RUNOFF TREATMENTIN MIXED DEVELOPMENT AREA THROUGH LAYER MIXED WITH VEGETATIONCOMPOSITE BIORETENTION MEDIA: BOD REMOVAL

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Abstract

Bioretention systemhas become one of the common Best Management Practices (BMPs) for storm water management in Malaysia. As Biochemical Oxygen Demand (BOD) was one of the three major pollutants detected in main rivers in Malaysia, abioretention mesocosm study was conductedto assess the performance of Biochemical Oxygen Demand (BOD) removal in bioretention systems. Natural runoff from a mixed development area that consists of residential, commercial and urban agricultural areas was used as influent to compare the effluent quality from two types of enhanced bioretention media using mixtures of shredded newspaper and crushed cockle shell (uniformly mixed and layer mixed) and standard bioretention media. Comparison between vegetated and non-vegetated mesocosm has concluded that mesocosm with vegetation demonstrated better BOD level. Results showed that enhanced bioretention media, especially layer mixed with vegetation media is able to lower the BOD in effluentup to below 1mg/L, which is class I (conservation of natural environment) under National Water Quality Standards for Malaysia. Throughout the 16-week study, the layer mixed with vegetation media has performed 40% better than standard bioretention media, which indicatesits great potential in application to target on nutrient rich runoff treatment.

Key Words: Best Management Practices (BMPs), Biochemical Oxygen Demand (BOD), Bioretention Media, Stormwater Treatment, Water Quality

1. INTRODUCTION

Environmental Quality Report (EQR) Malaysia(DOE, 2012)has reported that biochemical oxygen demand (BOD) was one of the three major pollutantsdetected, despiteammoniacal nitrogen (NH3-N) and suspended solids (SS) in main rivers in Malaysia. Based on river classification as shown in Table 1, 34 rivers out of 473 rivers tested are classified as “polluted”. In terms of BOD, 17 rivers are classified as ClassIV and 17 rivers as Class V.

BOD Concentration (mg/L)	Class	Uses
<1	I	Conservation of natural environment. Water Supply I – Practically no treatment necessary. Fishery I – Very sensitive aquatic species.
1-3	II	Water Supply II – Conventional treatment required. Fishery II – Sensitive aquatic species. Recreational use with body contact.
3-6	III	Water Supply III – Extensive treatment required. Fishery III – Common, of economic value and tolerant species; livestock drinking.
6-12	IV	Irrigation
>12	V	None of the above

Table - 1 River water quality classification based on BOD concentration in Malaysia

(DOE, 2012)

High BOD can be attributed to inadequate treatment of sewage or effluent from agro-based and manufacturing industries.If water of a high BOD value flows into a river, thebacteria in the river will oxidize the organic matter,consuming oxygen from the river faster than it dissolvesback in from the air. If this happens, fish will die fromlack of oxygen, a consequence known as a fish kill. Insufficient amount of dissolved oxygen will also lead to organisms that are more tolerant of lower dissolved oxygen levels may replace a diversity of natural water systems.Therefore, it is important to control the pollution from the source, especially runoff from various municipal land uses and activities in urbanization.

For urban runoff treatment, bioretention systems has gained popularity for application in temperate countries, not only due to itsflexibility in terms of size and appearance but also its ability to remove nutrient efficiently(Bratieres et al., 2008).In recent years, studies on bioretentionand other Best Management Practices (BMPs) have shown advancement in nutrient removal by incorporation of additives, such aswater treatment residues (WTRs)(Glaister et al., 2014), newspaper (Stander and Borst, 2009) and oyster shells (Wang et al., 2013). However, due to different rainfall regime for temperate countries and tropical countries, where tropical countries' average annual precipitation is 3 times more than in temperate countries(Goh et al., 2015a), it is important to evaluate the performance of enhanced bioretention media using tropical shrub to treat nutrient rich runoff under tropical climate.

