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Reed-wetland beds for municipal wastewater treatment

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Abstract —The performance of 11 reed-wetland beds for municipal wastewater treatment is described in this paper. The interrelation between pollutants removal (BOD_5, SS, N and P) and hydraulic loading rate, organic loading rate, hydraulic retention time as well as the seasonal variation could be found in this study. The treatment efficiencies of reed beds are better than the secondary treatment standards with high and steady nitrogen and phosphorus removal. The total nitrogen and phosphorus of the final effluent are less than 10 mg/L and 0.5 mg/L, respectively.

Keywords: reedwetland beds; municipal wastewater treatment; China.

INTRODUCTION

The use of wetland for treatment of wastewater has been practiced in the U. K. for more than a century (Gersberg, 1985). In recent 20 years, U. S. and many European countries have paid more and more attentions in using artificial or constructed wetlands for domestic and industrial wastewater treatment (Reed, 1988). Reed-wetland bed is one of the types of wetland processes, as known as RZM (root zone method) in Europe or subsurface-flow system in U.S.A. It was developed by Professor Kickuth of Hassel University, Germany (Cooper, 1989). There have been many small-scale to pilot experimental systems in many European countries (Cooper, 1989), such as U. K., Denmark, Germany, Austria, France, Holland, Belgium, Luxembourg as well as in U. S. A., Australia and other countries. 11 reed beds have been constructed in the present study, with the purpose of providing preliminary design parameters for the application of this method to wastewater purification in China.

MATERIALS AND METHODS

Construction of the beds

11 reed beds have been built with different length/width ratio and materials, which are described in Table 1 and Fig. 1.

Table 1 Construction of the reed-wetland beds

Bed No.	A_1-A_5	B_1, B_2	B_3, B_4	C	D
Length × width, m	1.5×0.6	2×1	3×1	6×2	9×3
Depth, m	0.6	0.75	0.75	0.75	0.75
Slope, %	2	2	2	2	2
Liner	Grey-uPVC	Concrete	Concrete	Concrete	Concrete

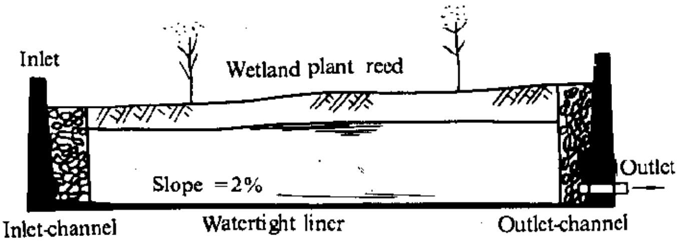

Fig. 1 Schematic representation of a reed-wetland bed

There is a channel along the bed width in each end of the bed, which is filled with 60−100 mm stones. The widths of inlet distributor zone and outlet collector zone are the same as 15−45 cm. The growth medium of the beds are mixture of top-soil with coarse pulverized fuel ash (CPFA) or fine pulverized fuel ash (FPFA). A slotted pipe is placed at the base of the collector zone, which is connected with a height-adjustable outlet pipe. All the beds have been constructed with a base slope of 2% and with a level surface for weed control (Cooper, 1989).

Reed planting

The common reed (Phragmiteds australis) is used in our experimental systems. The planting density is 6 clumps/m^2. The clumps (approx. 30 cm × 30 cm × 40 cm sections) with vigorous reed buds from the existing natural reed wetland have been transplanted in the early spring. Immediately after planting, the beds should be filled with water so that water table is 5 cm below the soil surface. Settled municipal wastewater are applied to the reed beds after 3 months planting.

Wastewater and sampling

The municipal wastewater of the Northern Wastewater Channel in Tianjin was treated in a primary settlement tank with the retention time about 1.1 h before entering the reed-wetland beds. Samples of influent and effluent were collected on one time of each week during the study (July 1989−July 1990), and analysed for BOD_5, SS, K-N, NH_4^+-N, TP and PO_4^{3-}.

RESULTS ANALYSES

BOD_5 removal

The treatment results of BOD_5 in all the beds are listed in Table 2. The average effluent

BOD_5 is 14.89 mg/L with the mean hydraulic loading rate of 6.2 cm/d, organic loading rate of 90.9 kg BOD_5/ha.d, hydraulic retention time of 5.1 days and influent BOD_5 148.76 mg/L. The mean removal rate of BOD_5 for all beds is generally above 90%.

