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Original Research Paper

The Treatment of Decentralized Domestic Sewage in a Rural Area With a Vermibiofilter in Different Seasons

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ABSTRACT

Aquatic plants were introduced in a Vermibiofilter (VBF) to form the artificial complex ecosystem constituted by plants, earthworms and microorganisms in the research. In addition to applying the pebbles, broken stones, coarse sand, fine sands and soil as the filter materials, *Oenanthe javanica* was utilized. With a hydraulic loading of 0.5 $m^3/(m^2.d)$ and the density of earthworms being 12 $g.L^{-1}$ in the soil, the treatment of the decentralized domestic sewage in a rural area using the VBF in different seasons was studied under the condition of intermittent water inflow. As demonstrated in the research results, the VBF shown the optimal treatment effect in the summer. The maximum removal rates of the VBF to COD_{Mn}, TN, NH_4^+-N and TP were 93.88%, 83.92%, 98.11% and 94.14% respectively. The contents of COD_{Mn}, TN and NH_4^+-N in the effluent water all reached the first level A criteria specified in the *Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant* (GB 18918-2002) in China.

INTRODUCTION

With the rapid economic development and the increasingly improved living standard in rural areas, the discharge of the domestic sewage in rural areas has been increased continually. However, the investigation regarding the 'Current Situation and Problems of Human Settlements in Villages' carried out by the Ministry of Construction in China demonstrated that 96% of villages do not possess the drainage channel and sewage treatment system (MOHURD 2010). Meanwhile, production and domestic sewage are discharged everywhere. In addition, the domestic sewage in rural areas contains large amounts of nitrogen, phosphorus and organic matters, and is difficult to be collected due to the widely distributed discharge points. Moreover, considerable amounts of pathogenic bacteria are contained in excrements (Ai et al. 2008, Liang et al. 2009). Owing to all these factors, the domestic sewage in rural areas has become one of the pollution sources in the rural areas of China (Tan et al. 2011).

In recent years, VBFs have attached much attention as a sewage treatment technology characterized by low investment and operation cost, as well as convenient management. A VBF is a complex artificial strengthened ecosystem comprised of earthworms, microorganisms and fillers, and has been studied in terms of the process improvement and the removal mechanism of pollutants. However, no research regarding the selection of plants has been studied so far. The plants endowed with a great root system, low temperature tolerance and ornamentals are usually selected according to the project experience and the investigation of the plants grown in constructed wetlands. Under such circumstance, this research proposed to investigate the water quantity, discharge characteristics and influencing factors of the decentralized domestic sewage in rural areas and introduce aquatic plants to VBF technology. Meanwhile, the purification effect of the complex plant-earthworm-microorganism system on the decentralized domestic sewage in rural areas was studied so as to explore the influence of the temperature and season on the growth of plants and earthworms. Finally, the optimal operation condition of VBF sewage treatment technology was obtained.

MATERIALS AND METHODS

Experimental water: The testing field is located in the farm of the Yaan campus of Sichuan Agricultural University, Yaan, China. The influent water was taken from the sewage treatment plant in the campus. The sewage mainly came from the excrements of the livestocks including cattle, sheep and pigs, as well as the domestic sewage produced by the students and staff at the farm. The water quality during the experiment is given in Table 1.

Test devices: The experimental system was constituted by the VBF system and a simple greenhouse. Thereinto, the VBF system was composed of a water tank, a peristaltic pump, rotationally sprayed water distribution pipes and a VBF filter (Fig. 1), while the size of the simple greenhouse was 4.0 m×2.0 m×1.8 m. The VBF filter was a circular plastic bucket

Table 1: Influent quality (unit: mg/L).

Season	COD_{Mn}	TN	NH4+-N	TP
Winter	98.62-128.75	12.16-28.67	3.27-19.36	2.13-4.56
Spring	156.63-275.96	18.82-36.69	23.66-38.93	4.23-6.61
Summer	294.36-428.94	32.42-48.74	14.46-48.22	5.75-6.92

Table 3: Effluent quality (unit: mg/L).

