Abstract

In the field conditions, the studies about subsurface horizontal flow constructed wetlands (SHFCWs) treating micro-polluted river were carried out to learn the purification efficiency and influences of temperature. Changes of pH, DO and ORP were studied, and analyses for removal efficiency of pollutants affected by temperature were presented. DO and pH varied from influent to effluent. Removal rates of \( \text{NH}_4^+ \)-N (ammonia), TN-N (total nitrogen) and COD (chemical oxygen demand) were increased with the raising temperature, which could be reached to 90%, 50% and 20%. Removal rates of TP-P (total phosphorus) varied from 30% to 60% in planted wetlands. Test results showed removal rates of \( \text{NH}_4^+ \)-N and TN-N were strongly correlated with temperature. Due to low concentration of influent, the correlation between COD and temperature was poor. Because PP-P (particulate phosphorus) was the main form in phosphorus removal, there was almost no relationship between TP-P and temperature.

Keywords: Temperature; Removal rates; Constructed wetland; Horizontal flow; Micro-polluted river

1. Introduction

The first attempt to use the wetland vegetation to remove various pollutants from water was conducted by K. Seidel [1] in Germany in early 1950s, and some successes have been obtained. Because constructed wetland (CW) is a kind of water treatment with lower cost, lower energy, lower technical-demanding, it has being widely used to treat wastewater. Currently a wide range of wastewater from domestic [2] and
industrial [3], including agricultural origin [4], but also landfill leachate [5] is treated in constructed wetland systems. In recent years, the constructed wetlands have been introduced as a cost-efficient alternative to conventional technologies for treatment of surface and groundwater polluted with organic chemicals [6].

In recent years, the majority of studies available about different CWs are related to the studies of nutrient flow, accumulation and transformations for entire systems mostly dealing with wastewater purification efficiency and its relationships with the constructional and operational parameters of wetlands [7]. However, these studies were largely carried out in the laboratory to treat sewage. In the field environment, there were few reports about study of micro-polluted river treated by CWs in small towns. In order to study the removal effect of organic matter, nitrogen and phosphorus in micro-polluted river, several subsurface flow constructed wetlands were built beside Lu shan River in Gaofeng Town, Chongqing (30°42’16”N, 108°19’33”E) with the warm-temperature monsoonal climate.

2. Materials and Methods

2.1. Description of the subsurface flow constructed wetland system

The subsurface constructed wetland systems with hydraulic characteristics of a horizontal flow were built near Lusan River in Gaofeng Town, Chongqing (30°42’16”N, 108°19’33”E) with the warm-temperature monsoonal climate. The climate was characterized by annual precipitation of 1243 mm, average temperature of 17.7°C. The dimension of each system was 3m×1.0 m×1.0m (L×B×H, the effective height is 0.9m; the superelevation is 0.1m) and the base slope was 2%. The bottom and around of wetlands were built with brick and plastered with concrete. There were three parts of every unit, which were catchment, treatment and effluent, respectively. The treatment part is filled orderly with bigger gravels (diameter between 40 and 60mm, height 200mm, local), bricks (diameter between 20 and 40mm, height 300mm, local), smaller gravels (diameter between 10 and 20mm, local) and local soils (height 10mm). The dimension of catchment part is 1.0m×0.5m (L×B), the effluent part is 1.0m×0.5m (L×B). The perforation tracery wall separated the catchment and treatment part to avoid short flow processing zone. The perforation tracery wall separates the treatment and effluent part to distribute water uniformity. Schematic diagram of SHFCW was showed in Fig. 1.

![Fig. 1. Schematic diagram of SHFCW](image)

Combined with local actual condition and landscape, the study adopted the perennial aquatic or wet plants which were easily cultivation with developed root, great root biomass, and suitable growth in
Chongqing. In addition, considering the object treated by CWs is micro-polluted water of western town in China, edible vegetables were used. The SHFCWs in the experiment were showed in Table 1.

