

USE OF A HORIZONTAL BIOFILTER AND A CONSTRUCTED WETLAND TO TREAT DOMESTIC WASTEWATER

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ABSTRACT

Industrial, livestock, and domestic wastewater are the three major polluting sources of rivers in Taiwan. Statistics showed that the annual discharge of domestic wastewater pollutants in 2005 exceeded 59% (676 tonnes BOD₅/day) of the daily load, which was far more than the industrial (22%) and the livestock (18%) wastewater. In this study, a two-stage constructed wetland system was set up to treat the domestic wastewater discharged to the creek. The intercepted wastewater was pumped and treated by an aerated biofilter, and followed by a subsurface flow constructed wetland. Dimension of the biofilter was 19.6 m (L) x 0.9 m (W) x 1.0 m (H), with an effective volume of 15.3 m³.

Two types of media in the biofilter were tested. The first was the rope, with the flowrates controlled at 15.3, 31.1, and 45.3 m³/d, which gave the HRTs of 23.6, 11.8, and 8.1 hours in the biofilter, respectively. The second was a high surface area filter medium (Matala[®]), and the flowrates were controlled from 15.5 to 117.3 m³/d, with the HRTs from 23.1 to 3.0 hours. Results from the rope medium in the biofilter with the constructed wetland showed the removal efficiencies of BOD₅, SS, TCOD, NH₃-N and PO₄-P were 75.3, 74.4, 74.3, 72.8, and 34.6 %, respectively. In the second part with the Matala medium in the biofilter and without the constructed wetland, the removal efficiencies were 69.1, 84.2, 74.7, 76.4, and 34.2%, respectively. It is believed that, due to a higher surface area and better biofilm attachment and/or retaining characteristics, the Matala[®] was found to perform better than the rope medium.

Keywords: biofilter, constructed wetland, domestic wastewater, nutrient removal, subsurface flow system.

1 INTRODUCTION

Economic and population growths from the last five decades imposed heavy load to the environment in Taiwan. As for the water pollution problem, it was found that more than 25% of the rivers in Taiwan are heavily polluted (ROCEPA, 2006). The three major sources of pollutant to the rivers are domestic, industrial, and livestock wastewater. With an efficient enforcement of the regulations, discharges from industrial and livestock sectors are significantly reduced and now are under well controlled. As to the domestic wastewater, due to the delay in the construction of the sewage system, most of the wastewater is discharged directly to the river. Statistics showed that the annual discharge of domestic wastewater pollutants in 2005 exceeded 59% (676 tonnes BOD₅/day) of the daily load, which was far more than the industrial (22%) and the livestock (18%) wastewater (ROCEPA, 2006). Reduction of the domestic waste load to the rivers has the highest priority.

The sewage treatment infrastructure can be regarded as the most effective measure in the reduction of pollution from domestic wastewater. However, such infrastructure applies only in the urban area and even in the urban area the local governments are normally reluctant to allocate a sufficient budget to the construction of the sewage system considering the high construction cost, a long construction time, and the low engineering visibility. At the end of 2005, domestic wastewater treated was as low as 31.1%, with the sewer connection percentage being as low as 14.04% in Taiwan area. Even in Taipei city, the Capital of Taiwan, this ratio was only 76.24% (Ministry of Interior, ROC, 2007). Therefore, in order to reduce the load to the rivers, the promotion of sewage treatment within the urban area needs

to be speed up. At the same time, for the area with no sewage system planning, the constructed wetland system can play an important role in the pollutant reduction.

The application of natural treatment systems in water quality management has been widely reported (Reed and Brown 1995; Adler et al. 1996; Kemp and George 1997). In recent years, constructed wetland used in water quality improvement has become popular and received wider acceptance. The wetland system is typically applied in the removal of BOD₅, SS, and nutrients such as nitrogen and phosphorus of domestic wastewater after secondary treatment (Juwarkar et al. 1995; Thomas et al. 1995). Applications in industrial (Simi and Mitchell 1999), agricultural (Moore et al. 2001), landfill leachate (Kozub and Liehr 1999; Rush and Liehr 1999), and acid mine drainage (Mays and Edwards 2001; William et al. 1999) wastewaters were also reported. Wetland systems have the advantages such as low initial cost, easy to operate and maintain, low energy consumption, and no chemical addition. In this study, a plug flow biofilter was combined with a subsurface flow constructed wetland to treat domestic wastewater. Two types of media in the biofilter were tested: the rope and the flat sheet (i.e., the Matala®). In part I of the on-site test, rope medium was used in the filter and its effluent flowed into the constructed wetland. Overall removal efficiencies of BOD₅, SS, TCOD and NH₃-N ranged from 72.8-75.3%. In part II of the test, the rope medium was replaced with the Matala® in the biofilter, and the removal efficiencies of BOD₅, SS, TCOD and NH₃-N from the filter only without passage through the constructed wetland ranged from 69.1-84.2%.