Table 2 BOD_5 removal efficiencies of reed beds

Bed No.	Hydraulic loading rate, cm/d	Organic loading rate, kg/ha.d	Hydraulic retention time, day	Inlet BOD_5, mg/L	Outlet BOD_5, mg /L	BOD_5 removal, %
A_1	8.2	113.5	3.8	138.41	19.37	86.0
A_2	8.2	112.8	3.8	137.60	18.42	86.6
A_3	7.5	103.2	3.3	137.60	13.40	90.3
A_4	7.7	105.7	3.3	137.22	13.35	90.3
A_5	8.1	117.2	2.2	144.72	35.66	75.4
B_1	5.4	86.8	5.4	160.74	13.45	91.6
B_2	5.9	94.8	4.6	160.75	7.93	95.1
B_3	3.3	49.5	8.8	150.15	8.89	94.1
B_4	3.5	52.7	7.7	150.50	6.78	95.5
C	6.1	96.9	5.3	158.91	17.17	89.2
D	4.2	67.1	7.8	159.73	9.32	94.2

Interrelation between BOD_5 removal and hydraulic loading rate

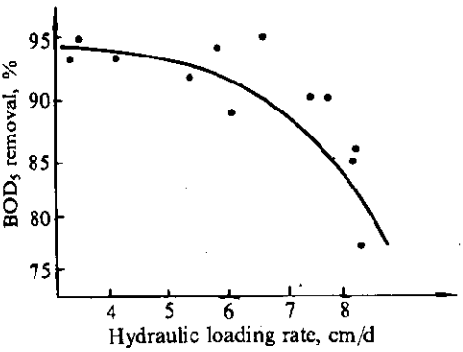

Fig. 2 Interrelation between BOD_5 removal and hydraulic loading rate

As seen in Fig. 2, BOD_5 removal rate decreases with the hydraulic loading increasing. The BOD_5 removal rate reach up to 95% with a hydraulic loading of 4 cm/d. When the hydraulic loading rate is below 7cm/d, the removal rate is still over 85%. The removal efficiency will decrease significantly with the hydraulic loading above 8cm/d. The most suitable hydraulic loading rate of the wetland should be below 7cm/d with a BOD_5 reduction over 85%.

Interrelation between BOD_5 removal and organic loading rate

As shown in Fig. 3, BOD_5 removal decreases with the organic loading increasing. BOD_5 removal rate is as high as 95% with an organic loading rate of 64 kg BOD_5/ha.d, and still over 85% with loading below 110 kg/ha.d. The removal efficiency will decrease sharply with the organic loading above 120 kg BOD_5/ha.d. The most suitable organic loading of this type of wetland should be lower than 110 kg BOD_5/ha.d with a BOD_5 removal over 85%.

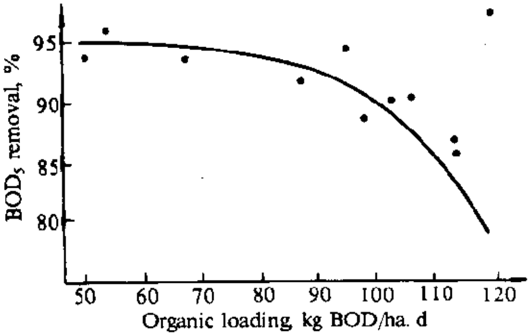

Fig. 3 Interrelation between BOD_5 removal and organic loading rate

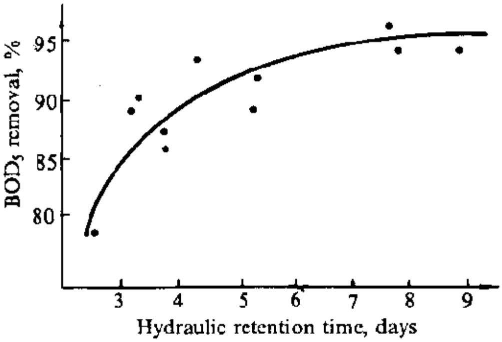

Fig. 4 Interrelation between BOD_5 removal and hydraulic retention time

Interrelation between BOD_5 removal and hydraulic retention time

As illustrated in Fig. 4, BOD_5 removal rate will increase with the retention time inceasing. The removal efficiency decreases with the retention time less than 3.5 days. The BOD_5 removal rate is as high as 90% with a retention time over 5 days, and 95% removal with the retention time of 7.5 days. The removal efficiency will not increase obviously with the retention time over 8 days. Therefore, the best retention time of wastewater in reed-wetland beds should be 5 to 8 days.