Table 1. SHFCWs in the experiment

<table>
<thead>
<tr>
<th>SHFCWs</th>
<th>Aquatic plants</th>
<th>Planting Time</th>
<th>Plants density (plants/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WL1</td>
<td><em>Arundo donax</em></td>
<td>2008.07</td>
<td>10–15</td>
</tr>
<tr>
<td>WL2</td>
<td><em>Canna indica</em></td>
<td>2008.07</td>
<td>10–15</td>
</tr>
<tr>
<td>WL3</td>
<td><em>Acorus calamus</em></td>
<td>2008.07</td>
<td>10–15</td>
</tr>
<tr>
<td>WL4</td>
<td><em>Ipomoea aquatica</em></td>
<td>2008.07</td>
<td>10–15</td>
</tr>
<tr>
<td>WL5</td>
<td>Blank</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2. Quality of purified water

Lushan River originated from Puan Reservoir, and eventually inflow into Gaofeng Reservoir, which spanned nearly 10 kilometers. According to the survey, the main pollution sources are domestic wastewater and non-point source pollution of agricultural. Quality of Lushan river was shown in Table 2.

Table 2. Water quality of experimental inflow

<table>
<thead>
<tr>
<th>Index</th>
<th>NH₄⁺-N (mg/L)</th>
<th>TN-N (mg/L)</th>
<th>TP-P (mg/L)</th>
<th>COD (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm season</td>
<td>0.13~0.61</td>
<td>0.59~1.87</td>
<td>0.09~0.29</td>
<td>3.80~5.17</td>
</tr>
<tr>
<td>Cold season</td>
<td>0.20~0.47</td>
<td>1.13~1.58</td>
<td>0.07~0.12</td>
<td>3.60~5.04</td>
</tr>
<tr>
<td>III standard of EQSSW</td>
<td>1.0</td>
<td>1.0</td>
<td>0.2</td>
<td>6</td>
</tr>
</tbody>
</table>

It could be seen from Table 2 that NH₄⁺-N and COD in warm season achieved the requirement of III standard of “Environmental Quality Standards for Surface Water, P. R. China” (GB3838-2002) (EQSSW). The average concentration of TN-N and TP-P in influent exceed the III standard of EQSSW. NH₄⁺-N and COD in cold season were lower than those in the warm season.

2.3. Operation Methods

The SHFCWs were built in March 2008. After completion of CWs, they were operated continuously by inlet valve from Lushan river, and then experienced start-up and stable operational phase. From July 2008 to September 2008, the system experienced a series of processes of a steady growth of plants and micro-organisms, and then the stable operation was started. As warm season operation, the hydraulic retention time was set between 0.5d and 2.0d from September to November, 2008. As cold season operation, the hydraulic retention time was set between 2d and 4d from January to March, 2009. Water quality of influent water during experiment was referred as Table 2. The physicochemical water parameters, such as water temperature, pH, and DO, were measured in situ. All the parameters mentioned above were determined by using the method and following the procedures described in the Standard Method for Examination of Water and Wastewater [8].
3. Results and Discussion

3.1. Variation of DO and pH in SHFCWs

Fig. 2(a) showed the changes of DO in influent and effluent. Compared DO of influent varied from 4.00 to 12.00 mg/L, DO of effluent changed a little, which was slightly higher due to the plants. The results supplied that plants provided oxygen for CWs. In addition, the root oxygen could be released, which promoted the reoxygenation of SHFCWs.

The variation of pH of influent and effluent in CWs could be illustrated in Fig. 2(b). The results showed that pH in effluent was higher than influent, except WL2 and WL4. A possible explanation for the relatively high pH in WL5 was the combination filler including gravel, waste brick and pebble released alkaline substances to water, resulting in the highest pH of effluent. Due to the preferences of the acidic environment, the roots of Canna indica and Ipomoea aquatica secreted a large number of acidic substances, which promoted pH decrease [9]. On the other hand, acidic substances were accelerated to secrete, with the decay of falling leaves.

