EVALUATION OF A SEMI-PASSIVE PEAT BIOFILTER SYSTEM TREATING LANDFILL LEACHATE UNDER VARIED LOADING RATES

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ABSTRACT

A semi-passive peat biofilter system was developed and evaluated for landfill leachate treatment by varying contaminant loading and hydraulic loading rates (HLRs). This system consisted of an attached growth aeration chamber followed by peat biofilters. The leachate was aerated (air flow rate of 3.4 m^3/day) for HRTs of 2 or 5 days in an aeration tank; and was fed to peat columns with an average HLRs of 8.28 and 10.82 cm^3/cm^2/day. The results show similar $cBOD_5$, COD, NH_3-N and TSS removal efficiencies and operational life of the peat columns at these different HLRs. However, the HRTs in the aeration basin was found to significantly increase the life expectancy of the peat biofilter by reducing the overall contaminants. After 3 weeks, 99% NH_3-N was removed in the aeration tank for 5-days HRT. Removal efficiencies above 80%, 90% and 86% were noted for COD, $cBOD_5$ and NH_3-N after 6 weeks of operation.

***Key words**: Peat, landfill leachate, aeration, biofilm, hydraulic loading, leachate treatment*

1 INTRODUCTION

Historically, landfills have been the most economical and environmentally acceptable method for the disposal of solid wastes throughout the world (Tchobanoglous et al., 1993). Controlled landfilling prevents some of the risks which have been associated with incineration processes. In spite of the number of advantages of using this waste disposal strategy, some inherent concerns exist which include the generation of odors and leachates. The treatment and management of landfill leachate are becoming more difficult due to increasingly stringent effluent discharge quality standards. The selection and design of a leachate treatment processes are not simple, since there is great variation in the quality and quantity of leachate generated from landfill to landfill, and over time as a particular landfill ages. Due to the complex nature of the leachate characteristics, neither conventional biological wastewater treatment nor chemical treatment processes separately achieve high removal efficiencies over the life of the landfill (Qasim and Chiang, 1994).

The Trail Road landfill in the City of Ottawa, commissioned in 1980, generates an average rate of 190m3 of leachate per day (Woytowich, 2004). The leachate from Trail Road landfill is hauled by tanker truck for treatment and discharge 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, $cBOD_5$, H_2S, boron, chloride, xylene, toluence, and barium. The landfill authority pays a surcharge for those contaminants that exceed the City Sewer Use By-Law limits. An on-site pretreatment system for the leachate would potentially reduce this leachate disposal cost to ROPEC, by bringing the landfill to compliance with the Sewer Use By-law limits.

In recent years, many researchers (Heavey, 2003; Li and Champagne, 2009; Speer et al., 2012) have identified peat as an alternative low-cost filter medium for on-site wastewater treatment including landfill leachate. Besides being plentiful and inexpensive, peat possesses several characteristics that make it a favorable filter medium for contaminant removal, such as high water holding capacity (Bergeron, 1994), low density (Buttler et al., 1994), large surface area (>200 m2/g) (McLellan and Rock, 1988), high porosity (Mclellan and Rock, 1988), and excellent ion exchange properties (Mckay, 1996). To date, there is limited information in the literature regarding the behavior of peat filter systems under varying contaminant, as well as hydraulic loading rates (HLRs) when operated in a biofilter configuration.

The properties of peat depend on several factors, including the ambient conditions existing during its formation, the extent of its decomposition and the method of harvesting (Couillard, 1994). To date, there is limited information in the literature regarding the behavior of peat filter systems under varying contaminant, as well as HLRs when operated in a biofilter configuration. In addition, the effect on the treatment efficiencies and on the total operational life of the peat filter systems, of varying contaminant loads, especially organic (COD, BOD_5), ammonia-N, and TSS concentrations, as well as HLRs is very important. Therefore, in this research, the removal performance and operational life expectancy of a peat biofilter preceded by an aeration chamber, operated at constant air flow rate of 3.40 m^3/d and HRTs of 5 and 2 days, with a support media for the growth of an attached biofilm, were investigated with particular emphasis on different hydraulic and contaminant loading rates under continuous flow condition. The attached growth medium, provided a large active surface area and texture promoting the rapid growth of a biofilm, thus significantly reducing the contaminant loads, especially ammonia-N and BOD_5, on the peat filters, and as a consequence, increased the operational life of the peat biofilter systems.