Based on previous study conducted, it was found that bioretention media added with shredded newspaper performed better in treating nutrient rich runoff(Goh et al., 2015a), and *Hibiscus rosa-sinensis* is able to adapt in nutrient rich runoff and grow well under bioretention media added withcrushed cockle shell (Goh et al., 2015b).In this study, to further enhance the performance in treating nutrient rich runoff, two types of enhanced bioretention media, namely layer mixed(ComA) and uniformly mixed (ComD) media, both containing crushed cockle shell and shredded newspaper as additives were used to compare its performancewith standard bioretention media (STD). The objective of the study is to investigate the BOD removal performance of the further enhanced bioretention media so that the effluent quality required by local design manualis met.

2. METHODOLOGY

2.1Media Selection and Mesocosm Preparation

In this study, standard bioretention media (STD) was used as the base line study, with composition according to Urban Stormwater Management Manual for Malaysia (MSMA)(CFWP & MDE, 2000; DID, 2011). The composition for various bioretention media is shown in Table 2.

Type of bioretention media	Symbol	Composition Description	Quantity of mesocosm
Standard Mix	STD	60% medium sand, 20% top soil and 20% compost	1 non-vegetated 3 vegetated
Layer Mixed (Composite media)	ComA	200mm (top): standard mix + 10% crushed cockle shell 400mm (bottom): standard mix + 10% shredded newspaper	1 non-vegetated 3 vegetated
Uniformly mixed	ComD	Standard mix + 5% crushed cockle shell + 5% shredded newspaper	1 vegetated

Table - 2 Bioretention media composition (by volume) and quantity of mesocosm tested

The experiment comprised bioretention mesocosm setup, plant selection and establishment, selected runoff as presented in Goh et al. (2015).The mesocosm were constructed from polyvinyl chloride (PVC) pipes with 300mm diameter, 750mm length and horizontal sampling port at the base to hold

50mm of gravel screenings drainage layer, 600mm of bioretention media and 150mm freeboard. Red Hot Chinese Hibiscus (*Hibiscus rosa-sinensis*) was cultivated using polybags before repotted into mesocosm for establishment. Natural runoff from surrounding municipal drain located nearby Universiti Sains Malaysia Engineering Campus was selected, as it received mixture of pollutant source from municipal grey water from residential and commercial areas, fertilizers from urban agriculture and runoff from the main road. A 500L tank equipped with auto-mixer was used to store the runoff collected.

2.2 Experimental Procedure and Data Analysis

During the 3-month establishmentperiod (February to April 2015) before the runoff test, each mesocosm was watered with 10L dechlorinated tap water weekly for plant root development. Duringthe 16-week runoff test (May to August 2015), 17.5L of collected runoff was dosed to each mesocosm weekly. BOD test was conducted for week 1, week 9 and week 15. During the BOD test week, 1L water sample was collected from the 500L tank before dosing and refrigerated at 4°C. Effluent sample for each mesocosm was collectedfrom enclosed effluent collection at 24 hours after dosing. BOD concentrations for all samples were tested withHACH Method 8043 using HACH nutrient buffer pillow, a dilution methodaccording toAPHA Standard Method5210-B(Eaton et al., 2005). The pH and temperature were measured during the runoff test using YSI handheld multi-parameter meter.

Dissolved Oxygen (DO) saturation (%) was calculated by:

$$DO_{sat} = \frac{DO_x}{C_S} x100\% \quad (1)$$

Where:
DO_{sat} = DO saturation (%)
DO_x = Measured DO (mg/L), based on assumption of atmospheric pressure at 760mm Hg for surface water and no salinity correction applied
C_S = Saturated DO concentration (mg/L) from Table 6.2-6 in National Field Manual for the Collection of Water-Quality Data(Wilde et al., 1998)

BOD_5 concentration (mg/L) for each mesocosm was calculated by:

$$BOD_5 = \frac{DO_0 - DO_5}{P} \quad (2)$$

Where:
DO_0 = Dissolved oxygen concentration at 20°Cfor day 1 (mg/L)
DO_5 = Dissolved oxygen concentration at 20°Cfor day 5 (mg/L)
$P = fraction\ of\ sample\ used = \frac{V}{300}$
V = volume of sample used (mL)