2 METHODS AND MATERIALS

2.1 Experimental set up

The test site was located in the Millennium Park of Pingtung City, Pingtung County, Taiwan. Untreated domestic wastewater from nearby households was discharged to the Wan Nian Creek, which flowed through the Park. Wastewater was pumped to a storage tank, and then flowed through a flow measuring device to the treatment system consisting of a biofilter equipped with a 2 Hp blower and a constructed wetland. In part I of the test, the performances of the biofilter with rope medium and of the constructed wetland were both monitored. In part II, the rope medium in the filter was replaced with the Matala® and only performance of the filter was evaluated. The testing period for the first part was from Feb. to May, 2003 and the second part followed, from June till end of Nov., 2003.

The aerated biofilter was a steel-made rectangular tank with a dimension of 19.6 m (L) x 0.9 m (W) x 1.0 m (H) and an effective volume of 15.3 m³. The filter was divided into 13 compartments, with an upper baffle installed every 1.5 m and a 30 cm height lower baffle installed in the center of each compartment. This design provided a plug flow pattern to prevent short circuit in the flow and prevention of the solids traveling to the outlet of the filter. The constructed wetland consisted of two 15 m long trapezoid channels, with the cross section shown in Fig. 1. Each channel was filled with 19.2 m³ of rocks. The porosity in the channel was found to be 0.468, with an effective volume of 9.0 m³ in each channel.

In the first part of the test, the first and the last compartment of the biofilter were filled with a ball-shape medium to retain the suspended solids. All other compartments were filled with rope medium, which had an outside diameter of 50 mm and a specific surface area of 222 m²/m³. The effective volume of the biofilter was 15.24 m³ (12.92 m³ of rope with 2.32 m³ of ball-shape). The porosity was greater than 99%, with a total length of 462.3 m rope installed, which provided a total surface area of 2866 m² in the biofilter. In the second part of the test, the rope medium was replaced with the flat sheet medium (the Matala®). Effective volume of the filter was 14.90 m³ (13.987 m³ of Matala® with 1.03 m³ of ball-shape). The total surface area provided in the filter was 2712 m², with detailed distribution information of each compartment shown in Table 1.

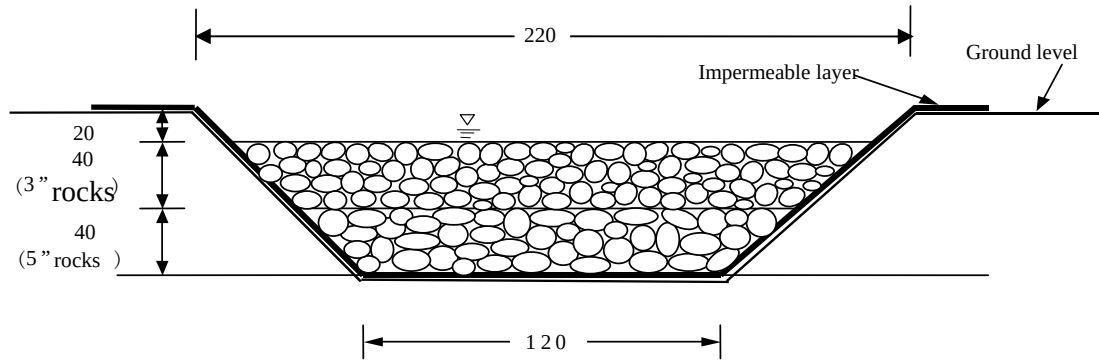


Figure 1 Cross section of the constructed wetland (unit: cm)

Table 1. Volume and distribution of the Matala medium in each compartment of the biofilter.

