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# The Research on the Effects of Substrate Types Using for Constructed Wetland

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## Abstract

In this study, pollutant removal effects of zeolite, ceramsite, quartz sand, and activated carbon were assessed its feasibility as a constructed wetland substrate using batch experiments. After 12 days of treatment, the removal rates of turbidity, surface color, true color, and chlorophyll of planktonic algae by 4~8 mm ceramic granules reached 93.6%, 92.1%, 89.7%, and 91.3%, respectively, which significantly improved the sensory effect of the landscape water. TN reached the class IV of the surface water, meanwhile, TP and permanganate index fulfilled the quality of the surface water class III. After being treated by ceramsites, the $UV_{254}$ and $UV_{280}$ values, as well as CDOM absorption coefficients of the landscape water, were much lower, and the values of $E_{250}/E_{365}$ were clearly higher than other substrates, which demonstrated excellent contaminant removal effect. All results indicated that 4~8 mm ceramsites were suitable substrates when used in CWs treating closed landscape water bodies. Long-term experiments should be carried out to test its pollutants removal performance in the future.

## Keywords

Small landscape closed water, Substrates type, Pollutants removal

## 1. Introduction

Constructed wetlands make full use of low-cost and high-efficiency substrates to exert their interception and adsorption functions, and combine with plant absorption and microorganism degradation to synergistically treat pollutants wastewater [1]. This technology has been applied in the fields of rainwater, water purification of rivers and lakes, rural domestic sewage purification, and deep treatment of wastewater treatment plant effluent.

Substrate is one of the main parts of constructed wetlands, which plays the role of adsorption and interception of pollutants and provides growth space for microorganisms [2]. The substrate links the plants and microorganisms together and is an important foundation for the plants and microorganisms to fully play their roles [3]. The physical and chemical properties of different substrates were really differences. Therein, the species, numbers, activities, and biofilm hanging speeds of microorganisms attached to the surface of the substrate also showed great differences [4].

The commonly used substrates in constructed wetlands were activated carbon, zeolite, quartz sand, ceramsite, rocks, and so on [5]. Activated carbon has good adsorption performance due to its large surface area, which is widely used in water treatment of constructed wetlands and can effectively remove odor, dissolved organic matter, and other micro-pollutants. Zeolite is a kind of water-bearing silicate mineral with a large specific surface area and high porosity, which has excellent adsorption, ion exchange, and catalytic effects. Wang et. al reviewed zeolite substrates used in constructed wetlands and found that zeolite has a large surface area and good pore structure, and which has a high $NH_4^+$-N adsorption capacity [6]. Quartz sand has good compressive and abrasion resistance, and it has good chemical stability, and long service life, and showed good dirt trapping ability in experiments [7]. Ceramsite has the advantages of strong adsorption capacity, good chemical stability, easy regeneration, environmentally friendly, and low price. Its specific surface area was very favorable to the growth of microorganisms and reflects a better removal effect on both nutrient salts and organic matter [8].

Therefore, in this study, the type of substrate was investigated to improve the effect of constructed wetland wastewater treatment in view of the pollution characteristics for the closed landscape water treatment.

## 2. Materials and Methods

### 2.1 Experimental water

Experimental water was acquired from a community pond in Shenzhen, the pond's main recharge was rainfall and surface runoff, and there were no other pollution sources. The water quality is shown in Table 1.

**Table 1. Experimental raw water quality**

| Indicator | Turbidity (NTU) | Surface color (degree) | True color (degree) | TN (mg/L) | TP (mg/L) | Permanganate index (mg/L) | Chlorophyll a(μg/L) |
|---|---|---|---|---|---|---|---|
| Value | 9.5~17.5 | 17~41 | 7~17 | 1.2~3.0 | 0.04~0.15 | 6.8~15.4 | 17.8~38.5 |

### 2.2 Experimental Methods

Sands and pebbles were selected as the water distribution layer and the support layer of the constructed wetland. The removal efficiencies of zeolites, ceramsites, quartz sands, and activated carbons with particle sizes of 2~4 mm and 4~8 mm were compared as the functional layers, respectively. Plexiglas columns with 140 cm diameter and 120 cm height were used for the experiments, with the top filled with 100 cm of the above substrates for comparison and the bottom filled with 5 cm of pebbles with 16~32 mm particle size.

