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Sewage Treatment with Constructed Wetland of Multiplayer Plants Configuration in South China*

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Abstract: Constructed wetland is efficient in waste water treatment by simulating the natural wetlands. In practice, plant diversity is always a problem, however. In this study, a combined constructed wetland mesocosm with multilayer plants was compared with another one with traditional plants which are high in height and great in biomass. After transplantation, the plants in both mesocosms grew well and it was closer to natural plant communication structure in the mesocosm of multilayer plants configuration though some species could not survive there. When the domestic wastewater streamed from the constructed wetlands, 65.7%, 64.6%, 84.5%, 20.2% and 18.3% of COD_{Cr}, BOD5, TP, TN and NH3-N were removed from the mesocosm with multilayer plants respectively, compared with 69.0%, 71.6%, 78.5%, 33.6% and 36.7% in the mesocosm with traditional plants. It indicated that the mesocosm of new plants configuration could decrease the pollutants effectively. However, it is noteworthy that plants selection is necessary when different plants are collocated together.

Keywords: wastewater treatment; plant configuration; plant bed

1 Introduction

Constructed wetland is designed and constructed by simulating the structure and function of natural wetland[1]. Plants are important in constructed wetlands and play crucial functions in the system. The macrophytes stabilize the surface of the beds, provide good conditions for physical filtration, prevent vertical flow systems from clogging, insulate the surface against frost during winter, and provide a huge surface area for attached microbial growth. Their roots give off oxygen to substrate to increase aerobic degradation of organic matter and nitrification. Macrophytes also have additional site-specific values such as providing habitat for wildlife and making wastewater treatment systems aesthetically pleasing[2]. At present, the plants used in the constructed wetlands are of high biomass and economic values, including bulrush (*Scirpus* sp.), cattail (*Typha* sp.) and reeds (*Phragmites* sp.)[3]. However, there is potential to use other types of wetland plants in constructed wetlands. Different plants in layers make the constructed wetland colorful and viewable, and are nearer to the natural plant community. Our research has made a comparison between multilayer plants configuration with those with traditional plants configuration to prove the efficiency of multilayer plants configuration in constructed wetland to dispose the waste water, thus it will offer a practice and theory reference for the popularization of constructed wetlands.

2 Material and Methods

2.1 Design of the Constructed Wetland Mesocosm

The constructed wetland mesocosm was near to the limber sewage coming from Guangzhou Ballet Troupe and Guangzhou Art School, and located in the South China botanical garden. The mesocosm includes pumping pond, precipitation pond, water distributing pond, vertical down-flow plant bed (DFPB), vertical up-flow plant bed (UFPB) and output tank. The DFPB and UFPB were connected by the pipe in the bottom in series, and there were two sets of such series in parallel (Fig.1). The size of each plant bed (PB) was 5×5 m^2, and PB 5 and 7 were 30 cm higher than PB 6 and 8. The substrate in the PBs consists of 20 cm gravels in the surface and 100 cm quartz

