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A Semi-Passive Peat Biofilter System for the Treatment of Landfill Leachate

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ABSTRACT

Peat is an alternative low-cost filter medium for on-site wastewater treatment, including landfill leachate. The effectiveness of peat biofilter under various organic, ammonia and total suspended solid loadings is critical in the operation of such systems. The purpose of this study was to evaluate the performance of a bench-scale sequential aerated peat biofilter system treating landfill leachate at different hydraulic loading rates under continuous flow condition. The leachate was aerated at a constant air flow rate of 3.4 m^3/day for HRTs of 2 or 5 days. The aerated leachate was then fed to peat columns, operated at average hydraulic loading rates of 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day. Similar $CBOD_5$, COD, NH_3-N and TSS removal efficiencies and column life expectancies were obtained at the two hydraulic loading rates. However, the HRT in the aeration basin was found to significantly increase the life expectancy of the peat biofilter by reducing the overall contaminant loading to the biofilter. For a HRT of 5 days and constant air flow rate of 3.4 m^3/day, 99% NH_3-N was removed in the aeration tank after 3 weeks. Removal efficiencies above 80%, 90% and 86% were noted for COD, $CBOD_5$ and NH_3-N after 6 weeks of operation.

Keywords: Peat; landfill leachate; aeration; biofilm; hydraulic loading; leachate treatment

1. INTRODUCTION

The Trail Road landfill in the City of Ottawa, commissioned in 1980, generates an average rate of 190 m^3 of leachate per day. Currently, leachate from Trail Road landfill is hauled by tanker truck for treatment and discharged at the Robert O. Pickard Environmental Center (ROPEC), the City's wastewater treatment facility. However, the concentrations of several contaminants of the leachate exceed or closely approach the City's Sewer Use By-law limit, particularly TKN, TSS, BOD_5, H_2S, boron, chloride, xylene, toluence, and barium. As such, the solid waste disposal facility must pay a surcharge for those contaminants that exceed the City Sewer Use By-Law limits. An on-site treatment system pre-treating the landfill leachate could reduce operational costs to the landfill, by bringing the landfill leachate to compliance with the Sewer Use By-law limits.

In recent years, studies (Garzon-Zuniga et al., 2003, 2005; Heavey, 2003; Kennedy and Van Geel, 2000; Kinsley et al., 2003; Lyons and Reidy, 1997; Rock et al., 1984; Speer et al., 2011, 2012; Talbot et al., 1996; Verma et al., 2006; Viraraghavan and Ayyaswami, 1987) have identified peat as an alternative low-cost filter medium for on-site wastewater treatment, including landfill leachate. Peat possesses several characteristics that make it a favorable filter medium for contaminants removal, such as high water holding capacity (Bergeron, 1987), low density (Buttler et al., 1994), large

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surface area (>200 m^2/g) (McLellan and Rock, 1988), high porosity (Buttler et al., 1994; Mclellan and Rock, 1988; Mitsch and Gosselink, 2007), and excellent ion exchange properties (Mckay, 1996; Sharma and Forster, 1993). The properties of peat depend on several factors, including the ambient conditions during its formation, the extent of its decomposition and the method of harvesting (Couillard, 1994). To date, few studies regarding the behavior of peat filter systems treating landfill leachate under varying contaminants, as well as hydraulic loading rates when operated in a biofilter configuration is available (Speer et al., 2013). In addition, the treatment efficiency and the total operational life of the peat filter systems, are vulnerable to varying contaminant loads, particularly organics (COD, BOD_5), NH_3-N (Gilbert et al., 2007, 2008), and TSS concentrations, as well as hydraulic loading rates (Garzon-Zuniga et al., 2003; Speer et al., 2013). However, it is evident that the performance of peat columns cannot outperform conventional systems. The use of peat systems and other passive treatment systems to mitigate landfill leachate could be beneficial in such cases as abandoned landfill sites, small or remote landfill sites, or sites where the land availability is not a barrier and the application of passive treatment approaches is warranted (Speer et al., 2012; Verma et al., 2006). Hence, the objective of this study was to investigate the performance of a bench-scale sequential aerated peat biofilter system treating landfill leachate at different hydraulic loading rates under continuous flow condition.

2. METHODOLOGY

Contaminant removal efficiency and the total operational life of the peat biofilter system are dependent on organics (COD, BOD_5), NH_3-N, and TSS constituent, as well as hydraulic loading rates (HLR). The removal efficiency and operational life of a peat biofilter preceded by an aeration chamber with a support media to promote the growth of an attached biofilm were investigated, under different hydraulic and contaminant loading rates and continuous flow condition. The properties of the peat and peat columns are summarized in Tables 1-3.

The attached growth medium provided a large active surface area and texture, which can promote the rapid growth of a biofilm, thereby, reducing contaminant loads, particularly NH_3-N and BOD_5, on the peat filter leading to an increase in the operational life of the peat biofilter system. Testing was conducted using the bench-scale experimental set-up shown in Fig. 1.

Raw leachate was collected in 20 L (28 cm × 23 cm × 40 cm) containers from the City of Ottawa Trail Road landfill and stored in a refrigerator at 4°C. The pH of the raw leachate was recorded but not adjusted. Prior to use, the raw leachate was allowed to equilibrate to laboratory temperature and then conveyed through a cylindrical aeration tank (64 cm × 44 cm ID) using a peristaltic pump at a flow rate 4.5 L/day, which was equal to the sum of the influent rates of the peat filter columns. An air pump, MAP2X Maxair 2XL, was utilized to inject air into the leachate at a constant air flow rate of 3.40 m^3/day. To aerate effectively, a 28 cm long perforated hose with a 1 cm OD was placed at the base of the aeration tank. In addition, a spun plastic medium was used in the aeration basin to get a better performance of the aeration basin by providing a support medium for biofilm growth.