Seasonal variation of BOD_5 removal

The BOD_5 removal efficiencies of all the beds are shown as in Table 3 and Fig. 5. There is no significantly seasonal variation of BOD_5 removal in system B, bed C and bed D. The removal rate of system A in spring is obviously lower than that in summer and autumn. The main reason is that all the beds in system A have smaller size than other beds, and have been placed over the soil surface and influenced by the low temperature in winter and spring.

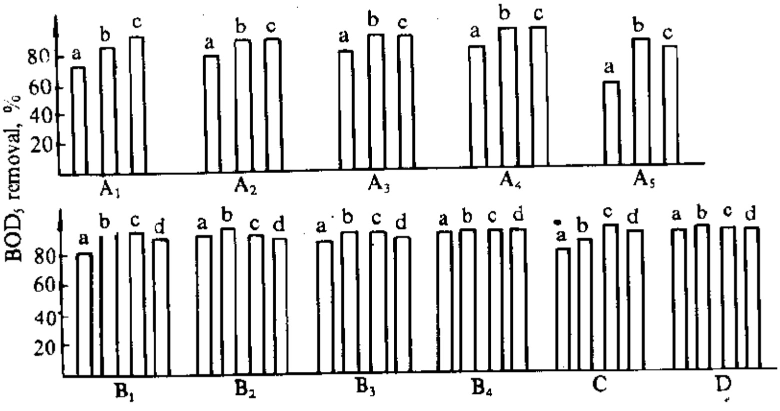

Fig. 5 Seasonal variation of BOD_5 removal in reed-wetland beds

(a, b, c and d represent BOD_5 removal rate of spring, summer, autumn and winter, respectively)

Table 3 Seasonal variation of BOD_5 removal, %

Bed No.	Spring (March to May)	Summer (June to Aug.)	Autumn (Sep. to Nov.)	Winter (Dec. to Feb.)
A_1	76.0	87.2	93.1	–
A_2	79.1	86.9	92.3	–
A_3	81.8	93.9	93.2	–
A_4	82.5	94.7	93.2	–
A_5	54.1	85.0	78.9	–
B_1	81.5	95.7	96.2	92.2
B_2	94.1	97.6	95.0	92.4
B_3	89.3	95.6	97.8	93.2
B_4	95.1	95.9	95.5	94.7
C	79.4	85.4	95.3	93.2
D	92.9	95.3	95.1	92.9

SS removal

The results of suspended solids removal in system A and B as well as beds C and D are shown in Table 4. The average influent SS is 136.0 mg/L, with the average effluent SS of 11.4 mg/L and mean removal efficiency of 91.6%. System (or bed) C and D are very effective in SS removal with the effluent SS lower than 10 mg/L because of the longer travel distance for the wastewater.

Table 4 SS removal efficiencies

System	Influent, mg/L	Effluent, mg/L	Removal rate, %
A	99.3	15.8	84.1
B	148.2	11.2	92.4
C	148.2	8.7	94.1
D	148.2	9.8	93.4
Mean	136.0	11.4	91.6

Nitrogen removal

As shown in Table 5, reed beds are very effective in removing nitrogen of wastewater. The average influent Kjeldahl-nitrogen (K-N) and ammonium-nitrogen (NH_4^+-N) concentrations are 37.70 mg/L and 30.22 mg/L, with the average effluent K-N and NH_4^+-N of 9.42 mg/L and 7.19 mg/L, respectively. The removal efficiencies of both K-N and NH_4^+ are over 75%. As shown in Fig. 6, K-N and NH_4^+-N removal efficiencies decrease with the nitrogen loading increasing. The removal rates of K-N and NH_4^+-N are over 70% with a nitrogen loading below 27 kg K-N/ha.d.

