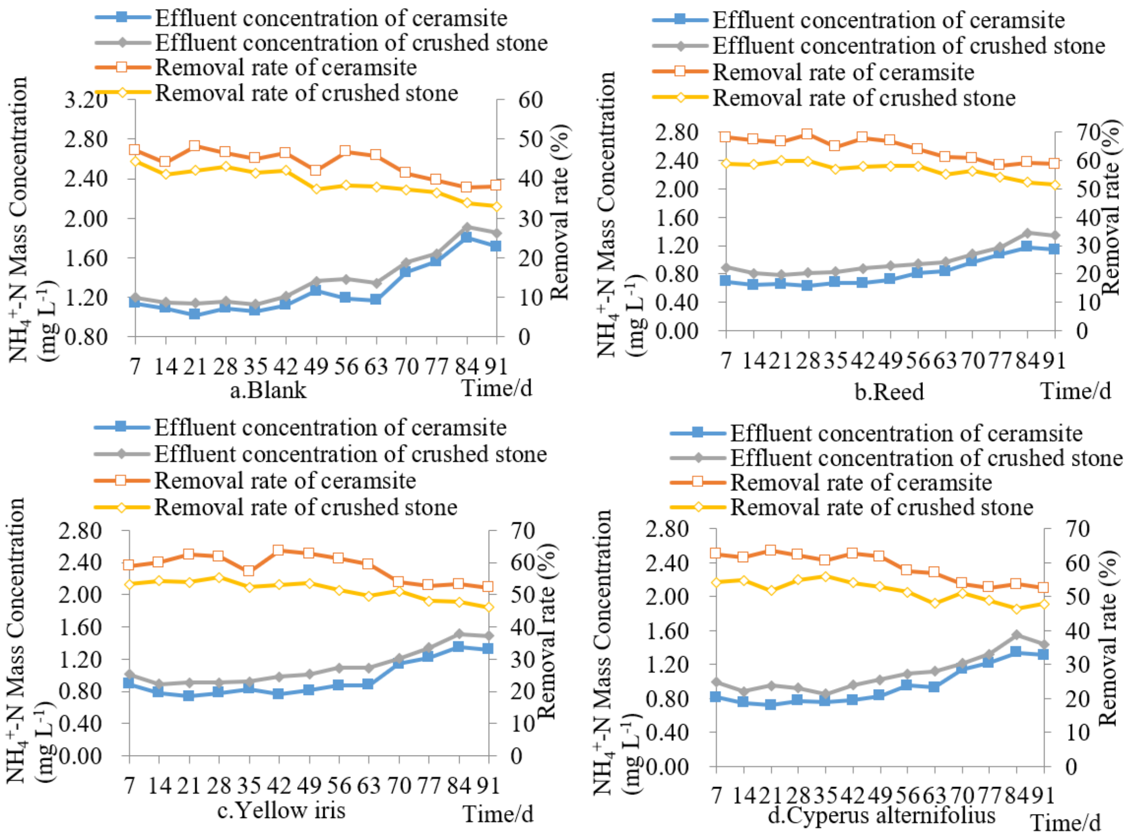

***Figure 7.** Comparison of removal rate of NH_4^+-N between ceramsite and crushed stone*

Discussion

From the above experimental results and analysis, it can be seen that the wetland system has good removal effect of pollutants in the water from Fuhe River, and the removal rate tends to decrease slowly in the later stage of the experiment, which has a great effect on the growth cycle of plants. As plants grow rapidly, they will absorb more and more pollutants, which makes the removal rate higher. In the later stage of the experiment, the absorption of pollutants by plants and fillers may reach a saturated state, even release some pollutants, which makes the effluent concentration increase. At end of October, with the decrease in temperature, the life activities of microorganisms are inhibited, the plants begin to wither gradually, with a decrease in the absorption capacity, and the removal rate of pollutants in wetlands gradually decreases.

The removal rate of COD, TP, and NH4$^+$-N in ceramsite-bed wetland is higher than that of crushed stone-bed wetland, which is related to the structure of filler. The surface of ceramsite is rough and easy to attach microorganisms, the void ratio is high, and the specific surface area is large, allowing more full contact between the river water and the filler, so its ability of absorbing pollutants is stronger, and the removal rate of pollutants is higher.

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Conclusions

The water quality of Fuhe River is improved by purification through the horizontal subsurface flow constructed wetlands, and the effluent water quality reaches the Class IV standard of surface water. Because of the strong adsorption ability of ceramsite, the wetland system with ceramsite as filler is better than the wetland system with crushed stone to remove the pollutants in the water. Cyperus alternifolius ceramsite-bed constructed wetland system has the best effect on COD and TP removal of Fuhe River, with the average removal rate of COD and TP as 56.18% and 61.97%, respectively, and the average concentration of effluent as 18.64 mg/L and 0.27 mg/L, respectively, reaching Class IV water standard of the Environmental Quality Standard for Surface Water (GB3838-2002); the reed ceramsite-bed constructed wetland system has the best effect on NH_4^+-N removal, with the average removal rate as 64% and the average concentration of effluent as 0.82 mg/L, reaching Class Ⅲ water standard of surface water. Blank ceramsite-bed constructed wetland system and blank crushed stone-bed constructed wetland system have less effect on removal of COD, TP and NH_4^+-N, with the average concentration of effluent as 24.98 mg/L and 27.48 mg/L, 0.36 mg/Land 0.40 mg/L, and 1.28 mg/Land 1.39 mg/L, reaching Class V water standard of surface water. This experiment mainly analyzed the purification effect of wetland system on Fuhe River water in summer and autumn. It can extend the test time in future research and analyze the removal effect of pollutants in water by wetland in different seasons.

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