The aerated leachate was fed from the aeration basin to two sets of triplicate peat columns by two sets of peristaltic pumps. One set of triplicate columns was fed at a rate of 8.28 cm^3/cm^2/day, while the other set was fed at a rate of 10.82 cm^3/cm^2/day (Fig. 1a). Masterflex® TYGON tubing was used to connect each of the stages: from the raw leachate container to the aeration basin, from the aeration basin to the peat column inlet, and from the distilled water container to the control peat column inlet. There were also two calibrated Masterflex® peristaltic pumps, maintaining constant flows from the raw leachate to the aeration basin, and from the distilled water container to the control peat column. Two sets of pumps were engaged to feed the two sets of triplicate peat columns with aerated leachate from the aeration basin. Each pump set was assembled with three Masterflex® Easy-Load® pump heads attached to a Masterflex® peristaltic pump to ensure a constant flow rate. The pumps were attached to a GRASSLIN (model CP-924) timer which turned all pumps on intermittently five times a day, for a total of ten minutes per day.

Table 1 Properties of peat biofilter medium

Parameter	**5-day HRT**		**2-day HRT**	
	Average	St. Dev.	Average	St. Dev.
Moisture Content (%)	51.04	18.45	14.21	0.09
Ash Content (%)	10.46	2.72	15.49	4.98
Organic Matter Content (%)	89.54	2.72	84.51	4.98

Table 2 Bulk and dry densities of peat columns at 5-day and 2-day HRTs

		Bulk Density (kg/m^3)		**Dry Density (kg/m^3)**	
		5-day HRT	2-day HRT	5-day HRT	2-day HRT
Avg. 8.28 cm^3/cm^2/day HLR	Column 1	512	421	339	369
	Column 2	460	431	305	378
	Column 3	497	433	329	379
Avg. 10.82 cm^3/cm^2/day HLR	Column 1	513	424	340	372
	Column 2	443	408	293	357
	Column 3	524	411	347	360
Control Column		289	438	191	384

Table 3 Hydraulic conductivities of peat columns at 5-day and 2-day HRTs

		Hydraulic Conductivity (cm/hr)	
		5-day HRT	2-day HRT
Avg. 8.28 cm^3/cm^2/day HLR	Column 1	30	20
	Column 2	18	19
	Column 3	27	13
Avg. 10.82 cm^3/cm^2/day HLR	Column 1	79	34
	Column 2	58	39
	Column 3	87	58
Control Column		108	52