Average BOD_5 concentration, μ was calculated by:

$$\mu = \frac{BOD_{w1} + BOD_{w9} + BOD_{w15}}{3} \quad (3)$$

Where:
BOD_{w1} = Average BOD_5 for week 1 (mg/L)
BOD_{w9} = Average BOD_5 for week 9 (mg/L)
BOD_{w15} = Average BOD_5 for week 15 (mg/L)

For BOD sub-index (SIBOD) calculation:

$$SIBOD = 100.4 - 4.23x \quad \text{for } x \leq 5 \quad (4)$$
$$SIBOD = 108 * \exp(-0.055x) - 0.1x \quad \text{for } x > 5$$

Where:
x = BOD_5 (mg/L)

3. RESULTS AND DISCUSSION

3.1 Dissolved Oxygen (DO)

Table 3 showspreliminary DO saturation (%) of influent and effluent over time. Over the 16-week on-site observation for the collected runoff (detailed results are not presented in this paper), theaverage DO saturation % was below 20%, indicating that the runoff was under polluted condition. From Table 3, it is shown that all types of bioretention media are able to increase the DO saturation, which means DO level in the effluent increased after treatment.Out of five types of bioretention media, the layer mixed with vegetation composite media (ComA“1”) shows the highest DO saturation, indicated that the vegetation worked well with the enhanced layered media to increase the DO level in the effluent. However, as the experiment conducted was mesocosm study, the DO reading for effluent was taken at the effluent collection tank. Therefore, the DO reading is only applicable for BOD calculation and it may not represent the real site condition.

Type of Mesocosm	Week 1	Week 9	Week 15	Average
C_{in}	13.09	15.18	13.75	14.01
STD“0”	56.44	55.34	55.23	55.67
STD“1”	57.68	56.58	56.03	56.77
ComA“0”	57.98	60.18	60.84	59.66
ComA“1”	59.70	64.10	64.28	62.69
ComD“1”	59.74	59.74	55.78	58.42

Table - 3Preliminary DOsaturation (%)with time for influent (C_{in}), standard columns, layer mixed (ComA) and uniformly mixed (ComD)(“0” indicated non-vegetated and “1” indicated vegetated mesocosm)

3.2 Biochemical Oxygen Demand (BOD)

Result ofBOD concentration over time and range of water qualityclassification by Department of Environment Malaysia (DOE, 2012)is shownin Figure 1. From the figure, it is found that average concentration of the collected runoff is more than 12mg/L, which is classified as “polluted” and the indication is the same as the classification obtained from DO saturation %. This result has proven that the DO concentration measured on site is able to providea preliminary classification for runoff without conducting BOD test.

Both vegetated and non-vegetated STD mesocosm are able to reduce the BOD concentration to the range between 1-3mg/L, which is Class II. For enhanced bioretention media, especially layer mixed media with vegetation (ComA“1”), the BOD concentration has been reduced to range lower than 1mg/L, which is Class I. This result has shown a significant improvement compared to previous studies by Hunt et al. (2008) on field-scale bioretention cell in North Carolina, which recorded an average BOD5 of 8.54 mg/L for influent and 4.18 mg/L for effluent. This can be explained by laboratory studies conducted by Meschke and Sobsey (2003) that found *E. coli* removal rates increased with less permeable soils. This can be confirmed by lower BOD_5 concentration recorded by mesocosm added with shredded newspaper and crushed cockle shell, due to lower hydraulic conductivity (Goh et al., 2015b). The fine soil particles such as clays and silts that mixed with additives in bioretention media, especially shredded newspaper may physically remove microorganism more easily and at higher efficiencies than pure sand fill soil (Goh et al., 2015a; Hunt et al., 2008; Meschke and Sobsey, 2003).