2 MATERIALS AND METHODS

2.1 Experimental Setup

Contaminant removal performance and the total operational life of the peat biofilter system are dependent on organic (COD, BOD_5), NH_3-N, and TSS constituent, as well as HLR. This study, therefore, investigated the removal efficiency and operational life of a peat biofilter preceded by an attached growth aeration chamber to promote the growth of biofilm, under different hydraulic and contaminant loading rates in a continuous flow condition. The attached growth medium provides 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. Laboratory investigations were conducted using the bench-scale experimental set-up illustrated in Figure 1.

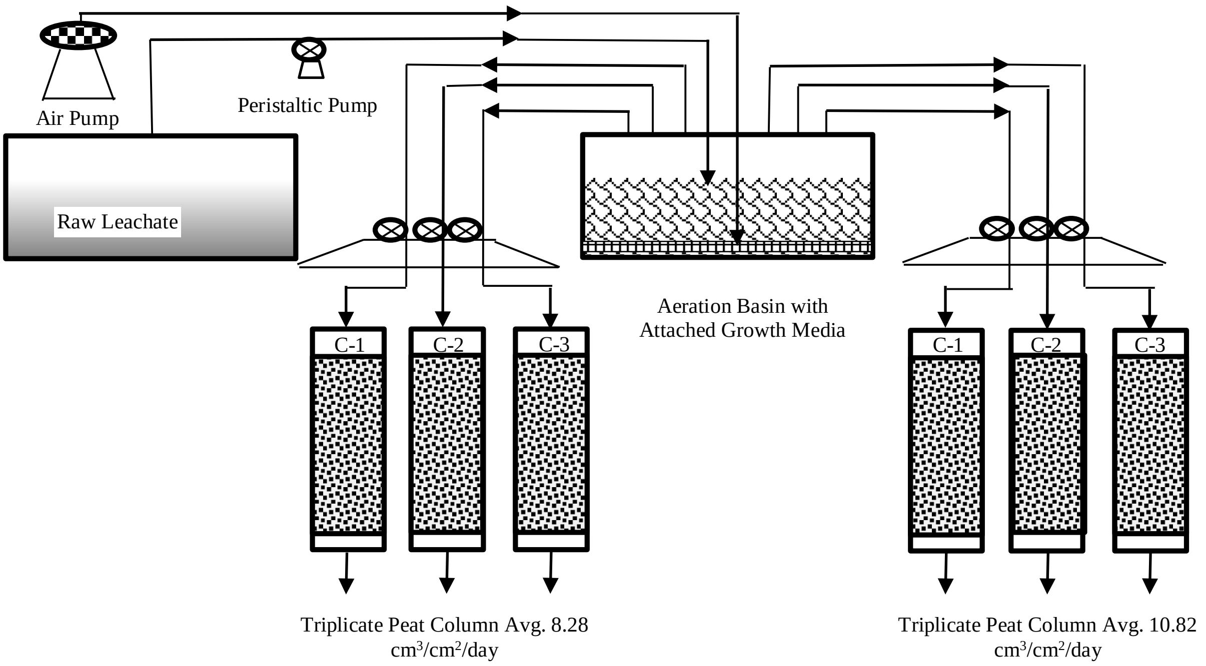

Figure 1 : Sequential aerated peat biofilter experimental set-up under varied loading rates.

Raw leachate was pumped into an aeration tank for 5-day HRT (Phase 1) and 2-day HRT (Phase 2). In each phases, the aerated leachate was then fed from the aeration basin to two sets of triplicate peat columns with different HLRs (Table 1). One set of triplicate columns was fed at a rate of 8.28 cm3/cm2/day, while the other set was fed at a rate of 10.82 cm3/cm /day (Figure 1). Leachate samples of the raw, aerated 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.