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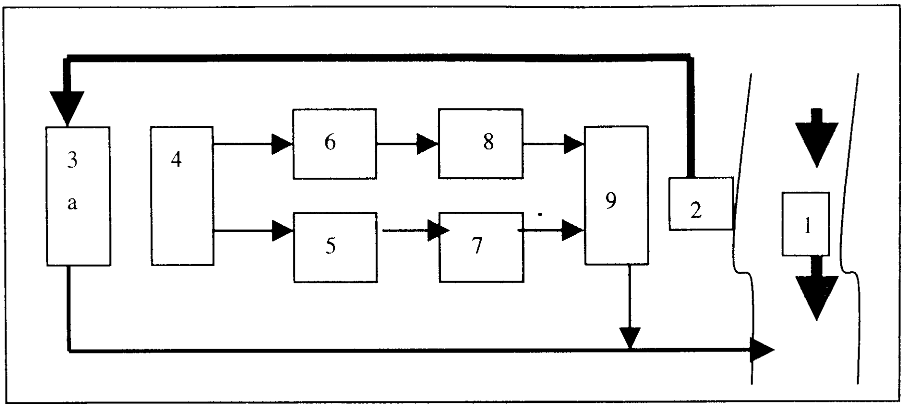
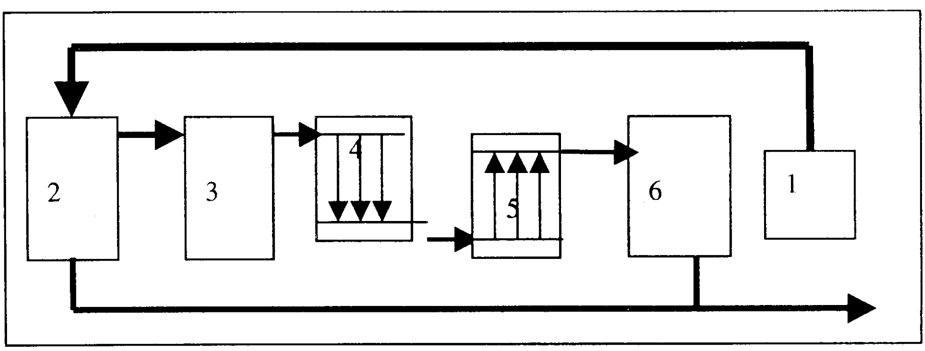
in the bottom. The running route of waste water in the wetland is shown in Fig.2.



1—Sewage; 2—Pumping pond; 3—Precipitation pond; 4—Water distributing pond; 5-6—DFPB; 7-8—UFPB; 9—Output tank

The arrows refer to the direction of the flux, and the thickness of the lines indicates the size of the flux; a-e refers to the water sampling sites

Fig.1 Flowing routine of the combined vertical constructed wetland



1—Pumping pond; 2—Precipitation pond; 3—Water distributing pond; 4—DFPB; 5—UFPB; 6—Output tank

The arrows refer to the direction of the flux

Fig.2 Cutaway view of the combined vertical constructed wetland

There are 44 species of aquatic or wetland plants collected from south China botanical garden and around it in PB 5 and 7 (Table1-2). The purpose was to test the efficiency for plant configuration in waste water treatment. There were 6 species in PB 6 and 8, including *Vetiveria zizanioides*, *Cyperus papyrus*, *Cyperus alternifolius, Thalia dealbata*, *Canna sp.* and *Phragmites australis*[4-8], which came from Shiyanhe Constructed Wetland in Shenzhen--an on-going constructed wetland with a much bigger area. These 6 plants were widely used around the world, and were tested here as a control experiment of PB 5 and 7, most of which were used in constructed wetland. All the plants in the 4 PBs were transplanted during the February and March of 2004. When transplanted, the species, height, density and number of the plants were the same in DFPB and UFDP.

The maintenance of plants and the test run of the wetland system began as the plants were transplanted. The plants survived and kept in good condition one month later. In the middle of April, the system began to work formally and dispose 40 m^3 of waste water everyday, that is to say, each series with a DFPB and A UFBP treated 20 m^3. The porosity of the substrates was 40% and the hydrological residence time was 24 h.

2.2 Plant Investigation and Water Sampling

Every month a survey was carried on the survival, height, tillers and coverage of the plants from April to June. According to the designed characteristics of the project, we chose 5 sites for sampling. They were input sampling site (a), DFPB sampling sites(b & c), UFDP sampling sites(d & e) (fig.1) . The water was collected to test one day a month, and four times a day (2am, 8am, 14pm and 20pm). By the end of the experiment, we got 16 water samplings.

