After treatment of landfill leachate in peat filters

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Abstract

The main objective of this study was to determine the treatment capacity of well mineralised *Sphagnum* peat in order to reduce BOD and COD values and nutrient concentration in landfill leachate. The peat filters were suitable for the reduction (up to 93%) of ammonia nitrogen. Good results were obtained in the reduction of total phosphorus from both raw and pre-treated leachate (up to 81% and 70-99% respectively). The purification rate of the landfill leachate depended on the contamination rate – the outflow results were better with pre-treated leachate, and the results also improved due to the lowering of the flow rate (on average by 60 times). Therefore, it is recommended that peat filters be used in combination with conventional treatment methods, e.g. as soil filters of subsurface flow constructed wetlands for the secondary or tertiary treatment of the leachate.
Keywords: ammonia-nitrogen, BOD, COD, peat filter, pre-treated landfill leachate, raw landfill leachate, total nitrogen, total phosphorus.

1 Introduction

Peat is partially fossilized decomposed plant matter that transforms in wet areas in the absence of oxygen. Compared to mineral soils, peat has a very high organic content (60% carbon). Peat has a surface area of >200 m^2 g^{-1} and is highly porous (80-90%) [1].

In Estonia, peat lands cover 22% of total land area. Estonian peat resources are estimated at 2.4 billion tonnes, of which 0.2 billion tonnes are less decomposed, and 1.4 billion tonnes are well decomposed [2].

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The potentially large availability of peat and its unique combination of biological, physical and chemical properties make it suitable for a wide variety of uses, including environmental protection [3]. For example, peat has been used in the treatment of wastewaters of various origin and quality.

Several laboratory and field experiments have demonstrated that peat as a filter material for constructed wetlands, and also for bio-filters and other conventional treatment systems can effectively reduce nitrogen concentration and remove suspended solids [4, 5, 6], pathogenic bacteria [4, 5], mineralise organic material, retain phosphorus [7, 8] and other heavy metals [1, 9]. Most peat filters are designed for the treatment of domestic wastewater [10], and several systems have also shown very good performance in the treatment of landfill leachate [11, 12]. Likewise, results of experiments on floodplain fens in Estonia have shown the high potential of peatlands in the after-treatment of wastewater [13].

Although peat is an inexpensive and attractive material, such advantages must be balanced against the importance of peatland conservation and the maintenance of habitat diversity [14].

The composition of landfill leachate varies greatly, being dependent on waste quantity and quality (the age of the waste and also its decomposition rate and landfilling technologies). Leachate is considered difficult to treat due to its typically high concentration of P (up to 100 mg L^{-1} [15]), ammonia nitrogen (up to 300 mg L^{-1} [11]), high COD value (up to 60,000 mg L^{-1} [15]), and heavy metals.

In Estonia there is a lack of long-term experience in the treatment of landfill leachate. There are only a few landfills where leachate is collected and purified using various methods.

The main objective of this study was to determine the treatment capacity of well mineralised *Sphagnum* peat in order to reduce BOD and COD values, and nutrient concentration in landfill leachate from different stages of the leachate treatment system. We also investigated whether peat filters improve the efficiency of conventional leachate treatment systems. In addition, the effect of the duration of the experiments on treatment efficiency, as well as changes in the composition of the peat, was studied.

2 Materials and methods

Two experiments were conducted at Väätsa landfill in Estonia, the first experiment (E1) in summer 2003 and the second experiment (E2) in 2005.

2.1 Site description

The Väätsa landfill is the first sanitary landfill in Estonia that meets the requirements of the EU Council Directive [16] and Estonian landfill directives [17]. The first stage of the landfill (1.0 ha) was in service from 2000-2005, and the second stage (1.5 ha) is in operation since November 2005. The landfill serves approximately 40,000 inhabitants. By the present time (February 2006), 60,000 t of mixed waste has been deposited [18]. The landfill has a proper lining, leachate collection system and two-stage biological leachate treatment system consisting of an activated sludge treatment plant and aerobic-anoxic pond (Fig. 1).

Figure 1: Aeration of landfill leachate in aerobic-anoxic pond in Väätsa, Estonia.