Table 1 : Two Phases of the Project

Project Phases	Aeration Basin	Peat Columns
Phase 1 **(5-day HRT)**	HRT= 5 days, and Air flow=3.40 m^3/day	HLR= Avg. 8.28 cm^3/cm^2/day for first set of triplicate columns, and avg 10.82 cm^3/cm^2/day for second set of triplicate columns.
Phase 2 **(2-day HRT)**	HRT= 2 days, and Air flow=3.40 m^3/day	HLR= Avg. 8.28 cm^3/cm^2/day for first set of triplicate columns, and avg. 10.82 cm^3/cm^2/day for second set of triplicate columns.

The raw leachate was pumped to a cylindrical aeration tank (64 cm X 44 cm ID) by a peristaltic pump at a flow rate 4.5 L/day, which was equal to the sum of the influent rates of the peat filters. An air pump, MAP2X Maxair 2XL, was utilized to inject air into the leachate at an air flow rate of 3.40 m^3/day. To attain an effective aeration a 28 cm long perforated hose with a 1 cm outside diameter, was placed in a spiral shape on the base of the aeration tank. In addition, a spun plastic attached growth media was used in the aeration basin in order to get a better performance of the aeration basin by providing a support media for biofilm growth. The aerated leachate was then pumped to two sets (triplicate) of peat columns from the aeration basin with a flow rate of 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively. Samples of the raw leachate, aerated leachate and column effluents were collected and analyzed in order to assess the performance of the aeration basin with biofilm growth for contaminant removal at different HRTs, 5 and 2 days, 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 at 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 conditions.

2.2 Analytical Methods

The particle size distribution; moisture, ash, and organic content; and hydraulic conductivity of the peat columns were determined using the ASTM Standards. The water quality parameters monitored in the research are summarized in Table 2. All leachate samples were preserved and analyzed for selected parameters (Table 2) according to the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF, 1995).

Table 2 : Water Quality Parameters

Organic	Inorganic	Biological
Chemical Oxygen Demand (COD)	Ammonia-N (NH_3-N) TSS	Carbonaceous Biochemical Oxygen Demand ($cBOD_5$)

3 RESULTS AND DISCUSSION

3.1 Properties of Peat

The results of the particle size distribution suggested that the peat used in this study was mostly fine. It included 55% fine (< 1.18 mm), 26% medium (<2.36 mm, >1.18 mm), and 19% coarse (>2.36mm) particles. The moisture, ash and organic matter content of the peat material used in this study were investigated for HRTs of 5-day and 2-day and are presented in Table 3. These properties of the peat samples were analyzed on an as received mass basis. In addition, a saturated hydraulic conductivity test for each peat column was conducted, using a constant head set-up, before the start of the leachate treatment study. Hence, the hydraulic conductivity test affected the moisture content of the peat filters. In its use as a biofilter, the moisture content of peat is very important during operation. It affects the degree of microbial activity. At moisture levels greater than 85%, the activity decreases slightly; while below 30% it ceases entirely (Valentin, 1986). The initial moisture content of the peat filter could have a dilution effect on the effluent, which becomes negligible as the filter is operated for an extended period of time.

Table 3 : Moisture, Ash and Organic Matter Content

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

The saturated hydraulic conductivity of each peat column in both the 5-day and 2-day HRTs was determined using the constant head set-up as illustrated in Table 4. The hydraulic conductivities were found to vary between 13 and 108 cm/hr, which represented a variation by a factor of 8. Nichols and Boelter (1982) reported that the hydraulic conductivity of peat can vary by a factor of 5000, depending upon the degree of decomposition. A slightly decomposed fabric peat can have a saturated hydraulic conductivity as high as 140 cm/hr. The hydraulic conductivity of a highly decomposed sapric peat, on the other hand, can be as low as 0.025 cm/hr (Narasiah and Hains, 1988).

Table 4 : Hydraulic Conductivity of Peat Columns for the 5-day and 2-day HRTs

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

3.2 Leachate Characteristics

The contaminants of concern of Trail Road landfill leachate was much higher than the typically domestic wastewater in terms of ammonia-N, TSS, COD, and $cBOD_5$. 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 in the Phase 1 (5-day HRT); and 1052 mg/L, 534 mg/L, 392 mg/L, 2 mg/L, and 135 mg/L, respectively, in Phase 2 (2-day HRT). This results indicate that the leachate is a high-strength wastewater in comparison to municipal wastewater.