Season	COD_{Mn}	TN	NH_4^+-N	TP
Winter	6.95-37.51	4.72-9.46	0.41-4.85	0.66-1.35
Spring	19.83-49.10	5.97-10.93	1.42-5.05	0.32-1.48
Summer	26.01-38.37	9.75-10.36	1.75-4.87	0.47-1.26
Discharge standard	50	15	5	1.5(B)

Table 2: The growth of plant (unit: cm).

Planting time		Winter		Spring		Summer	
Plant height	Stem diameter	Plant height	Stem diameter	Plant height	Stem diameter	Plant height	Stem diameter
8.96	0.40	9.27	0.42	12.64	0.51	14.55	0.56

made from polyethylene, with the diameter and height being 20 cm and 40 cm respectively. The matrices were filled for 35 cm high, and comprised of pebbles, broken stones, coarse sands, fine sands and soil from bottom to up with the thickness being 5 cm, 5 cm, 5 cm, 5 cm and 10 cm respectively. Thereinto, the particle sizes of the pebbles, broken stones and coarse sands were in the range of 20~60 mm, 5~15 mm and 2~3 mm respectively, while that of the fine sands was no more than 1 mm. These filter materials were separated with each other using petates of 1 cm thick, as shown in Fig. 2. Earthworms and plants were placed in the soil layer, where the density of earthworms was 12 g/L. *Oenanthe javanica*, which is grown locally and endowed with high survival rate and great biomass, and capable of growing at low temperature was applied as the experimental plant. Five plants of *Oenanthe javanica* were planted in each device at intervals of 10 cm. The experiment was started in early November, 2014. After the VBF system was operated for one month, the earthworms and the experimental plants presented a stable growth and all the indexes regarding the effluent quality were stable. Therefore, the effluent has been sampled to analyse daily since then.

According to the characteristics of earthworms and the filter materials, an alternate operation of flooding and drainage was adopted. Meanwhile, intermittent water inflow was adopted in the experiment: water was poured in every 6 hours, and kept inflowing for 12 hours every day. In addition, *Oenanthe javanica* was applied as the experimental plant, with the hydraulic loading as 0.5 $m^3/(m^2.d)$ and the density of earthworms being 12 g/L in the soil. The experiment lasted from December 2, 2014 to July 28, 2015, and the samples were collected at 10 a.m. and then detected every day.

Analytical method: The plants were transplanted in the early November, 2014. The survival rate and plant height of these plants were detected a month later and at the end of each season respectively. COD_{Mn} and NH_4^+-N were detected using the fast airtight catalytic method (MOEP 1989) and the Nessler's reagent photometry (MOEP 2002) respectively. TP and TN were detected utilizing the potassium-persulphate oxidation-molybdenum antimony anti-spectrophotometry (MOEP, 2002) and the alkaline potassium persulphate oxidation-UV spectrophotometric method (MOEP, 2002) respectively. The UV-8000 ultraviolet spectrophotometer produced by Shanghai Yuanxi Instrument Co., Ltd. was used in the research.

RESULTS

The growth of the plants: One month after the transplant, the survival rate of the *Oenanthe javanica* was 100%, indicating that all the *Oenanthe javanica* can adapt to the experimental water and cultivation method. Table 2 depicts the growth changes of the *Oenanthe javanica* during the experiment. It can be seen that although the survival rate of the transplanted *Oenanthe javanica* is high, it grew slowly. This is mainly attributed to two reasons: on the one hand, *Oenanthe javanica* cannot adapt to the new environment, and the high content of pollutants in the water inhibited its growth to some extent. On the other hand, the temperature in winter is low. *Oenanthe javanica* grows fast at the temperature ranging from 15 to 20°C, and stops growing when the temperature is lower than 5°C. Since the average temperature in the winter of Ya'an is around 7°C, the growth of *Oenanthe javanica* is thus inhibited. *Oenanthe javanica* grows rapidly in spring and summer, when both the plant height and stem diameter experience quick growth.

