Heat Preservation of Subsurface Flow Constructed Wetland in Cold Area in Winter and Its Operation Effect

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Abstract

To solve the heat straying problem of constructed wetland in north China, a series of measures was adopted in an engineering application case. The operation results showed that, after using the heat preservation measures, vertical current constructed wetland in the north went through the winter safely, and the gas exchanged with the air by water into and out efficiently, remitting oxygen inadequacy in the bed, greatly improving the pollution removal. In terms of the effect, the removal efficiency in winter was similar to that in summer, with little variation. The average removal rates of COD, NH4+-N and TP were 90.85%, 98.38% and 89.68% respectively, and the quality of effluent achieved the national emission standard.

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Keywords: cold area; vertical current constructed wetland; heat preservation

Introduction

Winter heat preservation effect of constructed wetland affects the treatment effect of wetland system severely in north cold areas, therefore, winter heat preservation of constructed wetland in cold area is one of the important factors that restricts applying constructed wetland to cold area widely[1-3]. Hunnan constructed wetland demonstration project in Shenyang, at the east of Huiyuan Xincun housing estate on Hunnan Road, with an area of 41,000m², made up with waste water subsurface (vertical current) flow constructed wetland and rainwater surface flow wetland, mainly treating sewage water and rainwater of Huiyuan Xincun housing estate. The project was completed on October 15, 2004. The summer system was put into operation on September 15, 2004 and the winter system started to operate on November 8, 2004. The treatment effect has been very stable for several years and provides valuable experience for the application of constructed wetland wastewater treatment system in North China.

General Situation of the Project

Hunnan constructed wetland system in Shenyang contained pretreatment and wetland system.
Pretreatment system contained horizontal flow sedimentation tank, auto rewash filter. Wetland system contained subsurface flow constructed wetland and surface constructed wetland, waste water subsurface flow wetland was about 6500m² and rainwater surface flow wetland was 34000m². Subsurface flow constructed wetland was vertical current, composed of three nearly similar parallel beds, in which reed were planted, treating 1000t sewage water of Huiyuan Xincun housing estate per day. Surface flow constructed wetland was composed of pre-sediment pool (for initial rainwater) and wetland treatment tank, in which aquatic plants such as cattail, lotuses were planted. This paper mainly aimed to introduce the subsurface flow constructed wetland.

**Designed Parameters.** Designed quantity of sewage water was 1000t/d, designed remain time of subsurface flow constructed wetland was 3d, designed remain time of surface flow constructed wetland was 5d, hydraulic load of subsurface flow constructed wetland was 0.154m³/m²·d. Table 1 summarizes the water quality of inflow and outflow.

| Item                              | COD [mg·L⁻¹] | BOD₅ [mg·L⁻¹] | SS [mg·L⁻¹] |
|-----------------------------------|--------------|---------------|-------------|
| Inflow                            | ≤300         | ≤150          | ≤100        |
| Outflow subsurface flow wetland   | ≤120         | ≤30           | ≤30         |
| Outflow surface flow wetland      | ≤50          | ≤10           | ≤20         |

**Internal Structures of Vertical Current Constructed Wetland.** Vertical current constructed wetland was composed of three paralleling beds, total length was 116m, total width was 56m, and total area was about 6500m². There were uniformity gravel of about 0.30m diameter on the bottom layer of 0.50m depth. Thick sand and thin sand was set upward successively and diameter varied from 20mm to 10mm gradually. The average depth of sand was about 1m. In order to keep warm in winter, an air layer of about 0.15m was set above the sand layer, and a turfy soil of about 0.20m was set above the air layer. There was impermeable membrane at the bottom, preventing waste water leaking into the underground.

**Water Distribution Way of Vertical Current Constructed Wetland.** Considering that Shenyang is in the north cold area and the temperature is lower in winter, so Hunnan constructed wetland demonstration project adopted two water distribution pipelines. The water distribution pipeline lay on the surface of sand layer of bed in summer, and the water distribution pipeline lay 300mm under sand layer. Winter water distribution system would be start up when the air temperature was less or equal to 5 degree Celsius. Summer water distribution pipeline was PVC materials, and winter water distribution pipeline used US GEWFLOW trickle irrigation pipeline that was artificial composite materials. This material would not form bio-membrane, so that the problem of bed blocking caused by plant root system growing was solved.