3.3 Column Experiments

The results of this study showed that the aeration basin was not able to significantly remove COD from the raw leachate for both the 5-day and 2-day HRTs, respectively (Figure 2). On the other hand, the $CBOD_5$ concentration in the aeration basin was 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 Figure 3. A steady-state removal of NH_3-N was observed for the higher HRT of 5 days after approximately two weeks of operation, whereas, similar NH_3-N removal was not observed for the 2-day HRT after approximately three weeks of operation. The higher 5-day HRT also led to better nitrification than the 2-day HRT.

The TSS concentration of aerated leachate was observed to decrease prior to days 70 and 78 for the 5-day and 2-day HRTs, respectively. After that the TSS concentration of aerated leachate exceeded that of the raw leachate TSS concentration, which might be due to the fact that sludge in the aeration basin was not collected and disposed of throughout the course of each experimental run. In addition, higher metal precipitation was a possibility because of the increase in pH from 7.36 and 7.31 to 8.24 and 8.38 for the 5-day and 2 day HRTs, respectively.

A steady-state removal of NH_3-N was observed for the higher HRT of 5 days after approximately two weeks of operation, whereas, NH_3-N removal was not significant for 2-day HRT after approximately three weeks of operation, which suggested that higher 5-day HRT also provided for better nitrification than the 2-day HRT. These results indicated that HRT was a limiting factor affecting the contaminant removal efficiencies of the aeration basin. Therefore, an increase in HRT would increase the removal of contaminants.