The experimental substrate was cleaned with tap water to remove floating ash and debris and then filled into the column. Under the same conditions, a certain amount of water from a small landscape-enclosed water body was recycled to compare the pollutant removal effect of substrates to be compared, therefore, select the prime substrate and particle size. The device running time was 12 d in total, and samples were taken every day for measurement and analysis.

### 2.3 Analytical methods

#### 2.3.1 Basic effluent quality indexes

The analysis of total nitrogen (TN) and total phosphorus (TP) was carried out according to the methodology described in Standard Method [9].

### 2.4 Other organic indicators

#### 2.4.1 $UV_{254}$, $UV_{280}$ 和 $E_{250}/E_{365}$

The degree of aromaticity of organic compounds in water can be characterized by $UV_{254}$ and $UV_{280}$, and the larger the value is, the higher the degree of aromatization is. $E_{250}/E_{365}$ indicates the ratio of absorbance of water at 250 nm and 365 nm, which can show the molecular mass and degree of polymerization of organic compounds, and the larger the value of $E_{250}/E_{365}$ is, the smaller molecular mass and the degree of aromaticity are. The water samples were filtered through a 0.45 μm membrane and then the absorbance at 250 nm, 254 nm, 280 nm, and 365 nm was determined by ultraviolet spectrophotometer (UV2600).

#### 2.4.2 Absorbance of chromophore dissolved organic matter (CDOM)

The concentration of CDOM in water cannot be determined directly, but can only be analyzed qualitatively, and is usually characterized by the absorption coefficient α(λ). The water samples were pre-filtered by 0.22 μm filter membrane, and ultrapure water was used as blank. The absorption coefficient of each wavelength was obtained by using a UV spectrophotometer (UV2600) to measure the absorbance D(λ) with a 1 cm quartz cuvette in the wavelength of 355 nm. The absorbance of 355 nm was calculated according to Eq. (1).

$$\alpha(\lambda)= 2.303\cdot D(\lambda)/r - \alpha'(700)\cdot\lambda/700 \quad \text{Eq. (1)}$$

α(λ) — corrected absorption coefficient at wavelength λ ($m^{-1}$);
α'(λ) — uncorrected absorption coefficient at wavelength λ ($m^{-1}$);
D(λ) — absorbance at wavelength λ;
r — optical path (m);
λ — wavelength (nm).

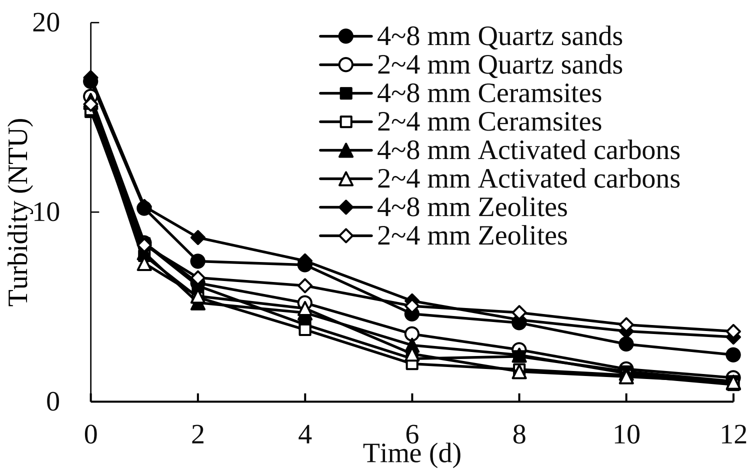
# 3. Results and Discussion

## 3.1 The comparison of substrate types

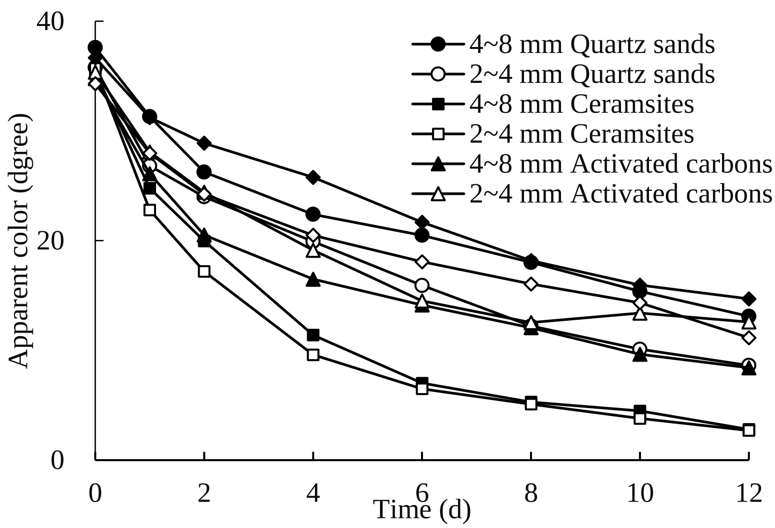
### 3.1.1 Turbidity and chromaticity removal