**Heat Preservations Measure and Heat Preservation Effect**

Heat preservation measures of constructed wetland in the north usually were the way that covered with ice, snow or air layer. But the above measures were restricted by climate conditions greatly, and the effect of heat preservation measures was not stable. Therefore, we must use suitable covering materials, and the ideal covering materials must content characteristics as follows: analyzable, and not causing the second organic load to the system; nutrition constituent balance; high fiber to provide good heat preservations; ensuring seeds’ exothecium contacting well with covering matter to make seeds germination; good capacity of keep moisture to prevent seeds suffering drought. Nonideal covering materials would be bad for plants growth. Covering materials such as tree fragments with high carbon nitrogen ratio would cause lacking nitrogen during plant growth period, and covering materials fragments too close would cause plant root seeping water difficulty. In addition, nonideal covering materials would decrease the treatment
effect. According to above characteristics, the heat preservation measures of Hunnan constructed wetland demonstration project chose comprehensive heat preservation measures with reed fragments which was carbonized, heat preservation material of Hunnan constructed wetland was reed fragments which was carbonized (turfy soil), and the thickness of heat preservation layer was 0.20m. Fig.1 shows the monitored result of bed’s temperatures in different depth from December 20, 2004 to January 15, 2005, where superficial layer was 0.2m depth of bed, middle layer was 0.4m depth of bed, and deep layer was 0.8m depth of bed.

Fig.1 Temperature distribution curves of bed from December 20, 2004 to January 15, 2005

Fig.1 shows bed’s temperatures in different depth had little difference, when air temperature ranged from -17 to -26 degree Celsius, and inflow temperature ranged from 11 to 14 degree Celsius, in the subsurface flow wetland with turfy soil to keep warm. The curve of mid-deep layer and superficial layer has a certain wave but not greatly, all the temperature is above 7 degree Celsius and the highest one is 12 degree Celsius. For heat of bed mainly came from inflow and ground supply in winter, compared with superficial layer temperature, deep layer temperature was more stable, and it maintained more than 11 degree Celsius and the highest one was 13 degree Celsius. The temperature curve illustrated that the whole bed had good breath ability and gases exchange keeps balance, which provided basic security to pollution degrading and water temperature.

In addition, from the view of outflow temperature of constructed wetland, heat preservation effect could be observed. Fig.2 shows monitored result of inflow and outflow temperatures of wetland bed from December 20, 2004 to January 15, 2005.

Fig.2 Temperature curves of inflow and outflow from December 20, 2004 to January 15, 2005

Fig.2 shows the highest air temperature chose from 2004 to 2005 was -17 degree Celsius and the
lowest one was -26 degree Celsius. Temperature of inflow was in different variation, and drain of swimming pool in the biotope club caused temperatures increasing suddenly, which resulted in a stand out point of the curve. Temperatures of outflow maintained more than 9 degree Celsius and very stable. The temperature curve illustrates that biology reaction in the bed was still in progress (temperature of biology reaction was around 5 degree Celsius), biochemical effect was obvious, and bed operated steadily.

**Analysis of biota in the vertical current wetland**

Biota in the wetland related to climate condition, plant growth and heat preservation. Table 2 to 5 is the bacterial community distribution in the vertical current constructed wetland in April (reed in the wetland bed just sprouted), July, August (plants grew exuberantly) and early December (temperature was lower after plants are harvested) in 2005, respectively.

**Table 2** Bacterial community distribution in the vertical current constructed wetland in April, 2005

| Sampling point       | Total bacterial count [n/g] | Fungus [n/g] | Actinomycetes [n/g] | Nitrobacteria [n/g] | Denitrifying bacteria [n/g] |
|----------------------|----------------------------|--------------|---------------------|--------------------|-----------------------------|
| Rhizosphere 5-30cm   | 7×10^7                     | 3.8×10^5     | 3.2×10^5            | 4.5×10^5           | 2.0×10^5                    |
| Rhizosphere 30-50cm  | 4×10^8                     | 8.4×10^5     | 7.5×10^5            | 3.0×10^5           | 1.4×10^6                    |
| Rhizosphere in sand layer 50-100cm | 6.9×10^4 | 8.6×10^5 | 5.5×10^5 | 1.7×10^5 | 2.95×10^7 |

(12.5 degree Celsius)

Reed just sprouted in April, biology in the bed was not abundant and bacterial community accumulated around plant root system, so this monitor mainly aimed at the environment of reed root system.