Table 1 Survival of the plants in PB 5

Species	Survival	Species	Survival
Lycoris aurea	0*	*Pilea martini)*	3
Rhaphidophora hongkongensis	0	*Pandanus tectorius*	3
Melastoma candidum	0	*Taxodium distichum*	3
Syzygium jambos	1	*Saururus chinensis*	3
Bauhinia adscendens	1	*Arundinella nepalensis*	4
Monstera deliciosa Liehn	1	*Artemisa argyi*	4
Rhaphidophora pinnata	1	*Iresine herbstii*	4
Lantana camara	1	*Calla palustris*	4
Aspidistra elatior	2	*Alocasi amarorrhiza*	4
Iris tectorum	2	*Colocasia antiquorum*	4
Tradescantia reflexa	2	*Coix lacryma*	4
Scindapsus aureus	3	*Pennisetum purpureum*	4
Lespedeza formosa	3	*Hedychium coronarium*	4
Polggonum chlnense	3	*Typha latifolia*	4
Syngonium podophyllum	3	*Heliconia latistaha*	4
Stromanthe sanguinea	3	*Hymenocallis speciosa*	4
Aglaonema moolestum	3	*Miscanthus floridulus*	4
Ophiopogon japonicus	3	*Phaius flavus*	4
Ophiopogon japonicus	3	*Limnocharis flava*	4
Typha latifolia Var variegatus	3	*Myriophyllu aquaticum*	4
Sansevieria trifasciata	3	*Oenanthe javanica*	4
Pilea cadierei	3	*Polygonum hydropiper*	4

* 0, 1, 2 indicate that the plants were dead when the investigations were held in April, May and June, respectively. 3 refer the plants that could survive, but couldn't live well when the experiment was over, and 4 refer those that could live well at that time.

Table 2 Survival of the plants in PB 5

Species	Survival	Species	Survival
Lycoris aurea	0*	*Typha latifolia Var variegatus*	3
Rhaphidophora hongkongensis	0	*Sansevieria trifasciata*	3
Melastoma candidum	0	*Pilea cadierei*	3
Syzygium jambos	0	*Pilea martini)*	3
Bauhinia adscendens	0	*Pandanus tectorius*	3
Arundinella nepalensis	0	*Taxodium distichum*	3
Artemisa argyi	0	*Saururus chinensis*	3
Iresine herbstii	0	*Calla palustris*	4
Scindapsus aureus	0	*Alocasi amarorrhiza*	4
Lespedeza formosa	0	*Colocasia antiquorum*	4
Monstera deliciosa Liehn	1	*Coix lacryma*	4
Rhaphidophora pinnata	1	*Pennisetum purpureum*	4
Lantana camara	1	*Hedychium coronarium*	4
Aspidistra elatior	1	*Typha latifolia*	4
Polggonum chlnense	1	*Heliconia latistaha*	4
Iris tectorum	2	*Hymenocallis speciosa*	4
Tradescantia reflexa	2	*Miscanthus floridulus*	4
Syngonium podophyllum	3	*Phaius flavus*	4
Stromanthe sanguinea	3	*Limnocharis flava*	3
Aglaonema moolestum	3	*Myriophyllu aquaticum*	4
Ophiopogon japonicus	3	*Oenanthe javanica*	4
Ophiopogon japonicus	3	*Polygonum hydropiper*	4

* The same as that in table1.

2.3 Items and Method of Water Quality Testing

The items studied in this research include temperature (T), dissolved oxygen (DO), pH, COD_{Cr}, BOD_5, TN, NH_3-N and TP. T and DO were tested by dissolved oxygen analyzer (model: TOA DO-11P). pH, COD_{Cr}, BOD_5, TN, NH_3-N and TP were tested by pH meter, rapid sealed digestion method, dilution inoculation method, potassium persulfate oxidation-UV spectrophotometric method, Nessler's reagent photometer and molybdenum-antimony anti-spectrophotometric method, respectively[9].

2.4 Statistical Analysis

The mean and variance were calculated for the eight items at the inlet and at each outlet of the four outlets of the four PBs. Pollutants removal were calculated by the mean of pollutants concentrations. The relativity of the items was tested by paired-sample *T* test between sites b and c, d and e, b and d, b and e (table3).

Table 3 Paired-sample *T* test of the items of water quality of sampling sites b, c, d and e

	COD_{Cr}	BOD_5	TP	TN	NH_4-N
b-c	0.410	1.054	2.379*	2.420*	2.917*
d-e	1.278	1.172	-3.004**	3.413*	3.463*
b-d	0.114	0.754	7.282**	0.811	0.189
c-e	0.552	1.905	14.483**	2.070	1.237

$^*P < 0.05$, $^{**}P < 0.01$

3 Results and Analysis

3.1 Survival and Growth of the Plants

31 species of plants in PB5 (table1) and 22 species in PB7 (table2) survived at last. Table 4 and table 5 show the height and tillers in PB 6 and 8 and part of the plants in PB 5 and 7. The coverage in PB 5 and 7 are [illegible] to 85% and 75% separately, compared to nearly 100% in PB 6 and 8.