2.2 Experimental design

In both experiments, custom-designed peat filters (F) (total four filter bodies) were used. In experiment 1 (E1) the two metal filter bodies (filters 1 and 2 – F1, F2) had a volume of 1 m^3, were rectangular in shape, and had a permeable floor (Fig. 2). In the second experiment (E2), two filter bodies (filters 3 and 4 – F3, F4) with a volume of 0.2 m^3, were made of PVC pipe (Ø 372 mm, h=1200 mm) (Fig. 2).

2.2.1 Peat type

All filters were filled with well mineralised fluffy *Sphagnum* peat collected from Lokuta peat bog, which is located near Väätsa landfill. The well mineralised peat was obtained from the lower deposits of depleted industrial peatlands. The peat was sieved through a 26 mm sieve to remove stones and roots.

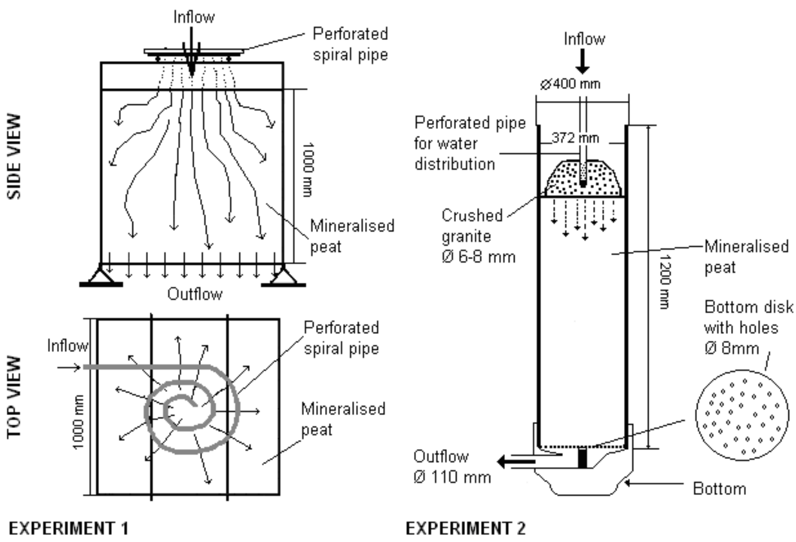

Figure 2: Design of the filter bodies and leachate distribution to the peat filters in experiment 1 (F1; F2) and in experiment 2 (F3; F4).

2.2.2 Distribution of leachate and loading of filters

For the loading of F1 raw leachate and for the F3 the leachate from the activated sludge treatment plant was used. For the F2 and F4 we used treated leachate from the pond (the outflow of the treatment system).

The even distribution of leachate into the F1 and F2 (E1) filters was achieved using perforated elastic pipes placed above the filter bodies in a spiral pattern (Fig. 2). The even distribution of leachate into the F3 and F4 (E2) filters was achieved using perforated pipe inside crushed granite (Ø 6-8 mm) on top of the filter material (Fig. 2).

All filters were loaded using timer-adjusted pumping. In the first experiment F1 and F2 were loaded for 36 days, with 2.9 m^3 m^{-2} in a day (in total about 104 m^3 per filter). In the second experiment, the filter 4 was loaded for a total of 5 months – from June to October 2005 – and the F3 since April 2005, for a total of 9 months. The loading rate for F3 was 0.083-0.033 m^3 m^{-2} d^{-1} (total amount about 13.7 m^3), and for F4 0.05 m^3 m^{-2} d^{-1} (about 7 m^3).

2.3 Sampling and statistical analyses

The leachate samples from the inflow and outflow of F1, F2 were taken on days 2, 4, 6, 8, 15 and 22, and once a month from the inflow and outflow of F3, F4: eight times from F3 and four times from F4.

In both experiments, BOD_7, COD, total N, NH_4-N, NO_3-N, NO_2-N, total P and pH were determined in the certified laboratory using standard methods. In experiment two we also analysed: PO_4^{3-}, conductivity, TSS, SO_4^{2-}, Ca^{2+}, Mg^{2+} and total hardness. In peat, the content of organic matter (%), N (%), pH_{KCl} and P, K, Ca, Mg (mg kg^{-1}) was determined.