The Removal of COD_{Mn}: The removal effect of the VBF on COD_{Mn} is illustrated in Fig. 3. According to Fig. 3, the content of COD_{Mn} in the influent water varies greatly with the

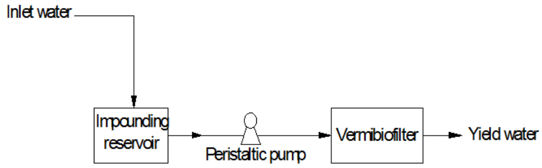

Fig. 1: Diagram of vermibiofilter system.

season and is in the range of 98.62-428.94 mg/L. The content of COD_{Mn} in the effluent water varies from 6.95-49.10 mg/L, with the removal rate in the range of 62.12%-93.88%. In the winter, the contents of COD_{Mn} in the influent water and the effluent water are 98.62-128.75 mg/L and 6.95-37.51 mg/L respectively, with the removal rate being 62.35%-93.88%. The contents of COD_{Mn} in the influent water and the effluent water are 156.63-275.96 mg/L and 19.83-49.10 mg/L separately in the spring, while the removal rate is in the range of 77.89%-91.08%. In the summer, the contents of COD_{Mn} in the influent water and the effluent water are 294.36-428.94 mg/L and 26.01-38.37 mg/L separately, and the removal rate varies from 91.08% to 91.88%. The removal rate exhibits an increasing tendency in the winter and declines slightly at the turn from the winter to the spring. Afterwards, it is on the rise before verging to be stable in the summer. Even if the content of COD_{Mn} in the influent water changes greatly, the removal rates are all higher than 62%, which indicates that the VBF is endowed with stable treatment effect on the COD_{Mn} in sewage. Meanwhile, the removal rate of COD_{Mn} is increased gradually with the rise of temperature, and reaches the maximum and is relatively stable in the summer. This is because the VBF is a complex ecosystem, where plants, earthworms, and considerable amounts of bacteria and fungi are grown. The VBF purifies the domestic sewage by utilizing the synergistic effects of the physical, chemical and biological functions of the complex ecosystem comprised of matrices, earthworms and microorganisms. In this way, pollutants are eliminated under the influence of mutually connected and restricted complex ecosystem. As to the removal mechanism, on one hand, at a high temperature, the activity ability of the plants and the earthworms is strengthened and the microorganisms present strong degrading ability, so the COD_{Mn} in the sewage can be eliminated more quickly. On the other hand, the organic pollutants in the VBF are filtrated mechanically, intercepted and adsorbed by the filter materials. Afterwards, the organic matters with great particle size are separated and broken by earthworms into organic matters with small particle size that can be readily degraded and utilized by the microorganisms (Yang et al. 2008). These organic matters are degraded and oxidized by the microorganisms in the system soon afterwards, so the adsorption ability of soil is rapidly recovered.

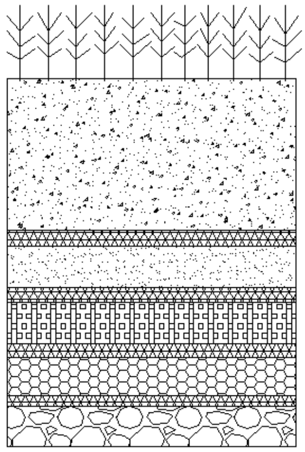

Fig. 2: Vermibiofilter.

Since COD_{Mn} is one of the indexes reflecting organic matters in the sewage, the COD_{Mn} in influent water can therefore be removed.

The removal of TN: The removal effect of the VBF on TN is demonstrated in Fig. 4. The VBF can effectively remove TN, with the removal rate reaching 57.2%-83.92%. The contents of TN in the influent water and the effluent water are 12.16-28.67 mg/L and 4.72-9.46 mg/L respectively in the winter, with the removal rate being 57.2%-70.11%. In the spring, the contents of TN in the influent water and the effluent water are 18.82-36.69 mg/L and 5.97-10.93 mg/L separately, and the removal rate is in the range of 61.20%-81.92%. The contents of TN in the influent water and the effluent water are 32.42-48.74 mg/L and 9.75-10.36 mg/L separately in the summer, and the removal rate varies from 67.66% to 80.26%. Therefore, it can be seen that the average removal rates of TN in the spring and the summer are obviously higher than that in the winter. This is because the VBF removes nitrogen by combining the adsorption function of the filter materials, the microbial metabolism and the absorption function of the plants.