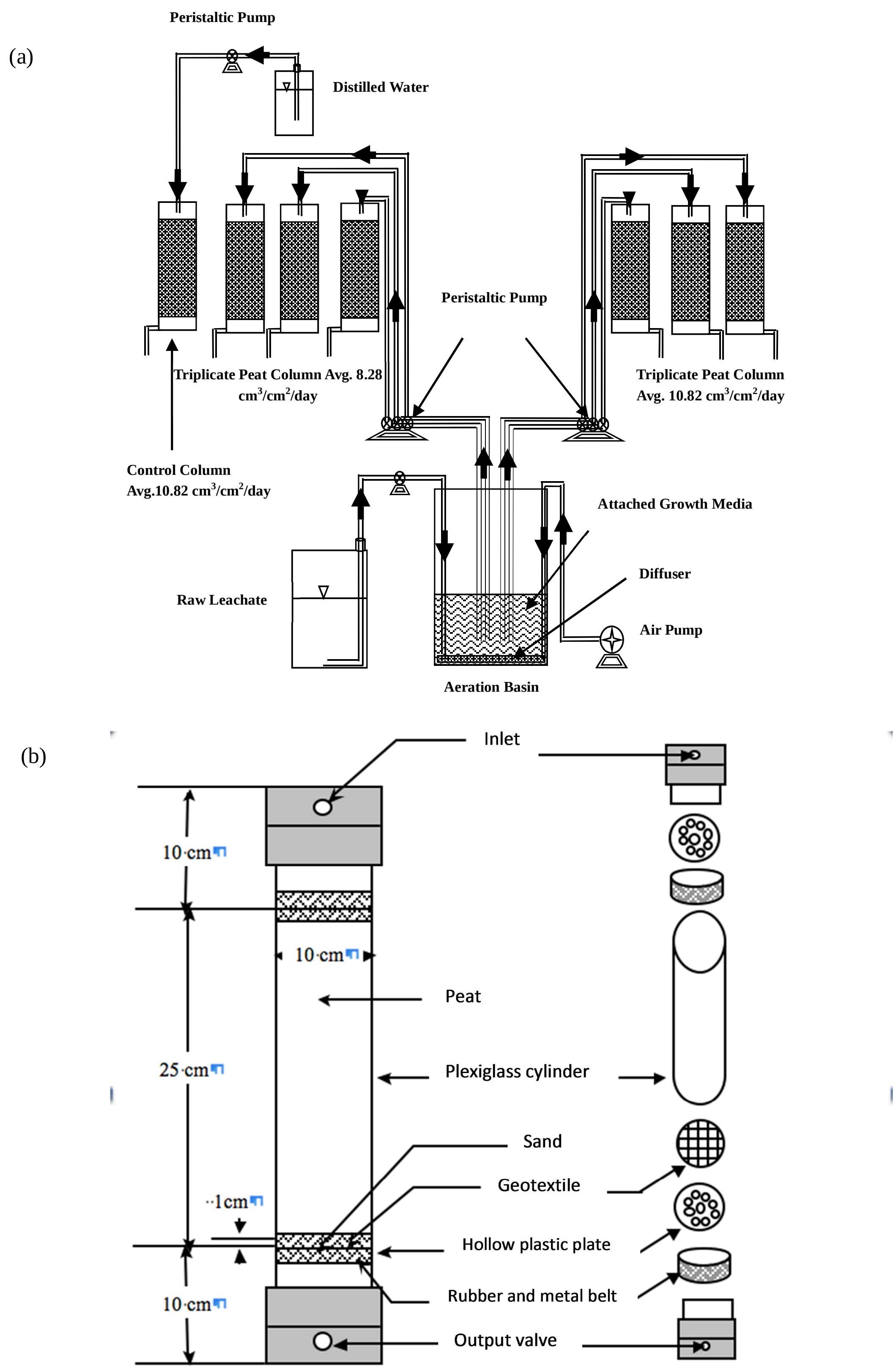

Figure 1 Sequential aerated peat biofilter experimental set-up (a) and peat biofilter column schematic (b)

Samples of the raw leachate, aerated leachate and column effluents were collected and analyzed for pH, temperature, COD, $CBOD_5$, NH_3-N, NO_3-N, and TSS removal in order to assess the performance of the aeration basin with biofilm growth for contaminants removal at 5-day and 2-day HRTs, as well as the removal efficiencies and life expectancies of the peat biofilters. A blank column was operated with distilled water in the same manner as the higher HLR an average 10.82 cm^3/cm^2/day to observe the potential leaching of constituents from the peat and the behavior of the peat filter under control condition.

The contaminant load in the Trail Road landfill leachate was much higher than is typically reported for untreated domestic wastewater especially in terms of the higher ammonia-N, TSS, COD, and $CBOD_5$ concentration. The average influent COD, $CBOD_5$, NH_3-N, NO_3-N, and TSS concentration were 899 mg/L, 340 mg/L, 511 mg/L, 2 mg/L, and 51 mg/L, respectively for the 5-day HRT. The average influent COD, $CBOD_5$, NH_3-N, NO_3-N, and TSS concentration were 1052 mg/L, 534 mg/L, 392 mg/L, 2 mg/L, and 135 mg/L, respectively, for the 2-day HRT. Therefore, these high contaminant concentrations indicate that the leachate is a high-strength wastewater in comparison to municipal wastewater.

3. RESULTS AND DISCUSSION

3.1 Temperature and pH

The pH of raw leachate, aerated leachate, and column effluents are shown in Fig. 2. After aeration, the pH of the aerated leachate increased, on average from 7.4 to 8.3 for the 5-day HRT, and from 7.3 to 8.4 for the 2-day HRT. This was likely due to carbon dioxide stripping during aeration. Water with higher alkalinity would tend to have a higher pH upon aeration, and one with lower alkalinity would tend to have a lower pH (Sawyer et al., 1994).The average pH of the aerated leachate, 8.3 for 5-day HRT and 8.4 for 2-day HRT, fell within the optimal pH range (7.0-8.5) for nitrification (Environment Canada, 2003) and operational pH range (6.5-8.5) for denitrification (Gerardi, 2002). As such, high removals of NH_3-N were anticipated for the 5-day HRT and significant nitrate-N removal was expected at both HRTs. However, an increase in pH could result in an increase in metal precipitation by complex formation, leading to a corresponding increase in TSS concentration in the aerated leachate, which could lead to the clogging of the downstream peat filters.

In this study, the pH levels of all column effluents were observed low in comparison with the aerated leachate at the initial condition, this might be due to the leaching of fulvic acids resulting from the chemical breakdown of peat, which improved after an extended period of operation, and protons from peat (Couillard, 1994; Fuchsman, 1980). In addition, metals react with the carboxylic and phenolic acid groups to release proton, thereby decreasing the pH (Brown et al., 2000). The pH level was observed to increase gradually during the first 20 days from 6.23 to 7.55 and from 6.27 to 7.74 at 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively in 5-day HRT. In the 2-day HRT, the pH levels increased from 6.23 to 7.56 at 8.28 cm^3/cm^2/day and from 5.92 to 7.73 at 10.82 cm^3/cm^2/day, respectively, at day 20. Finally, the pH of all column effluents was found to reach a steady state as a function of time. In addition, the pH of the control column effluent ranged between 5.88-7.43 and 6.15-7.11 in HRTs 5-day and 2-day, respectively. The pH of control column effluent was also observed to increase from 6.36 to 6.54 and from 6.15 to 7.11 in HRTs 5-day and 2-day respectively during the first 20 days of operation.