3.2. Influence of temperature and species of aquatic plants

It could be seen from Fig. 3(a) that daily average air and water temperature changed from November, 2008 to February, 2009, where the hydraulic retention time was 2d. Fig. 3(b-e) showed the changes of removal rates among NH₄⁺-N, TN-N, TP-P and COD. As the harvest of Acorus calamus and Ipomoea aquatica in winter, there was only warm-season data in WL3 and WL4.
Fig. 3. (a) daily average temperature; (b) removal rates of NH$_4^+$-N in different SHFCWs; (c) removal rates of TN-N in different SHFCWs; (d) removal rates of TP-P in different SHFCWs; (e) removal rates of COD in different SHFCWs

From Fig. 3, there was a closely correlation between temperature and NH$_4^+$-N, also to TN-N and COD. With the increase of temperature, the number of microorganisms was increased rapidly in the CWs increased. Correspondingly, the removal rates of NH$_4^+$-N, TN-N and COD were decreased, and the maximum removal rate were above 90%, 50% and 20%, respectively. With temperature dropping, the activity and reproduction of microorganisms was limited, also to the growth of plants and the supply of oxygen to the systems. The removal rates of NH$_4^+$-N and TN-N were generally lower in cold season, which was 60% and 20% respectively. Although the removal rate of COD in cold season had also been reduced, the amplitude of variation was little.

It could be concluded from Fig. 3 that the removal rates of TP-P in planted wetlands were inconsistent with the variation of temperature, but then the removal rate of TP-P in blank wetland was consistent with temperature. Removal rate of TP-P relied on interception and adsorption by filler in blank wetland. Although there was obviously positive correlation between phosphorus adsorption and temperature [10], plants absorb and withered in planted wetland affected the removal of TP-P.

3.3. Correlation analysis between temperature and the effects of purification

In order to find the impact of temperature on the pollutants removal, take WL2 as an example to analysis the correlation between temperature and removal rate, using linear regression method. The results showed there were linear relationships between temperature and the removal rates of NH$_4^+$-N, TN-N, respectively. The correlation coefficient ($R^2$) were bigger than 0.5, and moreover, the $R^2$ of TN-N was nearly 0.8. It implied that temperature greatly affected the removal of NH$_4^+$-N and TN-N in WL2. In addition, the influence of temperature on TN-N removal was greater than NH$_4^+$-N. According to other literatures, the removal of nitrogen in wetlands depended on nitrification and denitrification of micro-organism, the absorption of foliages and filler, and the volatilization of NH$_4^+$-N, where micro-organisms played a dominant role [11]. On one hand, temperature affected the absorption of inorganic nitrogen by plants [12]. On the other hand, it impacted the removal of nitrogen by doing influences to the metabolic activity of nitrobacteria and denitrobacteria. It was similarly to the treatment of sewage and other wastewater treatment by CWs.

The $R^2$ between COD and temperature is poor. Proper temperature was conducive to enhancing the activity of heterotrophic microbe. But in our experiment, the organic contamination in the raw water was more hardly to be removed due to the lower concentration. According to the results, there was basically uncorrelated relationship between removal TP-P and temperature, because the removal of phosphorus in micro-polluted water mainly was focused on PP-P, intercepted by filler, which was not DTP-P (dissolved phosphorus). So, temperature was not an important role on the removal of phosphorus in SHFCWs.
4. Conclusions

DO from the raw water was high enough to meet the need of degradation of pollutants. Plants did contributions to provide DO in the CWs. Acid material secreted by roots of aquatic plants and alkaline substance released by filler affected pH of CWs.

With the increase of temperature, the removal rates of NH$_4^+$-N, TN-N and COD were increased rapidly. Test results also showed the removal of NH$_4^+$-N and TN-N were strongly correlated with temperature. The correlation between removal rate of COD and temperature was poor. The removal rate of TP-P almost had no relationship with temperature.

Aquatic plants significantly affected the removal of NH$_4^+$-N, TN-N and COD in SHFCWs. The species of plants played important parts. PP-P is the main form in all sorts of removal phosphorus.

Acknowledgements

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References