Compartment	1	2	3	4	5	6	7	8	9	10	11	12	13
Item													
Medium vol. (m ³)	1.08	0.48	0.47	0.45	0.62	0.66	0.66	0.66	0.66	0.64	0.66	0.66	0.71
Individual medium surface area (m ²)	75.6	72.8	71.9	76.4	136.5	190.2	190.2	214.8	239.4	232.9	239.4	270.6	288.4
Accumulated medium surface area (m ²)	75.6	148.4	220.3	296.7	433.1	623.4	813.6	1028.5	1267.4	1500.8	1740.2	2010.8	2299.2
Individual compartment vol. (m ³)	1.03	1.04	1.07	1.08	1.09	1.12	1.14	1.17	1.20	1.22	1.23	1.24	1.34
Distance from influent (m)	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.6

2.2 Analyses

On-site monitoring of the test included pH, temperature, and dissolved oxygen (DO). Laboratory analyses included SS, VSS, TCOD (Total COD), SCOD (Soluble COD), NH₃-N, TKN (Total Kjeldahl Nitrogen), TP, and PO₄-P, and all followed the Standard Methods (1995). Solids were filtered using glass fiber filter paper (2540 D and 2540 E). BOD₅ was measured followed 5210 B. Total and soluble CODs were measured using the dicromate reflux method described in 5220 C. Here, soluble was defined as anything could pass through a 0.45μ membrane filter. Ammonia, and Total Kjeldahl Nitrogen (TKN) were analyzed following 4500-NH₃ C, and 4500-N_{org} B, respectively. Total and ortho-phosphate followed 4500-P E. For colorimetric methods, a Hitachi Spectrophotometer U-2000 was used.

3 RESULTS AND DISCUSSION

3.1 Performance of the biofilter and constructed wetland

Results from Part I of the on-site test are shown in Table 2. The influent concentrations are lower than the typical domestic wastewater. This is due to the fact that untreated domestic wastewater was discharged to the creek and was possibly diluted by other sources of water such as surface runoff or irrigation runoff, etc. During the test period flowrates of 15.5, 31.1, and 45.3 m³/d were tested, and this gave the HRTs of 23.6, 11.8, and 8.1 hours in the filter and 29.7, 13.9, and 9.5 hrs in the constructed

Table 2. Results from the biofilter and constructed wetland test.

Item \ Unit	Influent	Effluent of biofilter	Effluent of constructed wetland	Overall removal efficiency (%)
BOD	84.3±10.7(n=9)	41.7±10.0(n=9)	20.8±7.2(n=9)	75.3±7.7(n=9)
SS	42.1±23.1(n=9)	17.1±10.9(n=9)	9.0±4.3(n=9)	74.4±15.5(n=9)
VSS	25.2±13.3(n=9)	12.2±8.2(n=9)	5.4±3.9(n=9)	74.1±18.4(n=9)
TCOD	174.4±22.3(n=9)	81.8±17.3(n=9)	43.9±10.2(n=9)	74.3±7.8(n=9)
SCOD	91.8±20.3(n=9)	54.8±2.0(n=9)	27.2±9.8(n=9)	69.8±10.3(n=9)
NH ₃ -N	25.3±3.0(n=9)	16.4±3.0(n=9)	6.8±1.9(n=9)	72.8±7.9(n=9)
TKN	32.7±4.0(n=6)	22.7±2.5(n=6)	11.4±3.0(n=6)	64.7±9.5(n=6)
TP	5.2±0.7(n=6)	4.1±0.5(n=6)	3.3±0.7(n=6)	36.1±13.4(n=6)
PO ₄ -P	4.1±0.7(n=8)	3.3±0.5(n=8)	2.6±0.5(n=8)	34.6±12.0(n=8)

*All units are in mg/L, n = sample number.

wetland, respectively. The average water temperature during this period of time was 27°C. The removal efficiencies of BOD₅, SS, VSS, and TCOD are all greater than 50% (50-54%). The removal efficiency of SCOD was lower (40.6±13.8%), this is because the removal of SCOD relies mainly on microbial degradation. Performance of the biofilter in removal of N and P was not quite satisfactory, with efficiencies ranged 18 to 36%. But, after the second stage (the constructed wetland), the overall performance was significantly improved, with around 35% (TP and PO₄-P) to 73% (NH₃-N).