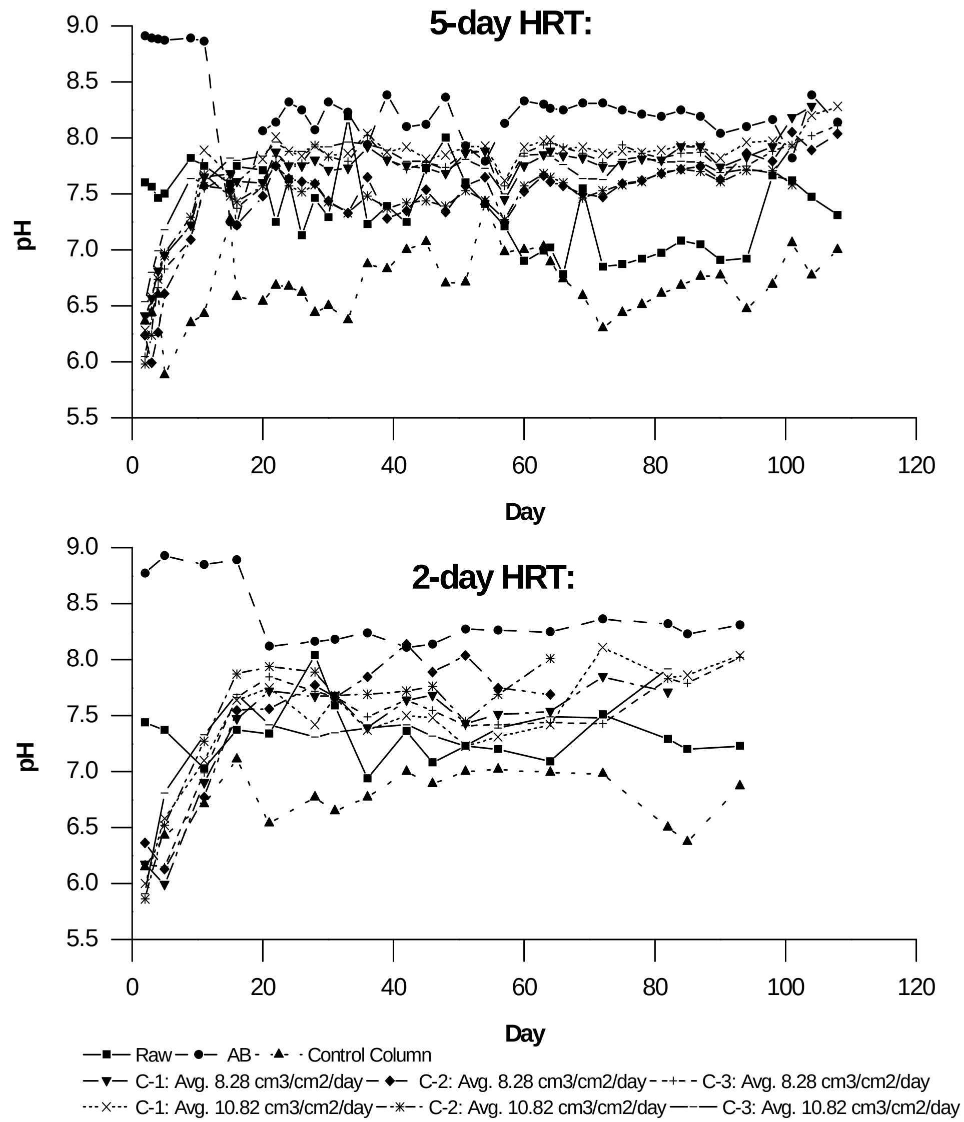

Figure 2 pH of raw leachate, aerated leachate and column effluents for the 5-day and 2-day HRTs

The temperature of raw leachate, aerated leachate, and all column effluents is presented in Fig. 3. Since this work was conducted in a laboratory environment, the fluctuations in temperature were not significant. The temperature of the column effluents ranged between 20.5-24.5°C and 19.0-22.8°C for the 5-day and 2-day HRTs, respectively. It should be noted that the temperature of aerated leachate and column effluents fell within the optimal temperature range for nitrification (30-35°C) and denitrification.

3.2 Aeration basin

The results of this study showed that the aeration basin did not significantly remove COD from the raw leachate for both the 5-day and 2-day HRTs, while $CBOD_5$ concentrations in the aeration basin were observed to decrease from an average 340 mg/L and 534 mg/L to 98 mg/L and 139 mg/L for the 5-day and 2-day HRTs, respectively as shown in Fig. 3. The TSS concentrations of aerated leachate were observed to decrease prior to days 70 and 78 for the 5-day and 2-day HRTs, respectively. Then the TSS concentration of aerated leachate was found to exceed the raw leachate TSS concentration, which is likely due to the fact that sludge in the aeration basin was not collected and disposed of throughout the course of each experimental HRT (Fig. 4). For N removal to occur, a sequence involving the aerobic nitrification of NH_3-N to NO_3^- mostly accomplished by autotrophic bacteria, and anaerobic denitrification performed by heterotrophic microorganisms capable of using NO_3^- as the electron acceptor to convert it to convert it to NO_2^-, must take place (Garzon-Zuniga et al., 2005; Gilbert et al., 2008). From Fig. 5, it can be noted that steady-state removal of NH_3-N was observed for the 5-day HRT after approximately 2 weeks of operation, while similar NH_3-N removal was not observed for the 2-day HRT even after 3 weeks of operation. The 5-day HRT also exhibited better nitrification than the 2-day HRT. In addition, an average NO_3-N generation of 108 mg/L was found for the 5-day HRT compared to 21 mg/L for the 2-day HRT (Fig. 6).