Table 4 Height of plants in the PBs cm

PB	Species	At the beginning		3 months later	
		DFPB	UFPB	DFPB	UFPB
6 & 8	*V. zizanioides*	20	20	164.0	208.3
	P. australis	26.0	25.3	133.0	110.5
	C. alternifolius	15.0	15.0	98.3	94.7
	C. papyrus	65.5	65.8	150.0	156.7
	T. dealbata	94.4	96.5	180.0	185.0
	C. sp.	35.0	31.2	170.7	175.0
5 & 7	*C. lacryma*	36.0	42.0	124.7	157.3
	H. coronarium	20.0	20.0	96.3	127.0
	P. purpureum	68.3	57.4	345.5	218.5
	H. latistaha	20	20	84.0	82.0
	P. flavus	15	15	119.3	109.3
	C. palustris	41.3	44.0	203.3	168.8
	C. antiquorum	70.0	78.5	114.3	134.5
	A. amarorrhiza	33.7	27.6	97.3	58.0
	H. speciosa	51.3	46.3	118.0	112.3

Table 5 Tillers of plants in the PBs

PB	Species	At the beginning		3 months later	
		DFPB	UFPB	DFPB	UFPB
6 & 8	*V. zizanioides*	4.0	4.0	10.3	12.0
	P. australis	9.5	10.0	38.0	31.0
	C. alternifolius	7.0	7.0	52.5	50.7
	C. papyrus	8.0	8.3	13.0	44.7
	T. dealbata	7.3	6.7	31.0	35.0
	C. sp.	6.3	7.0	13.0	14.0
5 & 7	*C. lacryma*	3.0	3.0	8.7	14.0
	H. coronarium	3.0	3.0	12.0	7.3
	P. purpureum	7.5	7.0	30.0	10.0
	H. latistaha	3.0	3.0	15.0	5.0
	P. flavus	4.0	4.0	11.0	15.0

3.2 Temperature, Dissolved Oxygen and pH

Temperature of the waste water changed little before or after being disposed, and so did it between the two series (Fig.3). During the process of disposal, water temperature was highly correlated with air temperature(r^2=0.987, p<0.05). The change of DO concentration presents a "V" shape, which indicates that oxygen had been depleted completely after the DFPB and more oxygen released from the roots in the UFPB. Furthermore, significant differences did not exist between the two series. pH in the waste water decreased after being deposed, which was more obviously in series of PB 6 and 8. However, pH in the DFPD and UFPD in the same series had no significant difference.