The removal of NH_4^+-N: The removal rate of VBF for NH_4^+-N is shown in Fig. 5. The content of NH_4^+-N in the influent water changes greatly from 3.27 to 48.22 mg/L, while its content in the effluent water is relatively stable. Meanwhile, the removal rate of NH_4^+-N in the system is basically more than 60%, which suggests that the VBF can effectively remove NH_4^+-N. In the winter, the contents of NH_4^+-N in the influent water and the effluent water are 3.27-19.36 mg/L and 0.41-4.85 mg/L separately, and the removal rate varies from 62.73% to 98.11%. The contents of NH_4^+-N in the influent water and the effluent water are 23.66-38.93 mg/L and 1.42-5.05 mg/L respectively in the spring, with the removal rate in the range of 70.25%-96.52%. The contents of

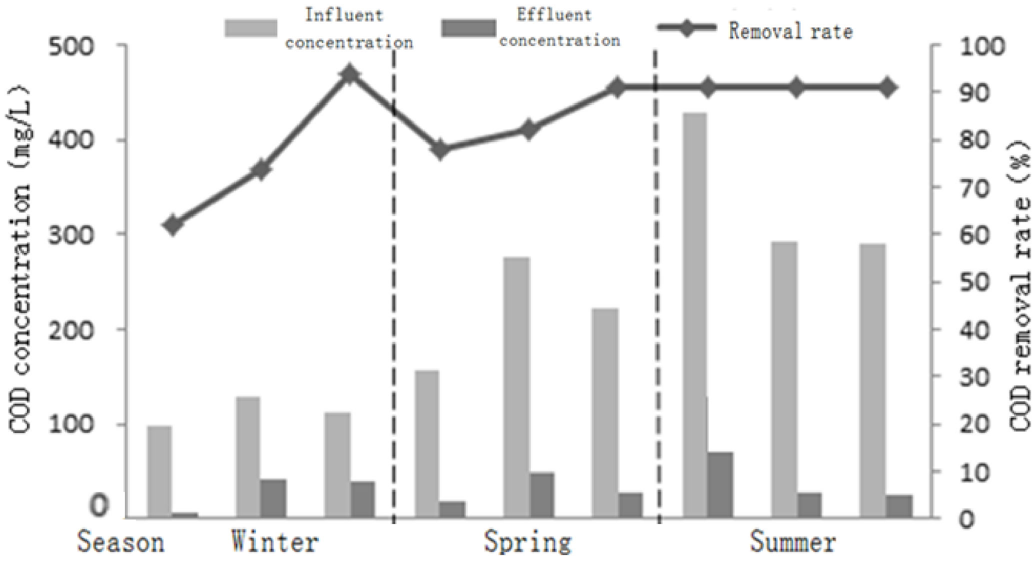

Fig. 3: COD_{Mn} removal effect in vermibiofilter.