With the design of a plug flow pattern and fixed film biological growth in the biofilter followed by the constructed wetland, removal efficiencies for BOD₅, SS, VSS, and TCOD were all around 74-75%. Even with the SCOD, around 70% removal efficiency could also be reached. Plant growth (*Ipomoea aquatica*) in the rock bed of the constructed wetland was also very helpful, not just in the N and P uptake, but also in the removal of SS and COD from mechanisms of filtration and biological conversion. Compared with traditional wastewater plant's high initial and running cost, high energy and chemical consumption, and complicated operational skill, this simple two stage design of biofilter with constructed wetland can also provide relatively high removal efficiencies in traditional pollutants such as BOD and SS, also in nutrients such as N and P.

The fixed film biological growth system has the advantages of long SRTs, low excessive biomass production, and low energy consumption (compared with the suspended growth system). During the test, 3 ropes (each had a length of 30 cm) were deployed in the front, middle, and end compartments to evaluate the biomass growth. After a steady state growth of the biofilm, the ropes were removed and biofilm was washed off for biomass determination. After calculations it was found that in the front, middle, and end compartments the SS concentrations were 735, 560, 375 mg/L, and the VSS were 553, 396, and 188 mg/L. A suspended growth system relies on recirculation of the settled sludge to increase the biomass concentration, as shown in conclusion of CSTR model (Metcalf & Eddy 2003):

$$X_a = \theta_c Y(S_o - S) / \theta (1 + b\theta_c)$$

In this fixed film system without recirculation of the sludge, a longer SRT enables a higher biomass concentration. Considering a typical value of yield coefficient of 0.5 for the treatment of domestic wastewater using activated sludge process and an influent concentration of 85 mg BOD₅/L, the suspended growth system without sludge recirculation could only support a biomass concentration of about 50 mg/L, while in this fixed film biofilter, a mean VSS concentration of 379 mg/L was observed. The superiority of fixed film system over the suspended growth is obvious in maintaining a higher biomass concentration.

3.2 Performance of the Matala[®] medium

Main purpose of the second part of the test was to evaluate performance of the Matala[®] medium in the biofilter. The testing period coincided with the flood season in southern Taiwan (May to October), and the plant growth on the rock bed of the constructed wetland was flooded several times. Therefore, in this part only the performance of the biofilter is discussed. Deployment of the medium in each compartment is shown in Table 1, with results of this test shown in Table 3. During the test flowrates of 15.5, 31.1, 59.5, 91.4, and 117.3 m³/d were tested, and this gave the HRTs of 23.1, 11.5, 6.0, 3.9, and 3.0 hours in the biofilter, respectively. The average water temperature during the test was slightly higher than the previous study, about 33°C. Due to the higher rainfall in the rain season the influent pollutant concentrations were much lower than the previous study. But, the performance of the medium was quite satisfactory. As shown Table 3, removal efficiencies of the BOD₅ and TCOD were around 70-75%, with SS and VSS removal efficiencies as high as 84-88%. Single digits of SS and VSS in the effluent were observed, and this could be attributed to the high surface area and good surface attachment and filtration of the medium. Nitrogen removal ranged from 72-76%, and this could be attributed to higher biomass concentration and longer SRT provided by the medium which enabled the nitrification to occur (this needs the nitrate data to prove). Phosphorus removal efficiency was between 34-38%. It is estimated that, with a constructed wetland following the biofilter, over 85% of the influent nitrogen and around 50% of the influent phosphorus can be removed. Of course, the higher in the efficiency of N and P removals, the more frequent harvesting is needed to control the plant growth on the constructed wetland, otherwise the decay due to seasonal variation would bring back the N and P into the water body again and causes the deterioration of the effluent quality.

Table 3. Results of the Matala medium test.