Figure 2 shows comparison of various bioretention media - STD, Com A and Com D in terms of BOD removal percentage from natural runoff over time.During the early stage of the mesocosm study, all types of mesocosm achieve similar removal rate, which is between 90%-94%. After 9 weeks, it was observed that the overall removal rate has reduced, especially for standard mesocosm. Over the period of 16 weeks, BOD removal performance in non-vegetated mesocosm has gradually reduced but vegetated mesocosm has still managed to maintain the removal at steady condition, particularly in ComA“1”, which managed to maintain the removal rate above 92%.

By comparing the average effluent concentration of both vegetated mesocosm for ComA“1” and STD, ComA“1” (0.86mg/L) performed 46% better than STD (1.60mg/L).This may be attributed to the anaerobic zone created by newspaper layer that reduced the oxygen demand in effluent (Goh et al., 2015a). This has shown the great potential of vegetated layered composite bioretention media for application in targeting runoff that contains high BOD level due to excessive nutrient. In overall, all types of bioretention media are able to remove more than 80% of BOD concentration. By comparing to the previous results conducted by Hunt et al. (2008), which recorded a 63% BOD_5 concentration reduction, this result confirmed theability of bioretention systems to reduce the BOD in receiving water, regardless of runoffconcentration.

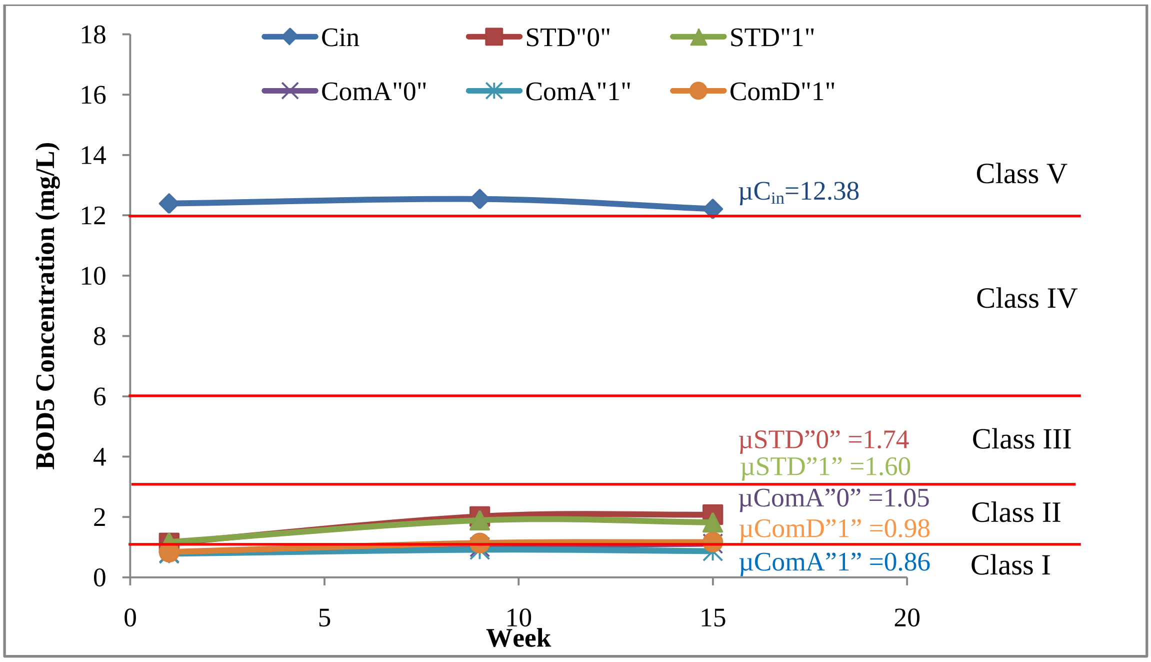

Fig 1.BOD concentration (mg/L) with time for influent (C_{in}), standard columns (STD), layer mixed (ComA) and uniformly mixed (ComD)