The turbidity of surface water is mainly caused by organic and inorganic particles, planktonic algae, etc., which could visualize the extent of water pollution. As can be seen from Fig. 1(a), the turbidity in each substrate column had a significant decrease with the treatment time growth. The removal rate of all substrates was higher in the first 6 d than last days, which trended to flat. Ceramsites, activated carbons, and 2~4 mm quartz sands showed better effects on the removal of turbidity, and the turbidity of the treated water can reach below 2 NTU. The removal of suspended solids by the substrate mainly owed to the interception and adsorption effects, as the activated carbons and ceramsites have large pore sizes and specific surface area, so the adsorption effect may be stronger, therefore the removal of suspended solids is more obvious. As for quartz sand, the specific surface area increases with the particle size decreases, which also has a better effect on pollutant retention.

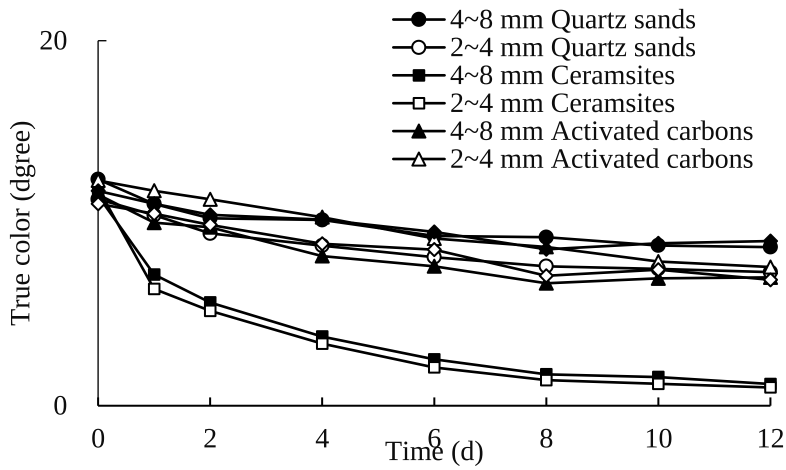
There are two kinds of chromaticity: apparent color and true color. The apparent color is the color of suspended matter, such as the presence of a large number of planktonic algae in the water can make the water show the corresponding color. The true color is the color of colloidal substances and dissolved substances, which can be measured by filtering the suspended matter. CDOM is widely found in natural water bodies, and it has complicated source and composition. It is mainly composed of humic acid, fulvic acid, amino acids and aromatic hydrocarbons, and other dissolved organic matter, which will make the true color of the water rise.




(a) turbidity




(b) apparent color




(c) true color

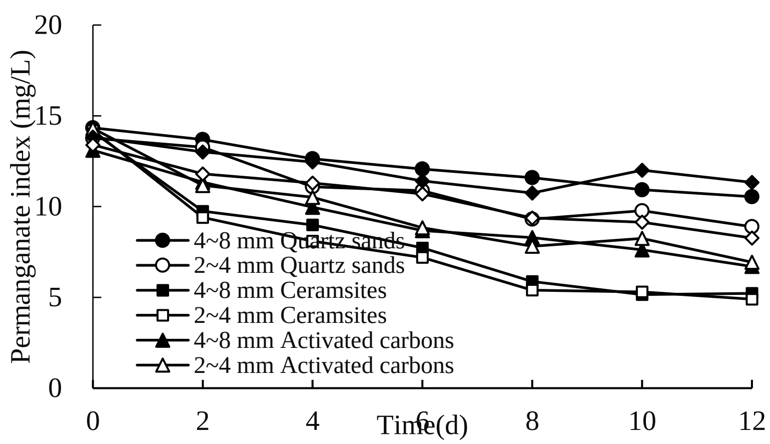
**Figure 1. Removal effect of turbidity and chromaticity under different substrates.**

As can be seen from Figure 1(b), the removal effect of ceramsites on the apparent color of the water body was significantly better than other substrates, and the apparent color of the ceramsites-treated water could reduce to less than 5 degrees at the 9d operation, and less than 2 degrees after 13 days. The cause of the apparent color includes both colored dissolved substances and non-dissolved substances, while the presence of non-dissolved substances affects the turbidity. From Figure 1(a), both ceramsites and activated carbons have good removal effects on turbidity and are not significantly different, hence the difference between the two kinds of substrates on the removal effect of surface color may be on account of the true color.