Table 2 shows that total bacterial count at the top of reed rhizosphere was bigger than that at the bottom, and it dropped off gradually with the increase of bed depth. Fungus and nitrobacteria dropped off gradually with the increase of bed depth, but denitrifying bacteria increased gradually.

**Table 3** Bacterial community distribution in the subsurface wetland in July, 2005

| Sampling point       | Total bacterial count [n/g] | Fungus [n/g] | Actinomycetes [n/g] | Nitrobacteria [n/g] | Denitrifying bacteria [n/g] |
|----------------------|----------------------------|--------------|---------------------|--------------------|-----------------------------|
| Rhizosphere 5-30cm   | 5.0×10^6                   | 1.3×10^6     | 1.3×10^6            | 1.3×10^6           | 1.3×10^6                    |
| Non-rhizosphere 5-30cm | 1.9×10^6                 | 3.1×10^6     | 3.6×10^6            | 4.5×10^6           | 1.1×10^6                    |
| Rhizosphere 30-50cm  | 1.2×10^8                   | 1.3×10^8     | 8.0×10^8            | 1.3×10^8           | 5.7×10^8                    |
| Non-rhizosphere 30-50cm | 1.8×10^6                 | 7.2×10^6     | 3.2×10^6            | 4.5×10^6           | 3.0×10^6                    |
| Rhizosphere in sand layer 50-100cm | 8.6×10^6 | 2.2×10^6 | 1.3×10^6 | 1.7×10^6 | 2.95×10^6 |
| Non-rhizosphere in sand layer 50-100cm | 2.2×10^4 | 8.1×10^4 | 2×10^2 | 0.9×10^2 | 1.1×10^6 |

(17.6 degree Celsius)

Plants accessed into grow exuberantly stage in July. Table 3 shows that even bacterial community numbers had little variation around the rhizosphere in superficial layer, but it was easy to see that large numbers of bacterium developed in the non-rhizosphere. Total bacterial count in the bed in the reed rhizosphere increased with the increase of depth, which illustrated that reed root system went deep into the beds, the number of bacterium in the non-rhizosphere was less than that in the rhizosphere in the same depth, increasing with the increase of depth. In sand layer, the number of bacterium in reed root system
was less than that in non-sand layer, and the number of bacterium in non-rhizosphere was less than that in rhizosphere. The variation rule of fungus, actinomycetes and nitrobacteria was the same as total bacterial count basically. In addition, it could be observed that denitrifying bacteria had little variation with the increase of bed depth, which illustrated that the environment of reed root system was nearly similar from up to down, but the number of denitrifying bacteria increased with the increase of bed depth in non-rhizosphere.

Compared with April and July, the total bacterial count, fungus in August in the whole bed increased greatly, which illustrated that reed grew fast and reached exuberance stage, microorganism acts frequently. The bacterium distribution rule in the bed was little variation.

**Table 4** Bacterium distribution in the subsurface wetland in August, 2005

| Sampling point                      | Total bacterial count[n/g] | Fungus [n/g] | Actinomycetes [n/g] | Nitrobacteria [n/g] | Denitrifying bacteria[n/g] |
|------------------------------------|-----------------------------|--------------|---------------------|---------------------|---------------------------|
| Rhizosphere 5-30 cm                | 1.88×10^8                   | 4.2×10^7     | 1.1×10^6            | 1.11×10^7           | 3.2×10^2                  |
| Non-rhizosphere 5-30 cm            | 9.71×10^5                   | 1.16×10^6    | 1.0×10^5            | 2.95×10^4           | 4.5×10^3                  |
| Rhizosphere 30-50 cm               | 1.28×10^5                   | 1.3×10^7     | 1.4×10^4            | 1.35×10^4           | 9.5×10^3                  |
| Non-rhizosphere 30-50 cm           | 2.91×10^4                   | 3.5×10^5     | 2.5×10^4            | 2.75×10^4           | 9.5×10^3                  |
| Rhizosphere in sand layer 50-100cm | 3.0×10^4                    | 1.0×10^7     | 2.8×10^4            | 1.2×10^7            | 9.5×10^3                  |
| Non-rhizosphere in sand layer 50-100cm | 6.5×10^5               | 2.6×10^5     | 2×10^4              | 4.5×10^5            | 4.5×10^4                  |

(28 degree Celsius)

Table 4 shows that total bacterial count, fungus and actinomycetes in the bed of 50-100cm depth increased in different degrees, but only denitrifying bacteria distribution rule was more obvious that increased with the increase of bed depth, and order of magnitude increased progressively. It could be observed that the number of denitrifying bacteria in August was less than that in April and July, which illustrated that reed propagated massively and too much oxygen was produced by photosynthesis, therefore the growth of denitrifying bacteria was confined significantly.