Table 5 Nitrogen removal efficiencies of reed-beds

Bed No.	Nitrogen loading, kg/ha.d	K-N, Inlet, mg/L	K-N, Outlet, mg/L	K-N, Removal, %	NH_4^+-N Inlet, mg/L	NH_4^+-N Outlet, mg/L	NH_4^+-N Removal, %
A_1	29.3	35.72	8.29	76.8	29.26	6.28	78.5
A_2	29.6	36.11	11.57	67.9	29.42	8.23	72.0
A_3	27.4	36.17	10.27	71.8	29.42	8.08	72.5
A_4	27.3	35.47	15.35	56.7	29.11	12.64	56.6
A_5	30.3	37.55	20.63	44.8	30.10	16.06	46.6
B_1	21.2	39.31	4.84	87.7	30.78	3.29	89.3
B_2	23.2	39.31	4.84	87.7	30.78	3.29	89.3
B_3	12.7	38.39	5.29	86.2	30.85	4.05	86.9
B_4	13.4	38.39	6.17	84.1	30.85	4.77	84.5
C	23.3	38.21	7.03	81.6	30.85	5.29	82.6
D	16.9	40.35	6.31	84.4	31.45	4.54	85.6
Mean	23.1	37.70	9.42	75.0	30.22	7.19	76.2

The removal of K-N for all the beds have seasonal variation (as seen in Table 6 and Fig. 7). The removal of K-N in warm weather (June to Nov.) are significantly higher than that in cold weather (Dec. to May). However, the effluent K-N concentrations both in warm weather and cold weather are below 10 mg/L.

Table 6 Seasonal variation of K-N removal, %

Bed No.	Spring (March to May)	Summer (June to Aug.)	Autumn (Sep. to Nov.)	Winter (Dec. to Feb.)
A_1	68.6	82.3	76.6	–
A_2	60.8	65.1	75.9	–
A_3	73.0	77.1	64.7	–
A_4	59.8	62.1	49.0	–
A_5	38.8	52.8	41.1	–
B_1	63.2	81.8	90.5	78.2
B_2	85.2	92.4	90.5	83.4
B_3	76.9	88.5	93.5	82.1
B_4	76.1	83.2	89.7	83.8
C	74.5	76.1	89.7	82.3
D	72.4	89.0	88.9	84.1

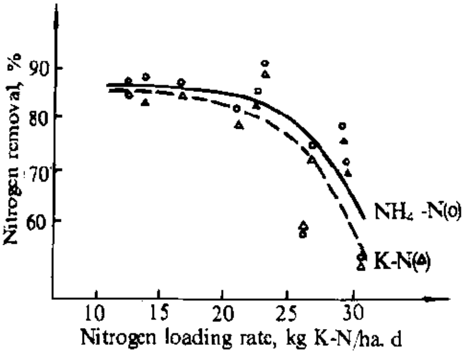

Fig. 6 Interrelation between nitrogen removal and nitrogen loading

Phosphorus removal

Table 7 lists the results of total phosphorus (TP) and phosphate (PO_4^{3-}). The mean removal efficiencies of TP and PO_4^{3-} of these beds are 87.9% and 79.6%, respectively. The effluent concentrations of TP and PO_4^{3-} are 0.328 mg/L and 0.067 mg/L, respectively. There is no significant interrelation between phosphorus reduction and hydraulic loading rate (3.3 to 8.2 cm/d).

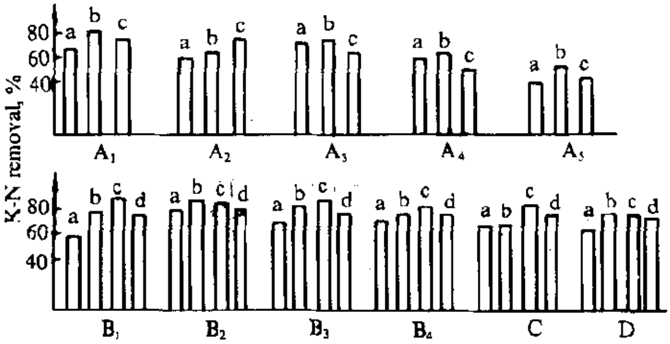

Fig. 7 Seasonal variation of nitrogen removal
(a, b, c and d represent nitrogen removal efficiencies of spring, autumn and winter, respectively)