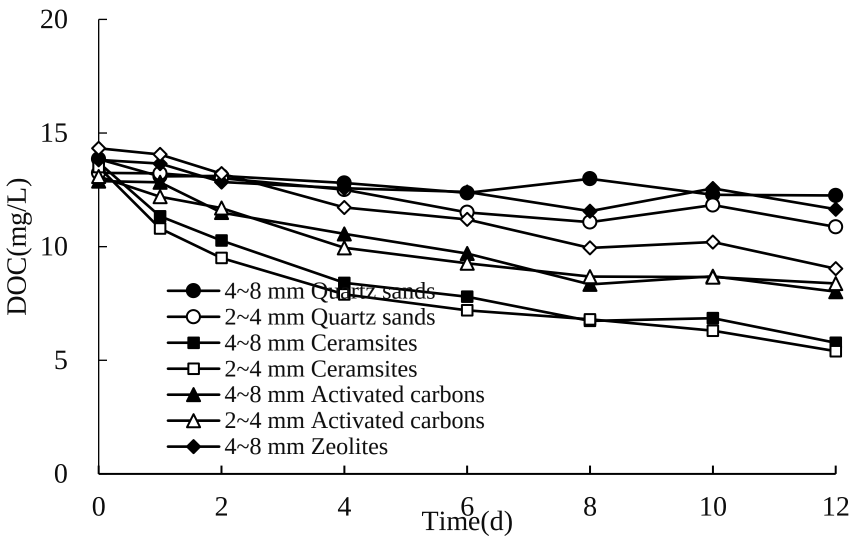
Figure 1(c) showed that ceramsites have a more obvious removal effect on the true color removal compared with zeolites, activated carbons, and quartz sands, and the effluent true color was 2 degrees or less. The treatment performance between the two ceramsites particle sizes of 2~4 mm and 4~8 mm on the removal of true color was not obvious. 2~4 mm quartz sand and zeolite on the true color removal was better than the particle size of 4~8 mm, while activated carbon showed the opposite trend.

### 3.1.2 Organic matter removal

The removal effect of organic matter by each substrate was compared by testing the permanganate index, DOC, $UV_{254}$, and $UV_{280}$ in our study. Figure 2(a) shows the variation of permanganate index in water after treatment with each substrate. It demonstrated that ceramsites have better performance than the other three substrates in the removal of permanganate index and it decreased to less than 5.5 mg/L after 12 d, which reached the Class III standards of the Environmental Quality Standards for Surface Water (GB3838-2002). The activated carbons reduced the permanganate index to less than 7 mg/L after 12 d treatment, and quartz sands and zeolites showed poor removal effects. There was little difference between the two particle sizes of ceramsites and activated carbons on the permanganate index removal, while zeolite and quartz sand were obviously better at the treatment effect of 2~4 mm particle sizes than 4~8 mm. Figure 2(a) revealed the removal effect of DOC using different substrates, and its change rule was consistent with the permanganate index.




(a) permanganate index




(b) DOC

**Figure 2. Removal effect of permanganate index and DOC under different substrates.**

$UV_{254}$ and $UV_{280}$ could characterize the level of the aromatization of organic matter in water, and the larger the value means the higher the degree of aromatization. $E_{250}/E_{365}$ indicated the molecular mass and degree of organic matter polymerization, and the larger $E_{250}/E_{365}$ showed the smaller molecular mass and degree of aromatization. Chromophore dissolved organic matter (CDOM) is an important part of the dissolved organic matter (DOM), which is a complex component that mainly includes protein-like (tryptophan-like and complexine-like, etc.) and humic substances (short-wave humic substances and long-wave humic substances). Table 2 showed that the $UV_{254}$ and $UV_{280}$ values as well as CDOM absorption coefficients of the ceramsites treated water were much lower, and the values of $E_{250}/E_{365}$ were clearly higher than other substrates. It could be seen that the degree of aromatization, organic matter conformation, molecular mass size, and degree of polymerization of the treated water was significantly reduced, and the colored dissolved organic matter was better removed.