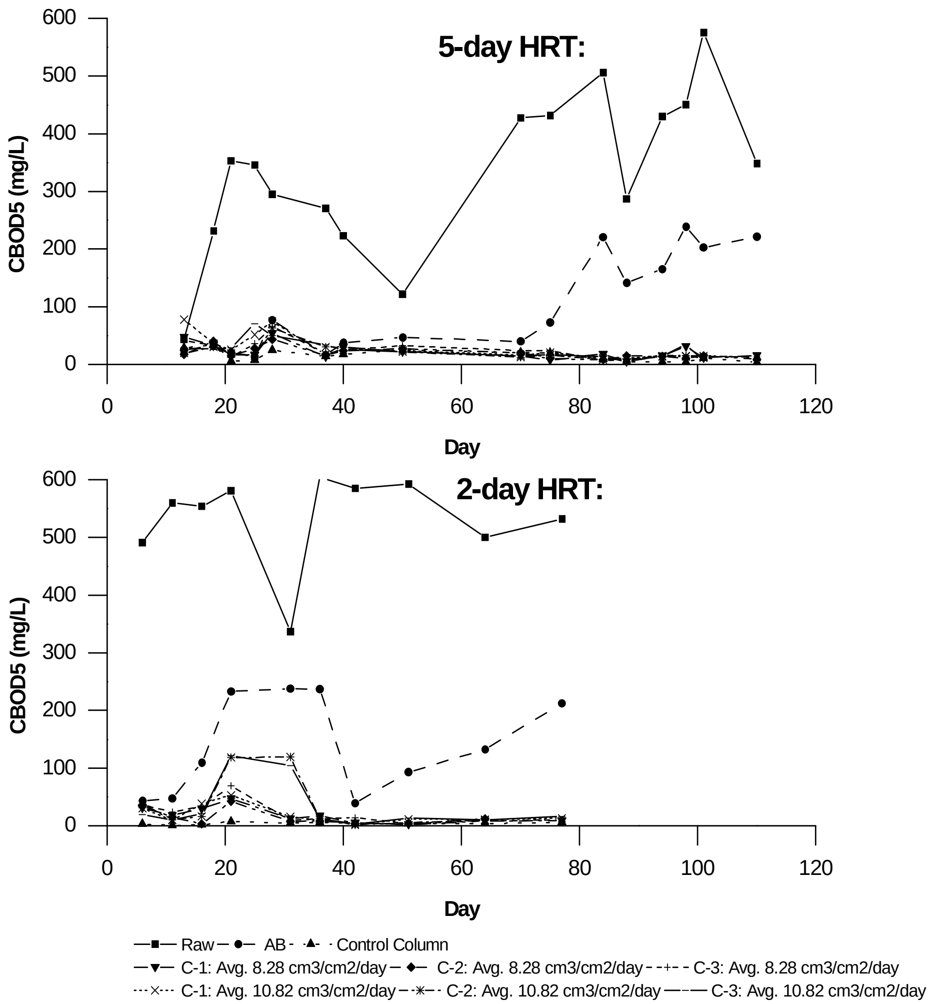

Figure 3 $CBOD_5$ of raw leachate, aerated leachate and column effluents for the 5-day and 2-day HRT

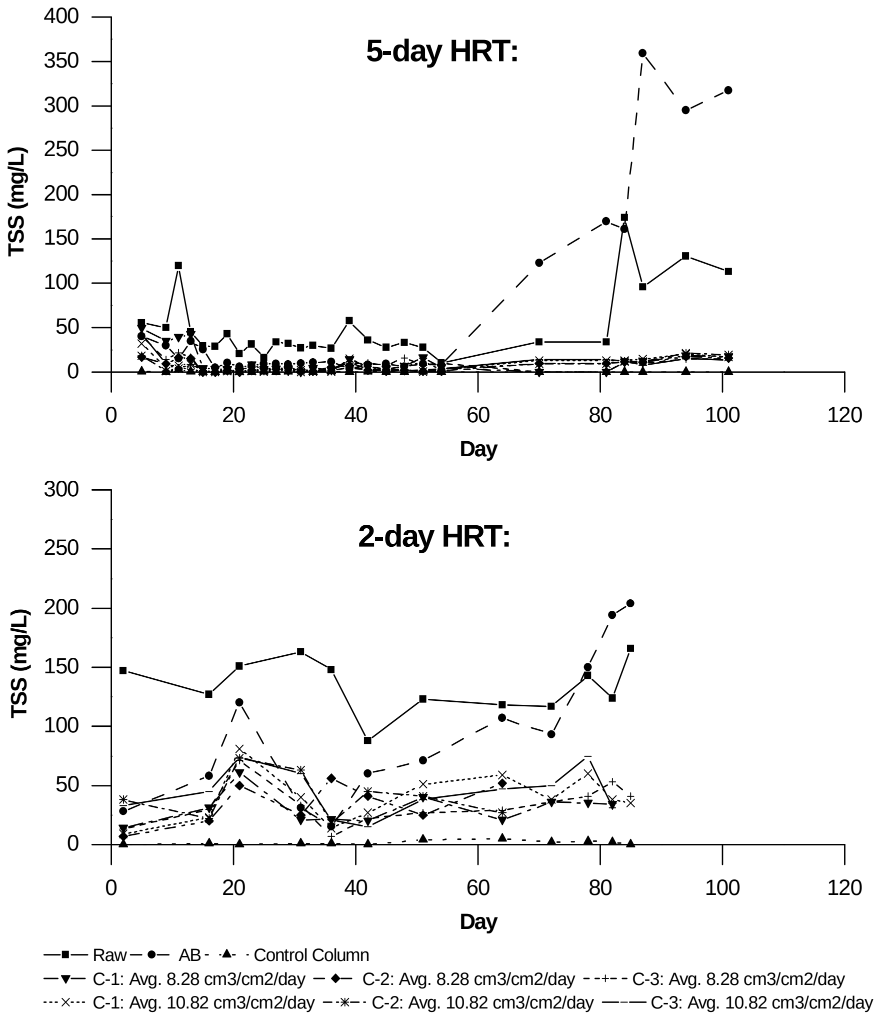

Figure 4 TSS of raw leachate, aerated leachate and column effluents for the 5-day and 2-day HRTs

Denitrification was also noted in the aeration basin after 44 and 42 days of operation for the 5-day and 2-day HRTs, respectively. The aeration basin allowed for NO_3-N removal as a result of the rapid formation of a biofilm onto the attached growth media in the aeration basin. As the microorganisms grow, the thickness of the biofilm layer increases, and the diffused oxygen is consumed before it can penetrate the full depth of the biofilm layer. Thus, an anaerobic environment is established near the surface of the media, which is likely the main mechanism for NO_3-N removal in the aeration basin after an extended period of operation. The concentration of NO_3-N was observed to decrease from 319 mg/L (day 44) and 96 mg/L (day 42) to 90 mg/L (end) and 1 mg/L (end) for the 5-day and 2-day HRTs, respectively.