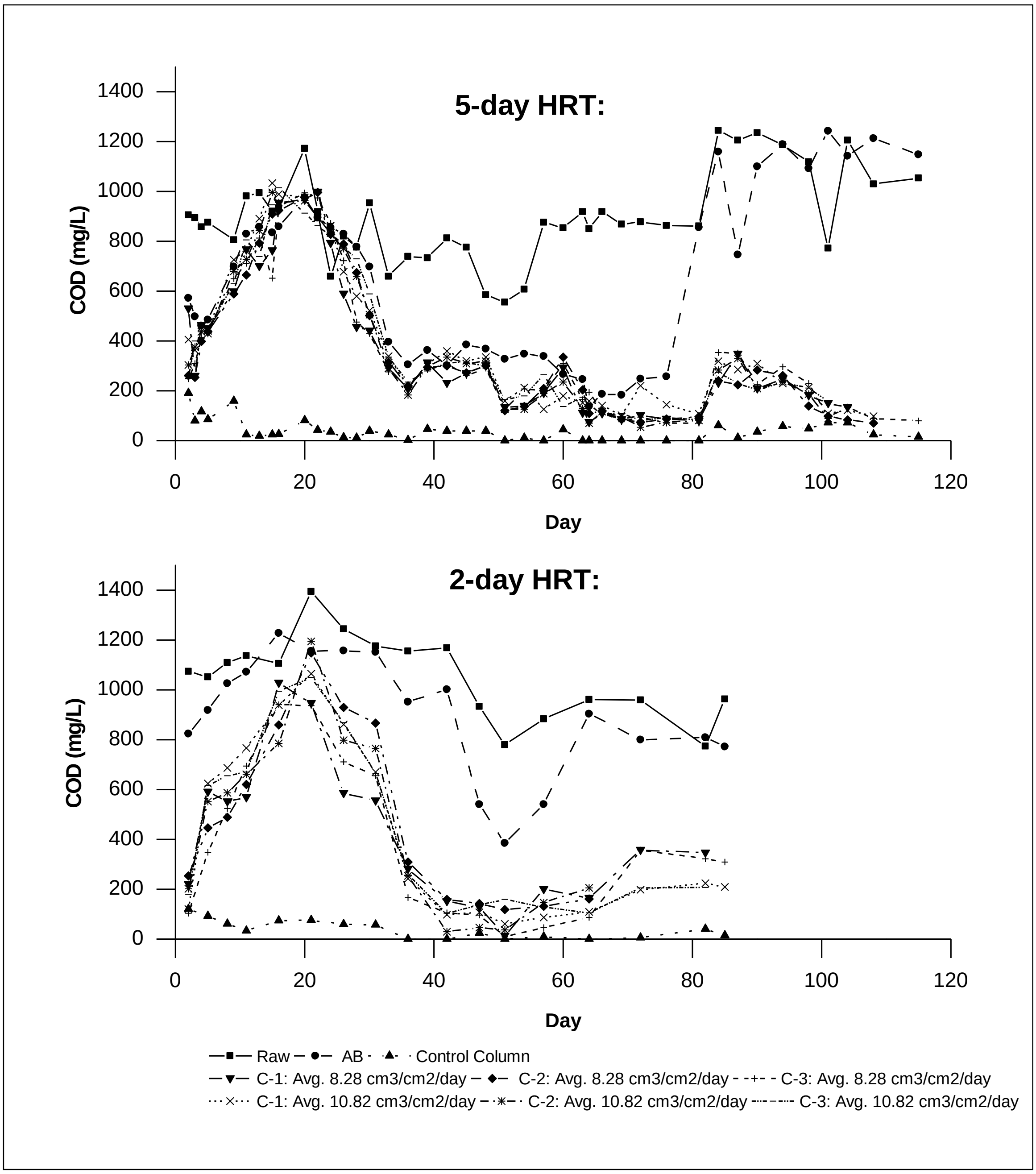

Figure 2 : COD of Raw Leachate, Aerated Leachate, and Column Effluents for the 5-day and 2-day HRTs

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 average of the triplicate columns was used in the presentation of the results and their ultimate evaluation. The results of this study demonstrated that the effluent of the peat columns had average COD of 356 mg/L and 383 mg/L at the HLRs 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively, for the 5-day HRT; while, an average effluent COD of 413 mg/L and 415 mg/L were observed for the 2-day HRT at the same HLRs. Peat itself contributed COD to the effluents which was confirmed by the effluent COD concentrations from the control column, an average of 39 mg/L and 39mg/L for the 5-day and 2-day HRTs, respectively. As a consequence, the overall COD removal was limited (Figure *2*).