**Table 5** Bacterial community distribution in the subsurface wetland in December, 2005

| Sampling point                      | Total bacterial count[n/g] | Fungus [n/g] | Actinomycetes [n/g] | Nitrobacteria [n/g] | Denitrifying bacteria[n/g] |
|------------------------------------|-----------------------------|--------------|---------------------|---------------------|---------------------------|
| Rhizosphere 5-30 cm                | 1.4×10^5                    | 7.4×10^7     | 3.5×10^7            | 1.4×10^7            | 7.5×10^7                  |
| Non-rhizosphere 5-30 cm            | 3.3×10^4                    | 9.4×10^9     | 4.0×10^5            | 2.5×10^4            | 3.5×10^4                  |
| Rhizosphere 30-50 cm               | 1.3×10^5                    | 4.8×10^9     | 2.5×10^2            | 1.1×10^4            | 2.0×10^4                  |
| Non-rhizosphere 30-50 cm           | 2.4×10^4                    | 5.8×10^9     | 3.0×10^2            | 9.5×10^3            | 9.5×10^4                  |
| Rhizosphere in sand layer 50-100cm | 1.0×10^4                    | 3.7×10^9     | 0.5×10^2            | 7.5×10^3            | 4.5×10^4                  |
| Non-rhizosphere in sand layer 50-100cm | 4.0×10^4               | 3.9×10^9     | 1.0×10^3            | 4.5×10^5            | 1.5×10^5                  |

(8 degree Celsius)

Table 5 shows that bacterial community of reed system decreased with the plant harvest, and the variation almost didn’t vary, denitrifying bacteria increases slightly, and the cause by analyses was that root system oxygen release ability weakened after plant harvest. In addition, it could be observed that although air temperature was low in winter, a large number of bacterium still distributed in the depth of more than 30cm in the bed, which illustrated that the heat preservation measures of the bed were appropriate and the temperature in the bed was suitable, and still much microorganism acted, and these contributed to purified water quality.
Observed from the bacterium distribution in April, July, August and December, there were much bacterium activity, it showed that the number of fungus bacterium was less than that of fungus and more than that of actinomycetes in the subsurface constructed wetland by the monitored result. The discrepancy between rhizosphere and non-rhizosphere was prominent, and the root system effect obvious, comply with the "root zone method". All kinds of microbe quantity decreased obviously with the increase of bed depth. During the exuberant stage, microorganism varied greatly in a month, and most of them increased by an order of magnitude. In addition, it could be observed that nitrobacteria quantity in the bed was much more and denitrifying bacteria quantity was much less, depended on total nitrogen degradation rate.

**Treatment effect**

Fig.3 shows monitored results of each pollutant.

![Average removal efficiency of each pollutant in vertical current wetland from February to December](image)

Fig.3 shows that Hunnan constructed wetland had a good removal efficiency to the waste water of housing estates, and the treatment effect of these pollutant was very good. The average removal rate of COD was 90.85%, the maximum was 97.65% and the minimum was 86.94%; The average removal rate of TP was 89.68%, the maximum was 94.25% and the minimum was 82.53%; The average removal rate of $\text{NH}_4^+$-N was 98.38%, the maximum was 99.37% and the minimum was 97.27%. It was worth indicating that the removal efficiency of the wetland system to each pollutant was nearly not affected, even the external environment temperature achieved -26 degree Celsius in February, 2005. It illustrated that heat preservation measures were appropriate and heat preservation effect was good, so it provided valuable experience in applying constructed wetland to the north.

**Conclusions**

1. Vertical current constructed wetland with some heat preservation measures can run normally in North China, with good effluent water quality. The average removal rates of COD, $\text{NH}_4^+$-N and TP reached 92.36%, 97.97% and 89.81% separately, and the water quality of the effluent met the requirement of national emission standard.

2. Rational construction of the bed and effective heat preservation measures are the pivotal keys to ensure subsurface constructed wetland operated steadily in cold area. An air layer of about 0.15m was set above the sand layer, and a turfy soil of about 0.20m was set above the air layer to provide oxygen to the bed by water exchanges, ensure the gas in the bed balanced, and ensure the basic energy balance of operation in winter.

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