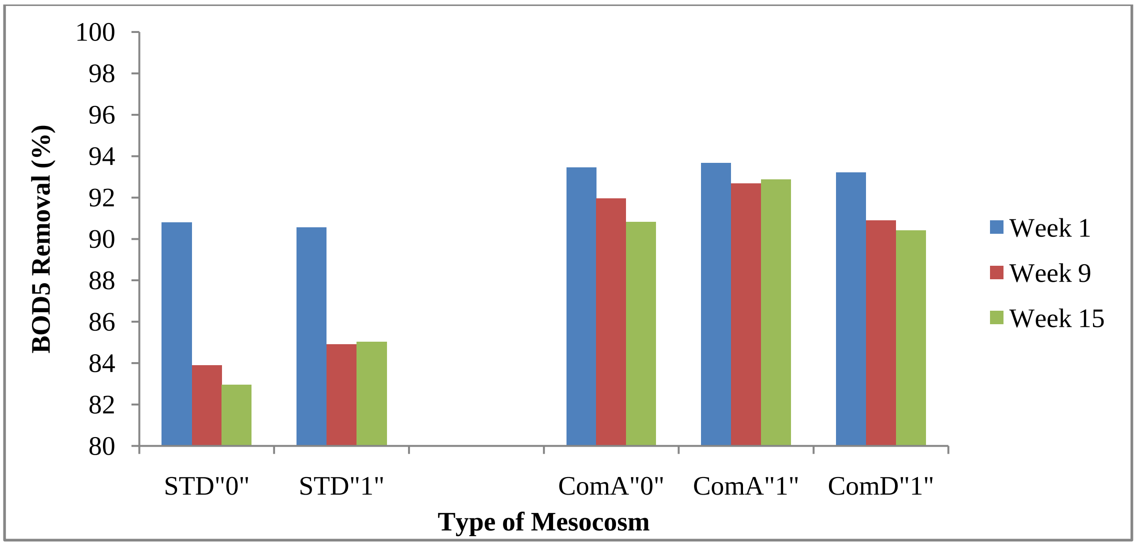

Fig 2.Comparison of BOD removal (%) from natural runoff bySTD, Com A and Com D over time

Similar to DO saturation, in terms of BOD sub index (SIBOD), all types of bioretention media are able to increase the SIBOD of effluent from “polluted” to “clean after treatment (Figure 3).