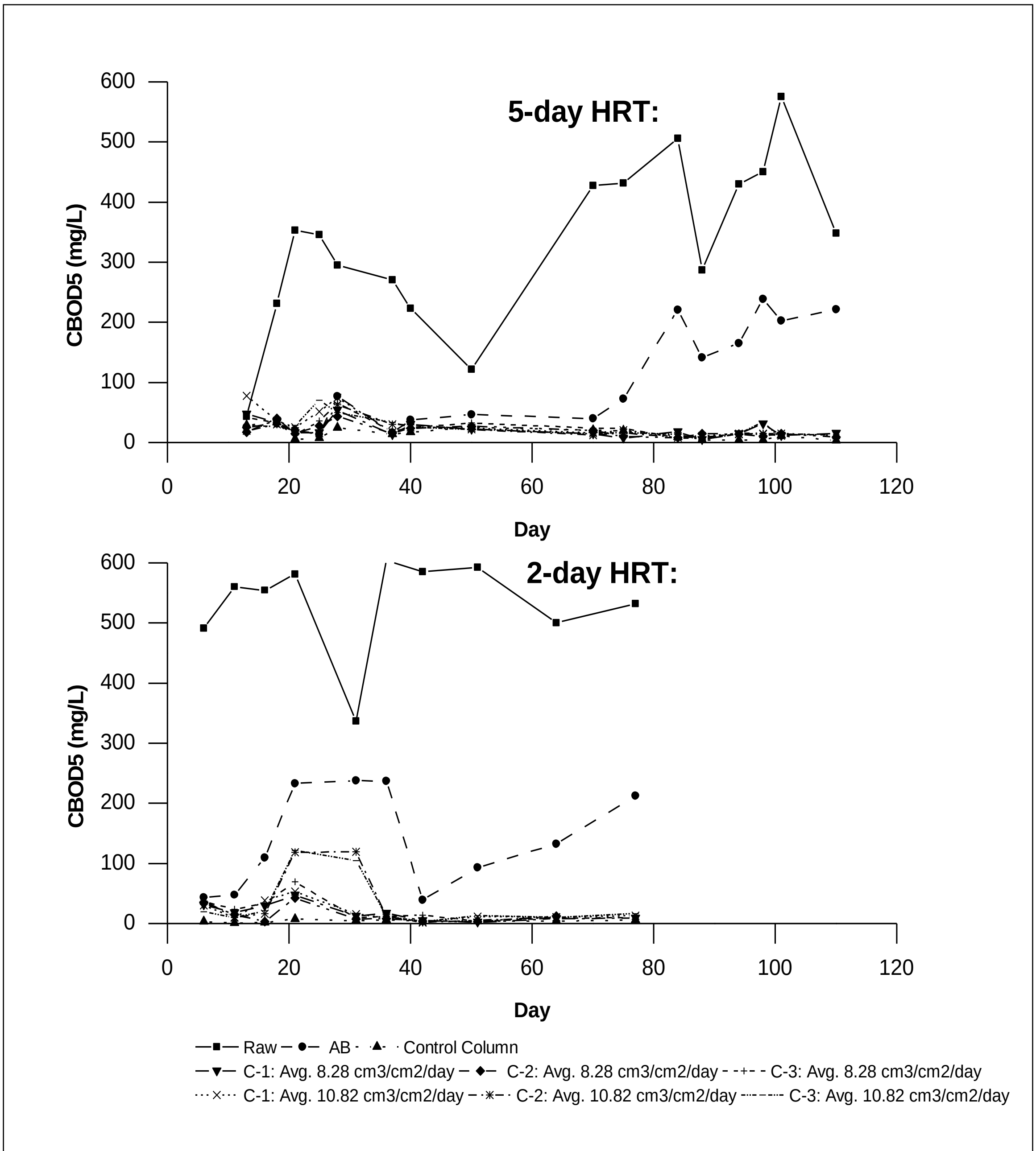

Figure 3 : cBOD5 of Raw Leachate, Aerated Leachate, and Column Effluents for the 5-day and 2-day HRTs

The $CBOD_5$ removals were achieved due to the biodegradation of organic matter in the peat system. 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, respectively were noted for the 5-day HRT, and 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. Comparatively, effluent NH_3-N concentrations were less than 2.18 mg/L and 2.15 mg/L after one month of operation for the 5-day HRT, and were less than 4.29 mg/L and 5.30 mg/L after 36 days of operation which increased at the end before clogging for the 2-day HRT, were found at 8.28 cm^3/cm^2/day and 10.82 cm^3/cm^2/day, respectively. The suspected main mechanisms of NH_3-N removal were adsorption of NH_4^+ onto peat up to the saturation of adsorption capacity for NH_4^+, followed by leaching of NH_3-N, and finally nitrification and denitrification (Figure 4).