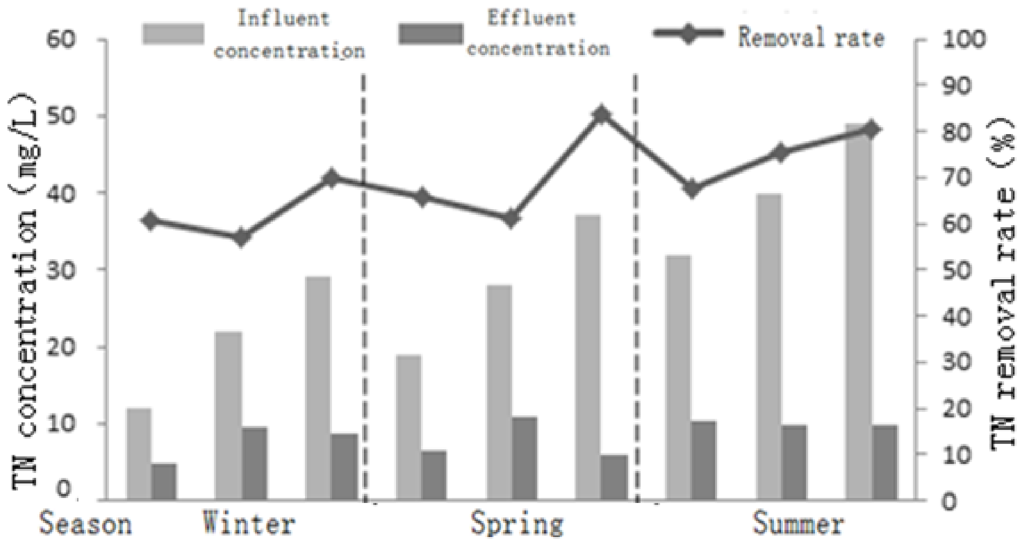

Fig. 4: TN removal effect in vermibiofilter.

NH_4^+-N in the influent water and the effluent water are 14.46-48.22 mg/L and 1.75-4.87 mg/L respectively in the summer, with the removal rate being 73.37%-98.05%. The great change existing in the removal rate of NH_4^+-N is related to the content of NH_4^+-N in the influent water. The VBF eliminates NH_4^+-N mainly by utilizing the absorption function of the earthworms in the soil layer, the degrading function of the microorganisms in the stone layer and the absorption function of the plants. The soil colloids are provided with negative charges, and therefore show great adsorption of NH_4^+-N. When the sewage is poured in the system, NH_4^+-N can be easily adsorbed by soil particles, which lengthens the residence time of NH_4^+-N (Zhang et al. 2006). In aerobic environment, microorganisms translate the ammonium ions adsorbed by soil particles into NO_2^- and NO_3^- through nitrosification and nitrification, so as to recover the adsorption ability of the soil for NH_4^+-N (Xing et al. 2008).

The removal of TP: The removal effect of VBF on TP is

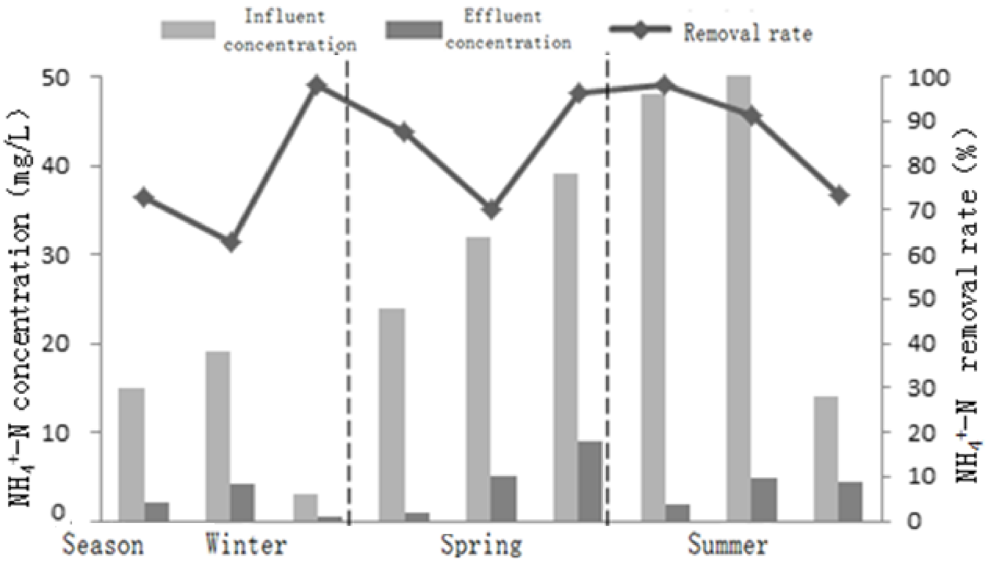

Fig. 5: NH_4^+-N removal effect in vermibiofilter.