3.3 Peat columns

In this study, two sets of triplicate columns were operated at HLRs of 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively, for both the 5-day and 2-day HRTs. The averages of the triplicate column effluents are used in the discussion of the results. The average effluent concentrations from the peat columns were 356 mg/L and 383 mg/L at HLRs of 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively, for the 5-day HRT; while average effluent COD concentrations of 413 mg/L and 415 mg/L were observed for the 2-day HRT at the same HLRs. From the control column effluent COD concentrations, it was found that the peat contributed COD to the effluents, with average COD concentrations of 39 mg/L for both the 5-day and 2-day HRTs. As a consequence, the overall COD removal was limited. Biodegradation of organic matter was observed in the peat columns through $CBOD_5$ removal (Fig. 3). Average effluent $CBOD_5$ concentrations of 22 mg/L and 24 mg/L for 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day HLRs, respectively, were noted for the 5-day HRT. Concentrations of 18 mg/L and 29 mg/L were obtained for the 2-day HRT, for the 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day HLRs, respectively. Average effluent TSS concentration of 9 mg/L and 6 mg/L in 5-day HRT, and 34 mg/L and 42 mg/L in 2-day HRT, were found for the HLRs of 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively (Fig. 4). The TSS removal was achieved through adsorption and physical filtration via its porous structure. Effluent NH_3-N concentrations were less than 2.18 mg/L and 2.15 mg/L after 30 days of operation at 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively, for the 5-day HRT (Fig. 5).

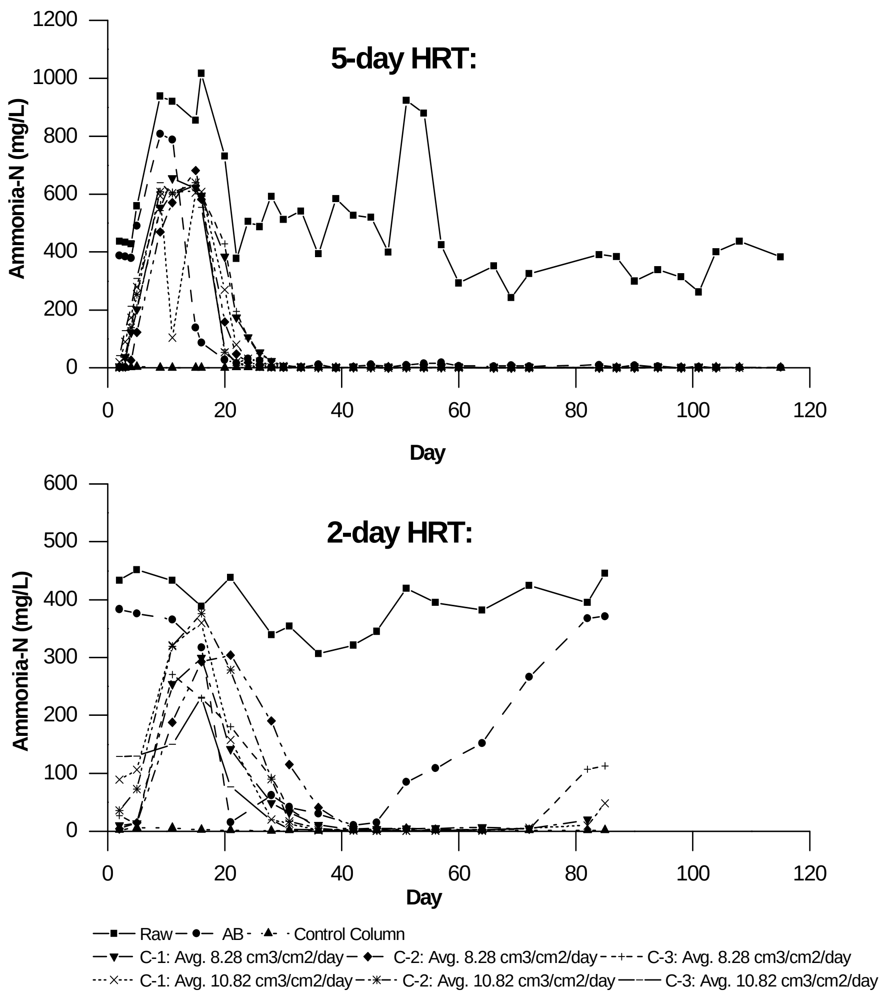

Figure 5 NH_3-N of raw leachate, aerated leachate and column effluents for the 5-day and 2-day HRTs

Comparatively, NH_3-N effluent concentrations were below 4.29 mg/L and 5.30 mg/L after 36 days of operation at 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively, for the 2-day HRT. The concentrations steadily increased at the end of the experimental run before clogging of the columns were observed. The likely mechanisms of NH_3-N removal were adsorption of NH_4^+ onto the peat up to the CEC saturation for NH_4^+, followed by leaching of NH_3-N, nitrification and denitrification. An average, NO_3^--N concentration of 121 mg/L and 119mg/L in 5-day HRT, and 38 mg/L and 48mg/L in 2-day HRT were observed for the HLRs of 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively (Fig. 6). Denitrification in the peat columns was generally observed after 49 and 36 days of operation; this might be due to the formation of anoxic zones at the bottom of the columns.