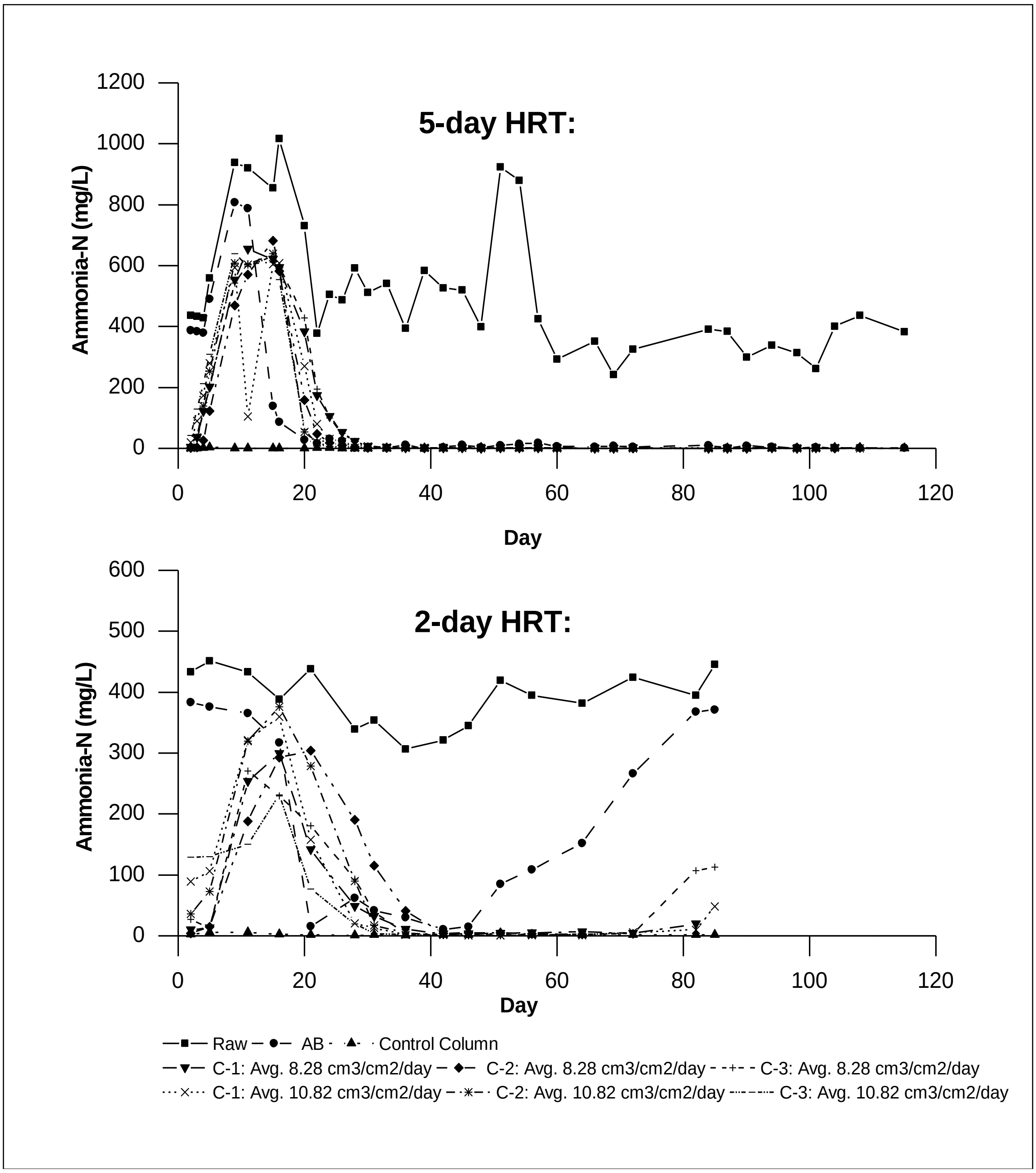

Figure 4 : Ammonia-N of Raw leachate, Aerated leachate, and Column Effluents for the 5-day and 2-day HRTs.

Average effluent TSS concentrations of 9mg/L and 6mg/L for the 5-day HRT, and 34 mg/L and 42 mg/L for the 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. TSS removal was achieved through adsorption and physical filtration via its porous structure (Figure 5).

One of the main objectives of this research was to investigate the total lifetime of the peat biofilter system under varied contaminant loadings, in terms of the HRT in the aeration basin, as well as the hydraulic loading rate. The operational life of each of the peat filters was considered to lie between the days when feeding of the peat columns with leachate commenced to the time clogging was observed as exhibited by surface ponding. In addition, two sets of triplicate columns were used for this assessment, and the total cumulative COD, $CBOD_5$, and TSS removal within the peat columns at the end of the experimental runs were also calculated under these different operational conditions, as presented in Table 5.