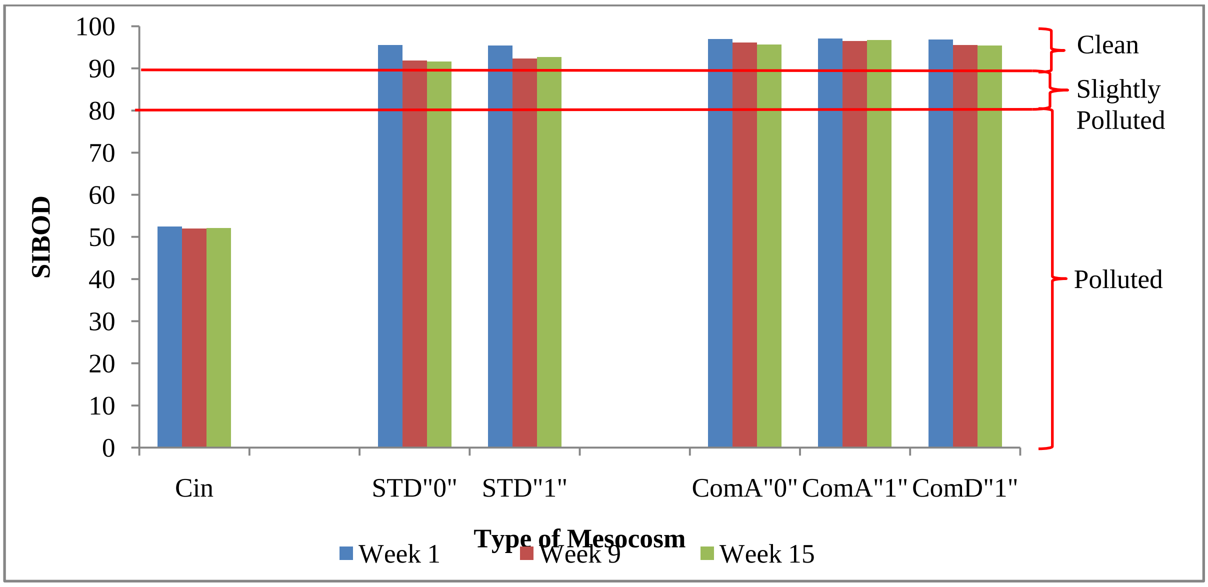

Fig 3. Comparison of SIBOD performance for STD, Com A and Com D

4. CONCLUSIONS

BOD removal performance of two different bioretention media mixtures with and without vegetation were evaluated and compared with the standard mixture according to MSMA. Over a testing period of 16 weeks, it is found that effluent from all mesocosm are able to increase the DO saturation and BOD sub index (SIBOD) of natural runoff from “polluted” to “clean”. In overall, all types of bioretention media able to remove more than 80% of BOD concentration, which confirms theability of bioretention systems to reduce the BOD in receiving water, regardless of runoffconcentration. Results showed that vegetated mesocosm for composite layer mixed media (ComA“1”) achieved 46 % of improvement compared to standard media (STD) in BOD removal. This result may be attributed to the use of shredded newspaper that bound well with silt and clay in the media to create less permeable soil to increase the removal of microorganism in the soil.This has proven that composite layer mixed media has performed the best in treating nutrient rich runoff, and it can be applied in mixed development areas to provide a better urbanscape management and protection of water quality.

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References

[1] Bratieres, K., Fletcher, T., Deletic, A. & Zinger, Y. 2008. Nutrient and sediment removal by stormwater biofilters: A large-scale design optimisation study. *Water Research,* **42(14),** 3930-3940.

[2] DOE. 2012. *Malaysia Environmental Quality Report*. Strategic Communication Division, Department of Environment Malaysia (DOE), Putrajaya, Malaysia.

[3] Eaton, A., Clesceri, L. S., Rice, E. W., Greenberg, A. E. & Franson, M. 2005. APHA: Standard Methods for the Examination of Water and Wastewater. *Centennial Edition., APHA, AWWA, WEF, Washington, DC.*

[4] Glaister, B. J., Fletcher, T. D., Cook, P. L. & Hatt, B. E. 2014. Co-optimisation of phosphorus and nitrogen removal in stormwater biofilters: the role of filter media, vegetation and saturated zone. *Water Science & Technology,* **69(9),** 1961-1969.

[5] Goh, H. W., Zakaria, N. A., Lau, T. L., Foo, K. Y., Chang, C. K. & Leow, C. S. 2015a. Mesocosm study of enhanced bioretention media in treating nutrient rich stormwater for mixed development area. *Urban Water Journal,* **(ahead-of-print),** 1-9.

[6] Goh, H. W., Zakaria, N. A., Lau, T. L., Foo, K. Y. & Chang, C. K. 2015b. The role of tropical shrub with enhanced bioretention media in nutrient rich runoff treatment. 36th IAHR World Congress, 28 June – 3 July 2015, The Hague, the Netherlands.

[7] Stander, E. K. & Borst, M. 2009. Hydraulic test of a bioretention media carbon amendment. *Journal of Hydrologic Engineering,* **15(6),** 531-536.

[8] Wang, Z., Dong, J., Liu, L., Zhu, G. & Liu, C. 2013. Study of oyster shell as a potential substrate for constructed wetlands. *Water Science & Technology,* **67(10),** 2265-2272.

[9] Wilde, F., Radtke, D., Gibs, J. & Iwatsubo, R. 1998. National field manual for the collection of water-quality data. *US Geological Survey Techniques of Water-Resources Investigations, Book,* **9**.