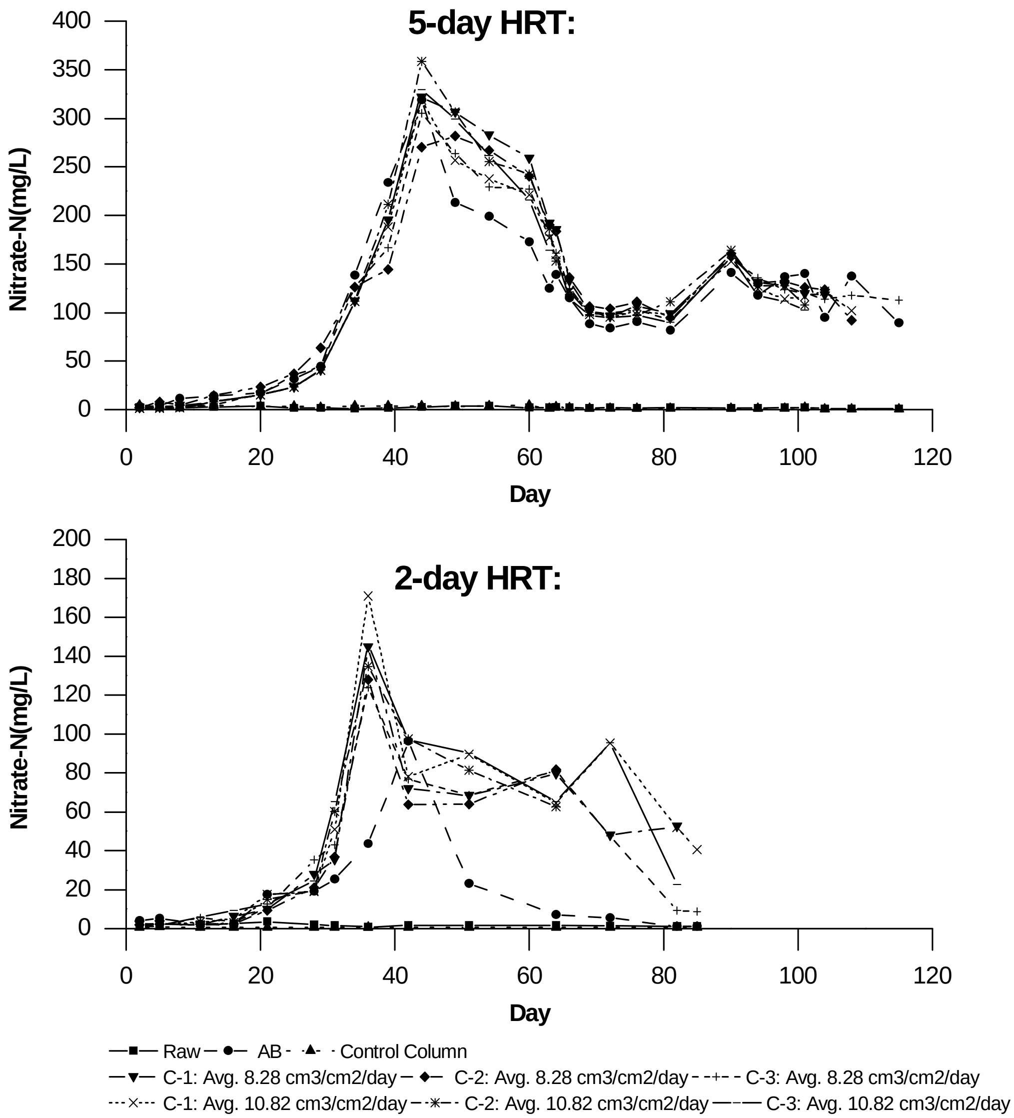

Figure 6 NO_3-N of raw leachate, aerated leachate and column effluents for the 5-day and 2-day HRTs

One of the main objectives of this research was to investigate the lifetime of the peat biofilter system under different contaminant loadings, HRT in aeration basin, as well as hydraulic loading rate. The operational life of each of the peat filters was defined as the number of days of operation between when the peat columns were initially fed with leachate to the time clogging was observed as exhibited by surface ponding. The total cumulative COD, BOD_5, and TSS removal of peat columns at the time of clogging for the two sets of triplicate columns were computed under the different operational conditions. The results are summarized in Fig. 7 and Table 4. In this study, sludge wasting strategies were not employed, which may have led to the high TSS accumulations in the system after a period of 1 month. The introduction of intermittent sludge wasting strategies in the aeration system (every 10-20 days of operation), would be expected to increase the longevity of the system as was noted by (Speer et al., 2011, 2012). The exhausted peat would need to be considered a hazardous material due to the potentially toxic nature of some of the constituents removed within the peat system.