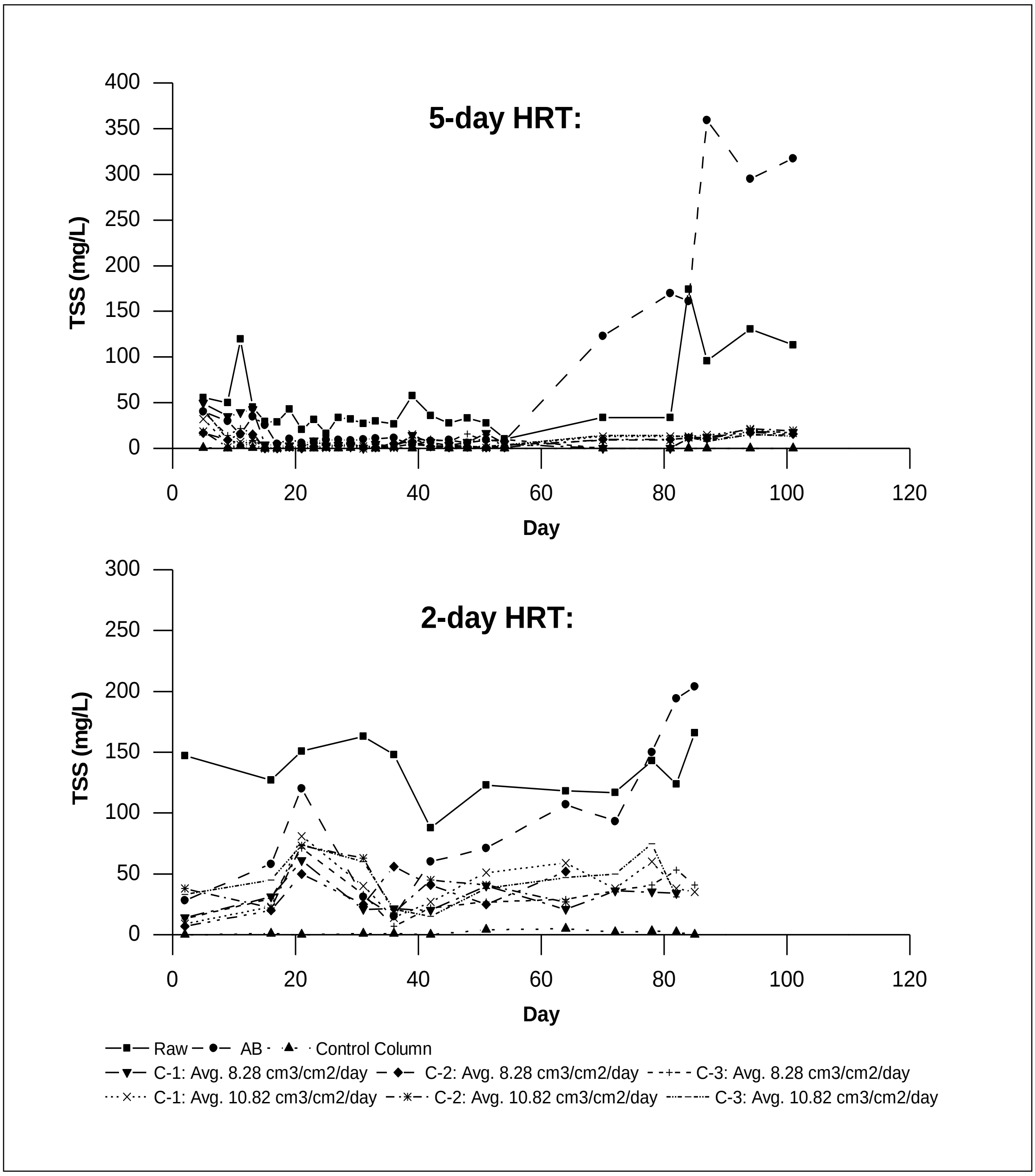

Figure 5 : TSS of Raw Leachate, Aerated Leachate, and Column Effluents for the 5-day and 2-day HRTs

A single factor ANOVA (Analysis of Variance) test was conducted with an alpha value of 0.05 for statistical comparison between the performances of the peat columns operated under different conditions. The results of this study indicated that statistically similar total cumulative organic (COD,

$cBOD_5$) removal of peat columns were observed under different HLRs and HRTs since F values were always less than $F_{critical}$ values in ANOVA test.. However, the higher 5-day HRT of aeration basin increased the operation life of peat biofilters compared to the 2-day HRT by lowering the contaminant loading onto peat biofilters.

Table 5 : Total Life and Cumulative Contaminants Removal of Peat Filters

Phases	Column ID		Total Operational Life (day)	Cumulative Removal (mg/ g of Peat)		
				COD	$cBOD_5$	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

4 CONCLUSION

The results of this study 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 NH3-N and NO3-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 NH3-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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