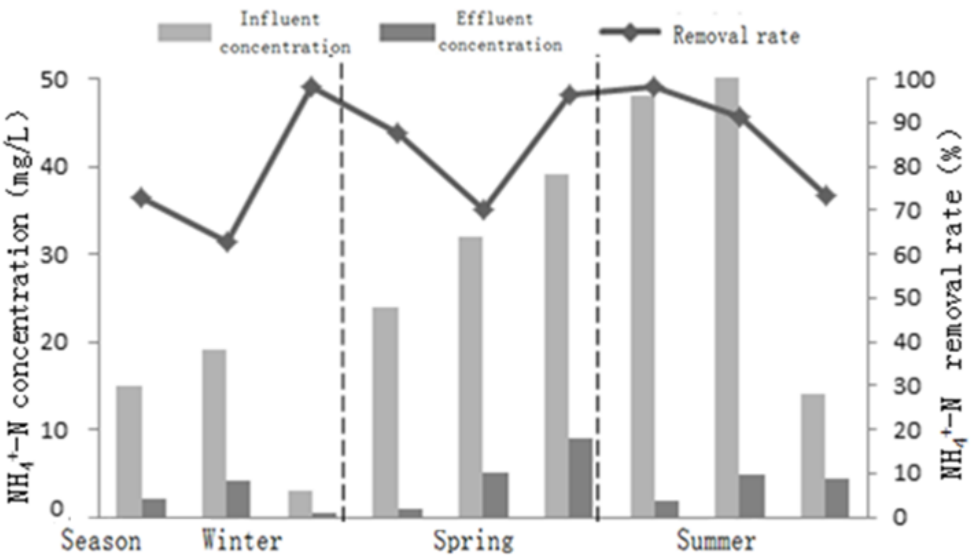

Fig. 6: TP removal effect in vermibiofilter.

demonstrated in Fig. 6. The content of TP in the influent water ranges from 2.43 to 8.12 mg/L, while its content in the effluent water of the VBF is reduced to 0.3-2.2 mg/L, with the removal rates all greater than 60%. The maximum removal rate can reach 94.11%. Thereinto, the contents of TP in the influent water and the effluent water are 2.13-4.56 mg/L and 0.47-1.26 mg/L respectively in the winter, with the removal rate being 61.9%-82.11%. In the spring, the contents of TP in the influent water and the effluent water are 4.23-6.61 mg/L and 0.32~1.48 mg/L separately, with the removal rate in the range of 64.46%-94.14%. In the summer, the contents of TP in the influent water and the effluent water are 5.75-6.92 mg/L and 0.47-1.26 mg/L respectively, and the removal rate varies from 74.70% to 94.11%. The unstable content of TP in the influent water has little influence on the removal of organic matters during the experiment. The high removal rate of TP indicates that the system has powerful resistance to impact load. However, the removal effect of VBF on TP is greatly affected by temperature: the high temperature in the summer is suitable for the growth of the plants and the earthworms, and therefore, the VBF exhibits better removal effect. The low temperature in the winter and the spring leads to the low removal effect because the activity of the plants and the earthworm is inhibited. Meanwhile, phosphorus is accumulated during the winter and the spring (Liu et al. 2009), which may be caused by the fact that some phosphorus in the root system of the withered plants in winter is dissolved to the water, giving rise to the increased content of phosphorus in the effluent water (Li et al. 2010).

Effluent quality of the VBF: The effluent quality of the decentralized domestic sewage in the rural area treated by the VBF is presented in Table 3. According to the table, the contents of each index in the treated effluent water vary a little in different seasons, indicating the stable effluent quality. Besides, the contents of COD_{Mn}, TN and NH_4^+-N in the effluent water all reach the fist level A criteria specified in the Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB 18918-2002) in China, while that of TP reaches the first level B criteria. This suggests that the VBF demonstrates favourable treatment effect on the decentralized domestic sewage in the rural area.

CONCLUSION

1. When the VBF was utilized to treat domestic sewage in different seasons under stable operation, the removal rates of COD, NH_4^+-N, TP and TN were in the range of 62.12%-93.88%, 62.73%-98.11%, 61.92%-94.14% and 57.2%-83.92% respectively.
2. The VBF shown favourable treatment effect on the decentralized domestic sewage in the rural area: the contents of COD_{Mn}, TN and NH_4^+-N in the effluent water all reached the first level A criteria specified in the Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB 18918-2002), while that of TP reaches the first level B criteria.

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