Item \ Unit	Influent	Effluent of biofilter	Removal efficiency (%)
BOD	41.1±21.6(n=11)	10.1±2.4(n=11)	69.1±12.9(n=11)
SS	27.1±9.5(n=12)	4.4±2.6(n=12)	84.2±5.4(n=12)
VSS	21.0±7.1(n=12)	2.7±2.2(n=12)	88.1±7.9(n=12)
TCOD	95.6±26.6(n=11)	22.1±3.9(n=11)	74.7±9.3(n=11)
SCOD	54.2±25.8(n=12)	18.5±4.5(n=12)	57.1±21.3(n=12)
NH ₃ -N	15.1±4.3(n=10)	3.4±1.0(n=10)	76.4±7.2(n=10)
TKN	19.5±5.2(n=10)	5.5±1.2(n=10)	72.1±6.2(n=10)
TP	2.8±1.1(n=9)	1.6±0.6(n=9)	37.5±15.7(n=9)
PO ₄ -P	1.6±0.8(n=7)	1.0±0.4(n=7)	34.2±15.2(n=7)

*All units are in mg/L, n = sample number.

Table 4 shows the concentration variation along the biofilter. With the flowrates ranging from 15.5 to 117.3 CMD, SS and VSS had the most significant removal efficiencies, with about 70% of solids removed in the front 1/3 of the reactor. In the TCOD, 70% removal occurred at the first 2/3 long of the filter's length (i.e., at 13.5 m from the influent). Soluble COD could travel the longest distance, with about 1/3 still remained at the end of the filter (19.6 m distance from the influent). As previously mentioned, fixed film process has the advantage of operating under higher SRTs, and thus supporting higher biomass concentrations. Table 5 shows the biomass concentrations of SS and VSS calculated from the wash-off of the biofilm along the distance of the biofilter. At the distance of 3 m the high SS and VSS concentrations could be interpreted as filtration mechanism, as the influent SS or VSS being retained in the very front of the reactor, with a ratio of VSS/SS = 0.53. At the middle of the biofilter (i.e., 10.5 m), extraordinary high levels of SS and VSS indicated the accumulation of influent solids and/or growth of biofilm. For other part of the reactor, an average of 1280 mg/L of SS concentration (VSS/SS = 0.78) was observed. This value was even higher than the rope medium, which was only 557 mg/L. This indicated the superiority of Matala[®] medium over the rope either due to a higher

Table 4. Concentration variation in the biofilter.

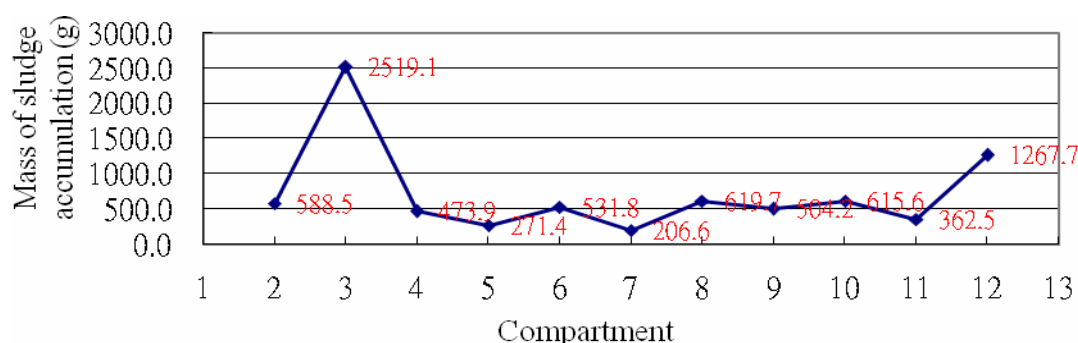
Concentration (mg/L)	Distance (m)						
	0	4.5	7.5	10.5	13.5	16.5	19.6
SS	25.0±3.0 (n=3)	9.9±3.8 (n=5)	7.6±3.1 (n=5)	6.8±1.4 (n=5)	9.3±6.1 (n=5)	5.3±2.1 (n=5)	4.0±0.5 (n=3)
VSS	21.7±3.3 (n=3)	8.4±3.5 (n=5)	6.3±2.3 (n=5)	5.4±1.3 (n=5)	6.7±4.7 (n=5)	4.1±1.4 (n=5)	2.5±0.5 (n=3)
TCOD	96.3±36.6 (n=3)	44.0±5.2 (n=5)	39.5±5.2 (n=5)	34.4±5.3 (n=5)	29.6±2.0 (n=5)	26.1±4.4 (n=5)	22.7±5.1 (n=3)
SCOD	59.0±37.5 (n=3)	36.0±5.5 (n=5)	30.5±4.5 (n=5)	27.6±3.1 (n=5)	24.9±3.9 (n=5)	23.3±5.9 (n=5)	19.0±6.6 (n=3)

Table 5. Variation of biomass in the biofilter filled with Matala® medium.