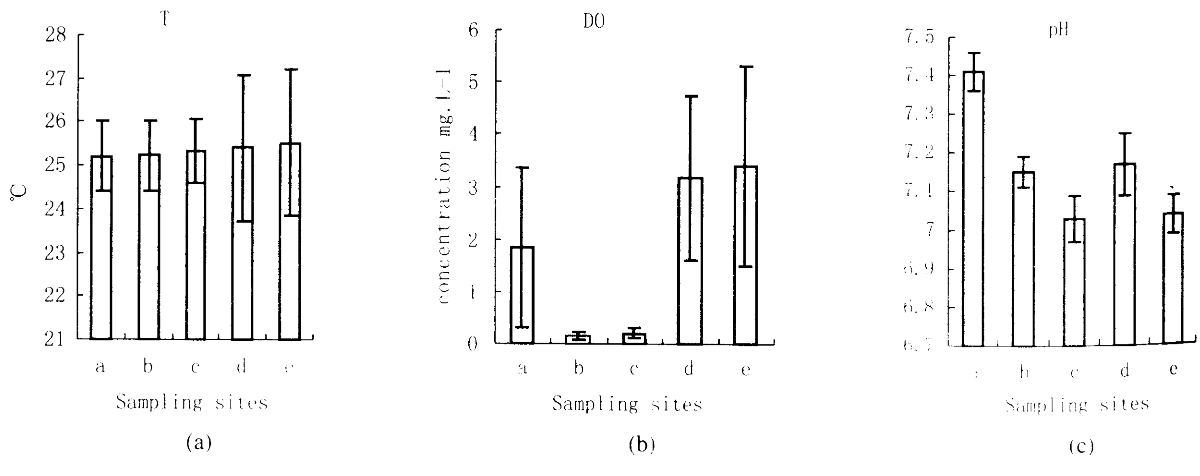


Fig.3 Changes in T, DO and pH in the five sampling sites.

3.3 Removal of Main Pollutants

After treated by the series of PB 6 and 8, 69.0%, 71.6%, 78.5%, 33.6% and 36.7% of COD_{Cr}, BOD_5, TP, TN and NH_3-N in the waste water were removed, and the removal rate were 65.7%, 64.6%, 84.5%, 20.2% and 18.3% respectively by the series of PB 5 and 7 (Table 6 and fig.4). It suggests that both the two series could remove the pollutants effectively, but the series of PB 6 and 8 was better than that of PB 5 and 7. And most TP was eliminated in UFPB.

Table 6 Results of major pollutants examed (Mean±SD, n =16)

Items	Sampling site a	Sampling site b	Sampling site c	Sampling site d	Sampling site e
COD_{Cr}	59.80 ± 15.28	21.24 ± 5.12	20.52 ± 8.38	20.51 ± 7.89	18.57 ± 3.89
BOD_5	39.72 ± 13.59	17.64 ± 6.02	14.96 ± 4.77	14.07 ± 6.71	11.27 ± 6.14
NH_3-N	12.41 ± 3.5	10.12 ± 1.57	8.30 ± 1.63	10.14 ± 2.19	7.85 ± 1.91
TN	14.13 ± 3.09	12.1 ± 1.30	10.64 ± 1.46	11.27 ± 2.15	9.39 ± 1.83
TP	1.36±0.48	1.23±0.25	0.94±0.21	0.21±0.03	0.29±0.22

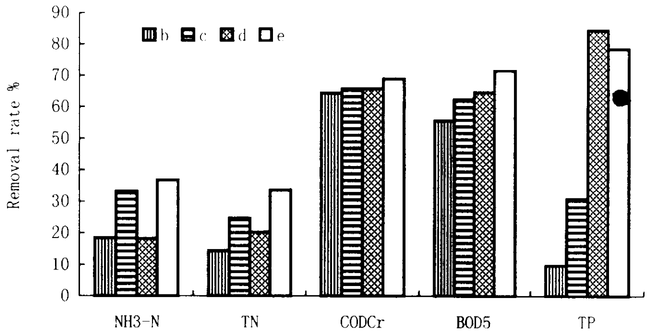


Fig.4 Removal rates of the pollutants

4 Discussion

4.1 Availability of Plants Configuration

PB 5 and 7 consists of many plants species and till the end of the research, they had formed the configuration of different layers. PB 6 and 8 are composed of traditional plants which grew better and had higher pollutant removal rates, but they owned less diversities and their landscape effect are monotonous[10, 11]. Although the plant configuration is with several layers and much more plants can increase diversity and look more beautiful, their pollutant removal rates often affected by the death of some plants which are not suitable to the controlled conditions of constructed wetlands. So it is still a long way for plant configuration in constructed wetlands.

4.2 Processes in Constructed Wetland

Though it is not the main aspect to remove N in the constructed wetland by plant absorption[12], the capacity to remove N in PB 5 and 7 is apparently less than that in PB 6 and 8 for the less survival and coverage in PB 5 and 7. This shows that the plants influence the removal of pollutant through some other approaches besides direct absorption. NH_3-N is the principle in the sewage, which plays an important role on the change of pH during the disposal of wastewater [13], and that caused the pH differ greatly between the two series and little in the same series. O_2 in the constructed wetland consists of the DO dissolved in the waste water and free water and released from the roots [14]. Since DO was seriously limited in both of the two series, there was no significant difference between the two series. As to the removal of P, it includes physical and chemical adsorption and biological assimilation, among which chemical adsorption is the chief approach [15]. Researches have been developed that the roots and the other organisms can release some substances such as phosphatase to restrain the combination of phosphate with other ions [16,17]. Because of these reasons, TP was mainly removed in the UFPB.