**Table 2. Removal effect of organic matter-related indicators under different substrates**

| | True color (degree) | $UV_{254}$ | $UV_{280}$ | $E_{250}/E_{365}$ |
|---|---|---|---|---|
| Influent | 9.8 | 0.161 | 0.118 | 6.6 |
| 4~8 mm Quartz sands | 9.0 | 0.151 | 0.110 | 6.8 |
| 2~4 mm Quartz sands | 7.0 | 0.128 | 0.092 | 7.8 |
| 4~8 mm Ceramsites | 1.2 | 0.029 | 0.022 | 10.0 |
| 2~4 mm Ceramsites | 0.9 | 0.026 | 0.019 | 10.8 |
| 4~8 mm Activated carbons | 6.4 | 0.096 | 0.070 | 7.1 |
| 2~4 mm Activated carbons | 6.8 | 0.102 | 0.078 | 6.8 |
| 4~8 mm Zeolites | 9.1 | 0.151 | 0.111 | 6.2 |
| 2~4 mm Zeolites | 6.9 | 0.120 | 0.088 | 7.4 |

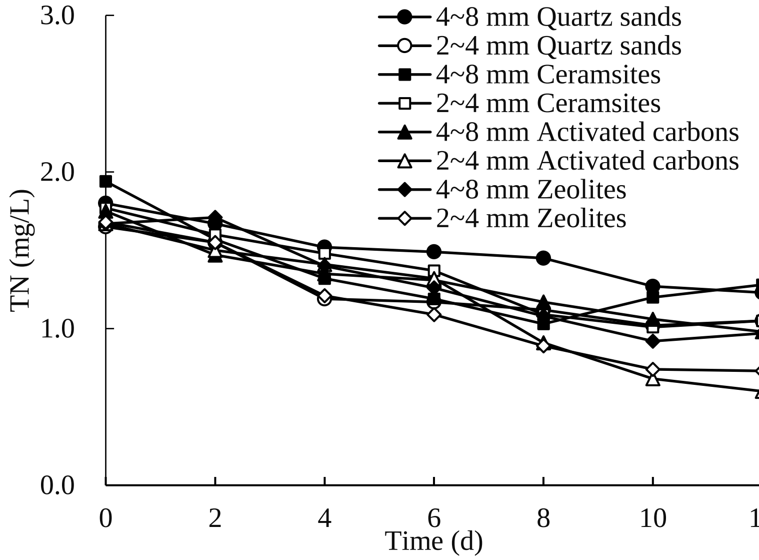
### 3.1.3 TN, TP, and planktonic algae removal

TN, TP, and planktonic algae are important indicators for evaluating the level of lake eutrophication, with the higher concentrations manifested serious eutrophication. The concentration of planktonic algae can be indirectly reflected by the concentration of planktonic algae chl-a, which is the main component of biologically suspended matter in the water, and its presence would increase the turbidity and surface color, consequently deteriorating sensory effects.

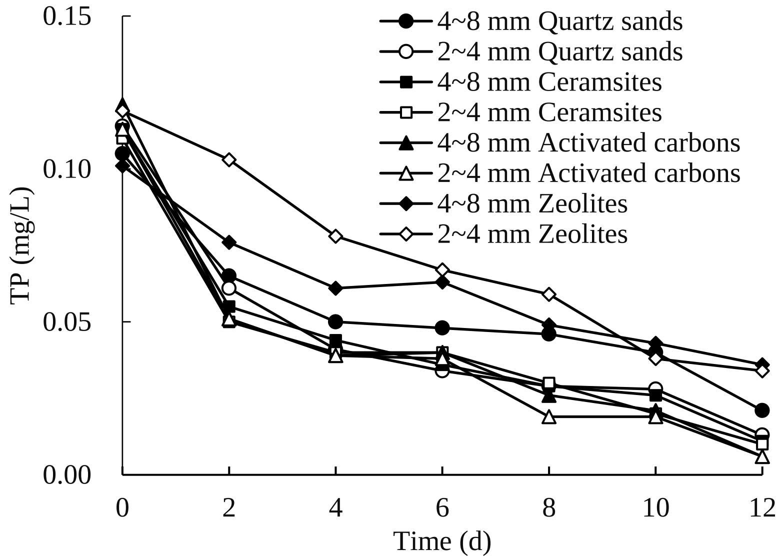
TN removal effect of each substrate was shown in Fig. 3(a). It demonstrated that 2~4 mm activated carbons have the best TN removal effect, followed by 2~4 mm and 4~8 mm zeolites. Activated carbons and zeolites have good adsorption properties, especially zeolites have a significant adsorption effect on ammonia nitrogen, so it showed a better removal effect on TN [10]. In terms of particle size, each substrate showed that small particle size had a better removal effect than large particle size, which was consistent with the findings of other studies [11]. Compared with other indicators, the TN removal efficiency was relatively low, and it was found that TN mainly existed in the dissolved state, which was more difficult to remove compared with the suspended state.