Distance (m)	3	6	10.5	13.5	16.5
SS (mg/L)	5644	1023	5689	1505	1315
VSS (mg/L)	2984	793	3959	1168	995
VSS/SS	0.53	0.78	0.70	0.78	0.76

specific surface area and the tridimensional distribution of the fibers and forming of bacterial flocks in the interstitial spaces or a better surface roughness to retain or to support the biofilm growth.

At the end of the test, the Matala® medium was removed to inspect the sludge accumulation in the compartments, as data shown in Figures 2 and 3. Compartment #3 had the highest sludge accumulation of more than 2.5 kg dry solids, with compartment #12 had the second highest sludge accumulation of 1.27 kg dry solids. The VSS/SS ratios in each compartment (0.28-0.56) was significantly lower than the ratio from the medium (0.78), indicating the sludge settled in the bottom of the compartment had less active biomass than the biofilm growth in the medium. This information could serve in the determination of frequency of each compartment for sludge withdrawal.

**Figure 2 Accumulation of the sludge along the length of the biofilter**

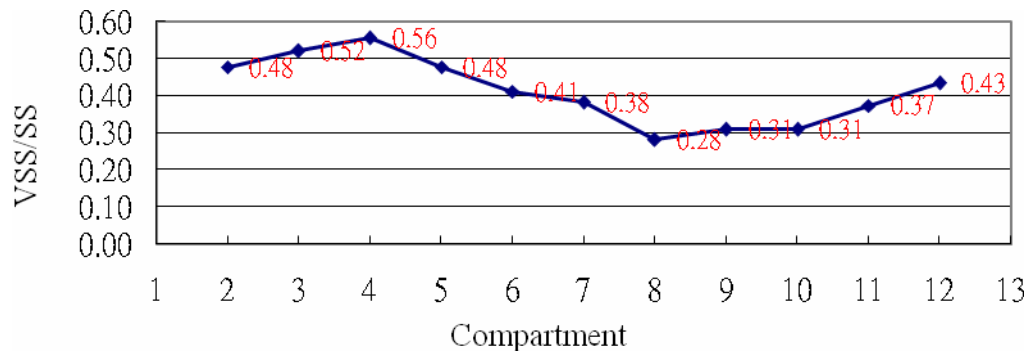


Figure 3 VSS/SS of the sludge along the length of the biofilter

4 CONCLUSIONS

1. The two-stage treatment process of aerated biofilter and constructed wetland has the advantages of simple design, easy operation, and low initial and O&M cost. With the rope medium in the biofilter and the constructed wetland, the removal efficiencies of BOD, TCOD, SS, and VSS BOD₅, SS, TCOD, NH₃-N and PO₄-P were 75.3, 74.4, 74.3, 72.8, and 34.6 %, respectively. With the Matala[®] medium in the biofilter and without the constructed wetland, the removal efficiencies were 69.1, 84.2, 74.7, 76.4, and 34.2%, respectively.
2. In the removal of SS and TCOD with Matala medium in the biofilter, around 70% of the removal occurred in the front 1/3 of the reactor, with the 30% removed by the 2/3 of the biofilter. Therefore, amount of the medium can be significantly reduced in the latter part of the reactor for cost consideration.
3. Due to the higher specific surface area and better biomass retainance or attachment characteristics, the Matala medium was found to perform better than the rope medium. The Matala[®] medium was operated under lower influent BOD levels (≈ 41 mg/L) than the rope medium (≈ 84 mg/L), but could support higher levels of biomass concentration (1280 mg/L vs. 557 mg/L).
4. The sludge accumulated in the compartments of the biofilter has to be regularly withdrawn in order to ensure steady removal efficiency. The plant growth in the rock bed of the constructed wetland has also to be regularly harvested in order to ensure a constant removal of nutrients such as nitrogen and phosphorus.

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