Table 7 Phosphorus removal efficiencies of reed beds

Bed No.	Hydraulic loading, cm/d	TP Inlet, mg/L	TP Outlet, mg/L	TP Removal, %	PO_4^3 Inlet, mg/L	PO_4^3 Outlet, mg/L	PO_4^3 Removal, %
A_1–A_5	7.9	2.547	0.350	86.3	0.325	0.024	92.6
B_1, B_2	5.7	3.096	0.354	88.6	0.329	0.031	90.6
B_3, B_4	3.4	2.791	0.253	90.9	0.316	0.038	88.0
C	4.2	3.194	0.357	88.8	0.331	0.062	81.3
D	6.2	2.790	0.339	87.9	0.328	0.067	79.6

DISCUSSION AND CONCLUSIONS

As analysed above, reed-wetland beds can attain the secondary treatment effluent standard (BOD_5 less than 20 mg/L, SS less than 20 mg/L) with high hydraulic loading (4–7 cm/d) and organic loading (64–110 kg BOD_5/ha.d). The main reason may be that the aerenchyma of reeds could supply oxygen to the buried plant parts. The roots and rhizomes, however, leak O_2 into the substrate, thereby creating oxidized microzones in an otherwise reduced substrate (Hans, 1987). The presence of these oxidized and anoxic zones around the roots creates a favorable environment for aerobic and facultative anaerobic microorganisms to decompose the wastewater organic pollutants.

Reed-wetland beds are effective in removing nitrogen and phosphorus with the effluent K-N less than 10 mg/L in winter and 7 mg/L in warm months.It is a relatively satisfactory approach to remove nitrogen and phosphorus from wastewater as compared to conventional secondary treatment works. Nitrogen removal is carried mainly by nitrifying bacteria in the oxidized microzones and denitrifying bacteria in the anoxic and reduced zones. By these processes, ammonia is oxidized to nitrate (NO_3^-), then to free nitrogen(N_2)which evaporate into the atmosphere. Plant uptake only play limited role in nitrogen removal (Reed, 1988).

There is no significant seasonal variation for BOD_5 and SS removal in reed-wetland beds with a high removal efficiency in all seasons. Although the nitrogen removal efficiencies decrease in winter and spring, the effluents during these periods are still lower than 10 mg/L , which is critical for this method to remove BOD_5 and nitrogen efficiently in cold-climate regions and need no storage in cold weather.

The average removal efficiency for TP in most of the beds are over 80%. The main reason is that the wastewater phosphorus concentration is relatively low, and the capacity of the growth medium (topsoil mixture) adsorption as well as the uptake by reeds is much greater than the total wastewater phosphorus applied to the reed-wetland beds.

It has been found that the BOD_5 and nitrogen removal efficiencies decrease extremely significant with the hydraulic loading over 8 cm/d, or organic loading and nitrogen loading over 110 kg BOD_5/ha.d and 27 kg K-N/ha.d, respectively, during the analyses of the interrelations mentioned above. These results may be related to the horizontal hydraulic conductivity of the beds' medium used. The hydraulic conductivity of the mixture of top soil with the pulverized fuel ash (PFA) is less than 10^{-4} m/s (Cooper, 1989). The wastewater will flow above the bed surface with an excessively high of hydraulic loading rate (over 8 cm/d) which leads to the obvious decreases of BOD_5 and nitrogen removal described above. These results indicate that the horizontal hydraulic conductivity of the bed's medium may be one of the important limiting factors affecting the treatment efficiencies of BOD_5 and nitrogen especially with a high hydraulic loading, which need further research.

In conclusion, reed-wetland beds seem to be a viable alternative to conventional wastewater treatment technology, especially suitable for small to medium sized communities. Their design is relatively simple and they require little tending. However, further research on experimental treatment systems together with long-term experiences from full-scale operations are needed, in order to establish the final design parameters for application of such a treatment system.

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