TP removal effects of each substrate on landscape closed water treatment were shown in Fig. 3(b). Activated carbons and ceramsites have the highest removal rate for TP, followed by quartz sand and zeolite, respectively. Phosphorus in water mainly exists in a suspended state and often attaches to particulate matter, therefore, the removal pattern of TP was highly related to turbidity, and TP could be removed by interception and adsorption.

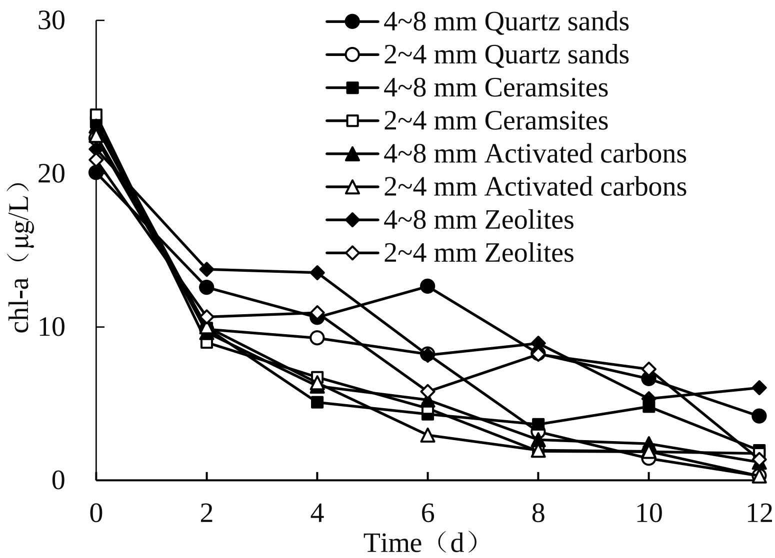
The removal effect on planktonic algal chl-a was shown in Fig. 3(c). The performance of two particle sizes of activated carbons and ceramsites on planktonic algal chl-a was better and more stable than quartz sands and zeolites. The concentration of planktonic algal chl-a reduced to less than 7 μg/L at the 4th d of operation; and acquired less than 2 μg/L at the 12th days. In addition, 2~4 mm quartz sands could also play the role of interception and effectively remove the planktonic algae in the water.




(a) TN




(b) TP




(c) Planktonic algae chl-a

**Figure 3. Removal effect of TN, TP, and Planktonic algae chl-a under different substrates.**

All in all, ceramsite showed a prominent removal effect on turbidity, color, organic matter, TP, and planktonic algae, especially for the chromaticity and CDOM. The removal rate of turbidity, surface color, and true color by using ceramsites could reach 93.8%, 94.6%, and 91.7% respectively; while the removal efficiency of permanganate index, TN, TP, and planktonic algae was 64.3%, 38.9%, 90.9%, and 92.4%, respectively. The effluent of ceramsites-treated water reached the water quality requirement of III class water of surface water. In addition, the degree of water aromatization and organic matter structuring, molecular mass size, and polymerization were also significantly reduced. Therefore, ceramsites were recommended as the substrate for the functional layer of the constructed wetland treating closed landscape wastewater.

## 4. Conclusion

The research led to the conclusion that ceramsites showed better purification ability for small landscape-confined water bodies compared with quartz sands, activated carbons, and zeolites. After 12 days of treatment, 4~8 mm ceramsites significantly improved the organoleptic effect of the water body. TN reached the class IV of the surface water, and TP and permanganate index satisfied the requirements of the class III of the surface water. In general, the most suitable constructed wetland substrate was 4~8 mm ceramsites in our study.

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