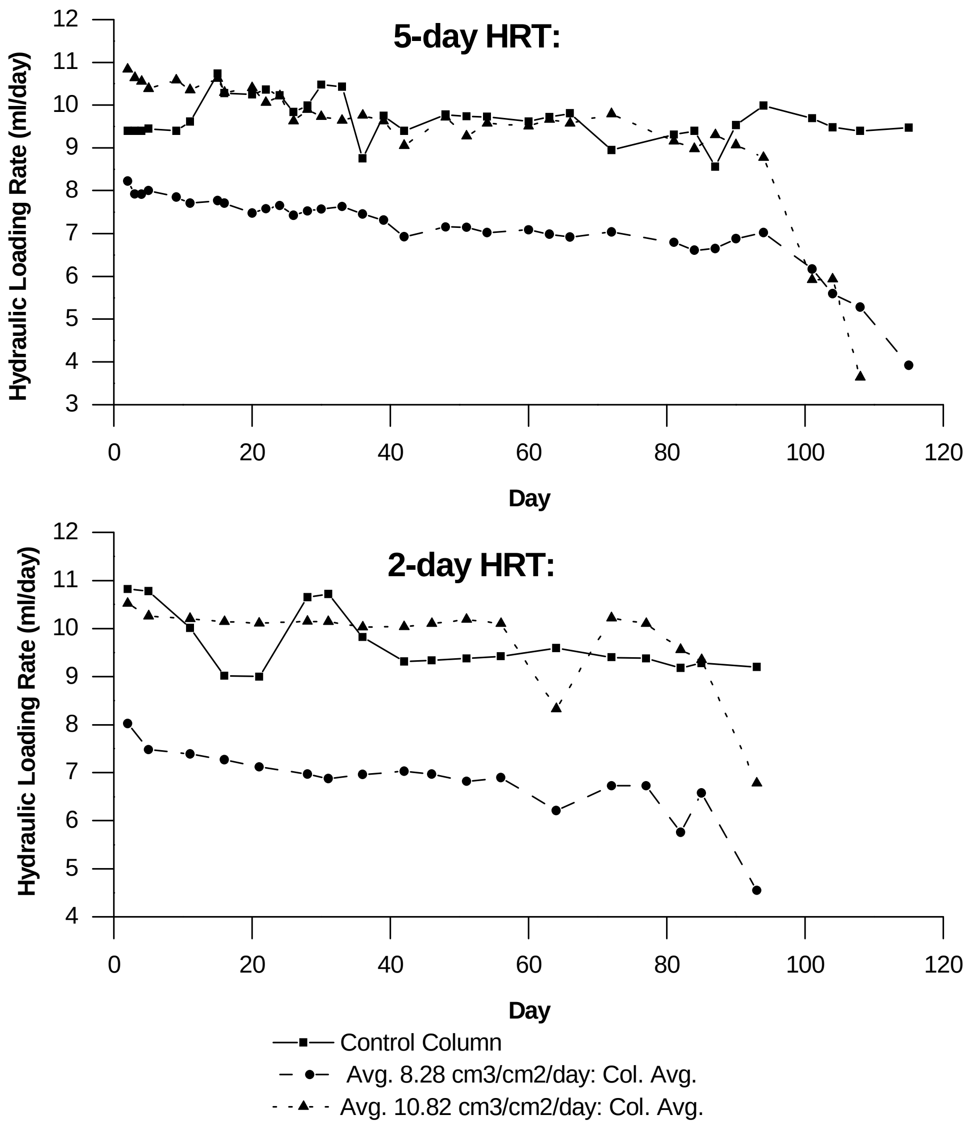

Figure 7 Operational life and cumulative contaminant removal of peat columns

Table 4 Operational life and cumulative contaminants removal of peat filters

Phase	Column ID		Total Operational Life (day)	Cumulative Removal (mg/g of Peat)		
				COD	BOD	TSS
5-day HRT	Controlled Column (DW)		No clogging	—	—	—
	Avg. 8.28 $cm^3/cm^2/day$	Column 1	104	34.68	6.42	10.92
		Column 2	108	46.88	9.42	15.28
		Column 3	115	48.12	8.86	15.59
	Avg. 10.82 $cm^3/cm^2/day$	Column 1	108	41.31	7.54	14.96
		Column 2	101	48.74	10.42	16.71
		Column 3	101	42.06	8.17	14.37
2-day HRT	Controlled Column (DW)		No clogging	—	—	—
	Avg. 8.28 $cm^3/cm^2/day$	Column 1	82	30.04	7.65	2.91
		Column 2	64	20.90	5.51	1.40
		Column 3	93	37.79	9.57	4.23
	Avg. 10.82 $cm^3/cm^2/day$	Column 1	93	51.68	13.50	5.20
		Column 2	64	31.10	5.80	1.32
		Column 3	82	46.77	10.60	3.26

A single factor ANOVA was conducted with an alpha value of 0.05 to statistically compare the performances of peat columns operated under different conditions. The results of this study indicated that statistically similar total cumulative organic (COD, CBOD5) removals were observed in the peat columns under different HLRs and HRTs since the F values were always less than Fcritical values in the ANOVA test. However, the higher 5-day HRT of the aeration basin increased the operational life of the peat biofilters when compared to the 2-day HRT through the lowering of the contaminant loading onto peat biofilters.

CONCLUSIONS

The contaminant loadings to the peat columns were considered to be a function of the HRT in the aeration basin. The results showed that the impact of the hydraulic loading rate was less significant than the effect of contaminant loading rate leading to a longer life of the peat filters. Statistically similar organics (COD, $CBOD_5$) removal performances and life expectancies could be obtained at hydraulic loading rates of 8.28 $cm^3/cm^2/day$ and 10.82 $cm^3/cm^2/day$ in both 5-day and 2-day HRTs. However, the higher HRT, 5 days, increased the life expectancy of the peat biofilter by approximately one month, due to the considerable decrease in the organics, NH_3-N, and TSS loading through the aeration basin. The results also suggested that the contaminant removal efficiencies of the peat biofilter columns were similar for the 8.28 $cm^3/cm^2/day$ and 10.82 $cm^3/cm^2/day$ HLRs.

The results indicated that the peat columns were unstable during the first month of operation, since leaching of COD to effluents by peat itself and saturating of CEC for ammonia-N followed by leaching of ammonia-N was observed during the first month of operation. The aeration basin with support media for biofilm growth was primarily effective for the removal of NH_3-N and NO_3-N through nitrification and denitrification. Steady-state nitrification was initially observed in the aeration basin after approximately 2 to 3 weeks of operation as this was likely the time required for the steady-state development of a biofilm on the attached growth media to which NH_3-N removal was attributed. Therefore, an anaerobic environment was established near the surface of the media, which was mainly responsible for denitrification in aeration basin after approximately 1.5 months of operation at both the 5-day and 2-day HRTs. From this study, it can be noted that HRT was a limiting factor affecting the contaminants removal efficiencies of aeration basin. Therefore, an increase in HRT would increase the removal of contaminants.

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