The normality of variables was checked using the Lilliefors and Shapiro-Wilk tests; for normally distributed variables (Total P, BOD, COD, NH4-N, pH), the inflow and outflow values in different peat filters were compared via the pairwise t-test. When the distributions were skewed, the nonparametric Wilcoxon pairwise test was used. When the assumptions of ANOVA were fulfilled, a Fisher LSD test was used for multiple comparisons of mean removal efficiencies in different filters. For the remaining variables, Kruskal-Wallis ANOVA and the multiple comparison of mean ranks for all filters was used. The STATISTICA 7.0 software was used and the level of significance of α=0.05 was accepted in all cases.

3 Results and discussion

3.1 Landfill leachate treatment at Väätsa

At Väätsa landfill, approximately 10-20 m^3 of leachate is produced per day and treated in a biological treatment system. The treatment efficiency of conventional activated sludge treatment, followed by aerobic-anoxic treatment in a pond, is high. However, the average values of BOD_7, COD, total N, and total P in the outflow from the aerobic-anoxic pond (Table 1) exceeded the limits required for treated wastewater in Estonia [19].

Table 1: Average treatment efficiency in Väätsa landfill leachate treatment system in 2004 and 2005 [20, 19].

Parameter	Unit	Two-stage treatment system				Overall treatment efficiency (%)	
		inflow		outflow			
		2004	2005	2004	2005	2004	2005
BOD_7	mg L^{-1}	2193	993	52	93	90	91
COD	mg L^{-1}	4133	1880	451	847	90	55
Total N	mg L^{-1}	401	282	117	115	60	59
Total P	mg L^{-1}	1.7	6.5	3.6	4.6		30
pH		7.4	8.2	8.7	8.8		

In Estonia there are special target values for leachate treatment [17]: contamination rate 25 mg L^{-1} (purification rate ≥90%) for BOD_7; 125 mg L^{-1} (≥75%) for COD; 2.0 mgL^{-1} (≥80%) for total P and 75 mg L-1 (≥75%) for total N. Pre-treatment of leachate in the Väätsa biological treatment system is not sufficient to fulfil prescribed values for effluent.

3.2 Leachate treatment in experimental peat filters

In the first experiment, biologically pre-treated leachate from the second stage of treatment purified about 2-5% easier than the raw leachate. When we compare E1 and E2, however, the treatment efficiency is better in the second. One explanation of why E2 had better results in the removal of contaminants than E1 may be that the selected loading rate was too high for the filters in E1 [11].

Average values of contaminants in the inflow and outflow of the peat filters, and differences between inflow and outflow values in all filters (significant differences when $p<0.05$, according to pairwise t-tests) are presented in Table 2.

Table 2: Average values and standard deviation of the contaminants in the inflows and outflows of the peat filters. Significant differences between the inflow and outflow values of the contaminants in all of the peat filters studied (pairwise t-test results): * - $p<0.05$; ** - $p<0.005$.

Parameter ($mg\ L^{-1}$)	F1		F2		F3		F4	
	in	out	in	out	in	out	in	out
BOD_7	1953 ±459	1728 ±505*	54 ±19	27 ±19*	79 ±32	24 ±15**	19 ±16	6 ±3
COD	3812 ±446	3462 ±555**	521 ±49	466 ±60**	1158 ±239	843 ±253*	598 ±37	592 ±150
Total P	1.3 ±0.2	0.7 ±0.3**	1.2 ±0.2	0.6 ±0.1**	5.6 ±1.9	2.0 ±1.7**	3.3 ±0.7	0.2 ±0.2*
Total N	447 ±24	401 ±63*	112 ±22	95 ±37	339 ±121	302 ±101	127 ±55	115 ±23
NH_4-N	369 ±60	327 ±44*	52 ±10	37 ±7*	254 ±115	97 ±85**	9.5 ±9	7.2 ±2
NO_3-N	5.8 ±2.2	5.8 ±1.3	18 ±6.7	17 ±2.7	38 ±53	143 ±93*	50 ±14	43 ±14
pH	7.5 ±0.1	7.8 ±0.2*	8.8 ±0.1	8.3 ±0.2**	8.5 ±0.2	8.2 ±0.2**	8.8 ±0.1	8.9 ±0.6

The average value of pH in leachate decreased in F2 and F3, and an increase took place in F1 and F4. The changes in pH value according to the pairwise t-test were significant in filters 1, 2 and 3 (Table 2). As stated by Patterson et al. [21], the slight change in pH could be related to the organic acid components flushed from the peat.