5 Conclusions

Through the results of comparing the PBs with multilayer plants configuration with those traditional plants configuration, multiplayer plants configuration was proved to be effective and available in constructed wetland. But multiplayer plants configuration should be combined with plant selection to ensure more effective configuration. The pollutants in waste water are mainly N, P, its removal rate is relative to the growth of plants, while TP is removed mostly by the substrates led by the plant.

References

[1] Xia Hanping. Mechanisms and efficiencies on wastewater treatment with constructed wetlands: a review. Chinese Journal of Ecology, 2002, 21(4): 51-59(in Chinese)

[2] Brix H. Do macrophytes play a role in constructed treatment wetlands?. Water Science and Technology, 1997, 35(5): 11-17

[3] Marco A, Eliseo C, Steve T, et al. Treatment of domestic wastewater in a pilot-scale natural treatment system in central Mexico. Ecological Engineering, 2004, 23 (4-5): 299-311

[4] Kantawanichkul S, Pilaila S, Tanapiyawanich W, et al. Wastewater treatment by tropical plants in vertical-flow constructed wetlands. Water Science and Technology, 1999, 40(3): 173-178

[5] Joseph K, Frank K, Lena G, et al. A comparative study of *Cyperus papyrus* and *Miscanthidium violaceum*-based constructed wetlands for wastewater treatment in a tropical climate. Water Research, 2004, 38(2): 475-485

[6] Selma Ç, Lütfi A. Treatment of wastewater by natural systems. Environment International, 2001, 26(3): 189-195

[7] John H, Jan M, Wang Tiangen. Growth and trace metal absorption by *Phragmites australis* in wetlands constructed for landfill leachate treatment. Ecological Engineering, 1995, 5(1): 21-35

[8] Liao Xindi, Luo Shiming, Wu Yinbao, et al. Comparison of nutrient removal ability between *Cyperus alternif olius* and *Vetiveria zizanioides* in constructed wetlands. Chinese Journal of Application Ecology, 2005, 16(1): 156-160(in Chinese)

[9] Wang Xinfang. Methods of the Water and Wastewater Inspection and Analysis. Beijing: China Environmental Press, 2002, 216-219(in Chinese)

[10] Wang Shengrui, Nian Yuegang, Hou Wenhua, et al. Microphyte selection in artificial wetlands. Journal of Lake Sciences 2004, 16(1): 91-96(in Chinese)

[11] Brix H. Treatment of wastewater in the rhizosphere of wetland plants -- The root-zone method. Water Science and Technology, 1987, 19(1): 107-118

[12] Liu Chunchang, Xia Hanping, Jian Shuguang, et al. A case study on domestic wastewater treatment in Shiyanhe constructed wetland in Shenzhen. Ecology and Environment, 2005, 14(4): 536-539(in Chinese)

[13] Xu Lezhong. Effect on N and P removals and control of ph and alkalinity. Water & Wastewater Engineering, 1996, 22(1): 10-14(in Chinese)

[14] Wu Xiaolei. Mechanism of wastewater treatment in constructed wetlands. Chinese J Environmental Science, 1995, 16(3): 83-86(in Chinese)

[15] Zhang Jian, Wei Jie, et al. Nitrogen and phosphorus removal mechanism in subsurface wastewater infiltration system. Chin Environ Science, 2002, 22(5): 438-441(in Chinese)

[16] Zhou Yiyong, Fu Yongqing. Phosphatases in natural water: origin, characteristics and ecological significance. J Lake Science, 1999, 11(3): 274-282(in Chinese)

[17] Liao Xindi, Luo Siming. Shiming treatment effect of constructed wetlands on organic matter in wastewater from pig farm. Chinese. Journal of Applied Ecology, 2002, 13(1): 113-117(in Chinese)

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