3.2.1 Reduction of BOD and COD values

A decrease in BOD value was observed after treatment in all filters (Table 2). The treatment efficiency in filters was 12-70% on average, and maximum reduction was achieved in F3 (95%). The outflow value that fulfils the prescribed limit of 15.0 mg O_2 L^{-1} [17] was achieved in F4, where the outflow value was 6.4 mg O_2 L^{-1} on average. The most effective removal of COD was achieved in F3, where the values were on average almost 30%.

The reasons why BOD and COD removal was some times not successful enough may be that factors were not favourable (pH range, the existence of inhibitors, the lack of substrate and phosphorus, temperature, contamination rate etc). For instance, the BOD and COD values in raw leachate were too high (Table 2) for it to be treated only with a peat filter.

3.2.2 Removal of nitrogen

The best results for nitrification were achieved in the F3 (Table 2), where ammonia nitrogen was reduced by 62% on average (Fig. 2). Only in F4 did no significant nitrification take place. The reduction of total N concentration was noticeably higher in F2 (35% on average). However, significant differences between inflow and outflow were only determined in F1. The reduction was not sufficient to fulfil the Estonian discharge limit [17].

Maximum removal of ammonia nitrogen (62% on average) was achieved by F3 (Fig. 2). Significant differences between inflows and outflows were determined in F1, F2 and F3 (Table 2). An approximately 12 and 30% reduction is obtained in F1 and F2 respectively.

Mæhlum [22] indicated that nitrification may be limited due to lack of oxygen. The amount of oxygen in peat was not directly measured, but the intermittent loading of leachate during the experiment was selected in order to increase the natural inflow of oxygen through the top and the bottom of the filter body. In experiment 2 the amount of oxygen was measured from the inflow and outflow leachate of the peat filters. The results show that the peat filters increase the amount of oxygen in leachate (e.g. 95% on average in F3).

Nitrification occurs at an optimum temperature of about 30ºC [23]. At 5ºC, the nitrification rate is only 15% of the rate at 20ºC [24]. The temperatures of raw and pre-treated leachate during the summer period in Väätsa were 14.8±0.3ºC and 18.0± 1.6ºC respectively. Thus there should be favourable conditions for the creation of nitrifying bacteria in that period.

The nitrification of ammonia also depends on the hydraulic loading [25]. We can confirm this fact, because E2 had better results in nitrification then E1. Also, when we lowered the hydraulic loading rate into the F3 filter several times during experiment 2, the ammonia nitrogen decreased, and NO_3-N and NO_2-N increased significantly.

3.2.3 Removal of phosphorus

The removal of total phosphorus from Väätsa leachate (Fig. 2) was very successful, and average outflow values were below the limits [15]. According to pairwise t-tests, the inflow and outflow values demonstrated a significant difference ($p \leq 0.005$) in all filters. The total phosphorus reduced in F1 and F2 was on average 49% and the F3 and F4 filters removed 64 and 92% respectively.

Mann [26], Kadlec and Knight [23] and Richardson et al. [27] demonstrated that the reduction of total P could be caused by the sorption, sedimentation and combination of complex compounds. A certain proportion of P may be bound to the biofilm [26, 27].

Phosphorus transforms easily from organic to inorganic forms and constitutes chemical complexes with organic and inorganic ligands, which can be adsorbed by or sedimented into the soil. In aerobic wetland conditions the P constitutes in dissolved complexes with oxidised Ca and Mg in alkaline conditions, and with Fe or Al in soil with acidic to neutral pH [22]. The content of the Mg and Ca in peat increased significantly, whereas the pH of the peat was neutral.

According to Mæhlum [22], it can be concluded that the fixation of P resulted in adsorption with Ca and Mg compounds, and these were settled in the peat filter. P content increased in peat, supporting this statement.

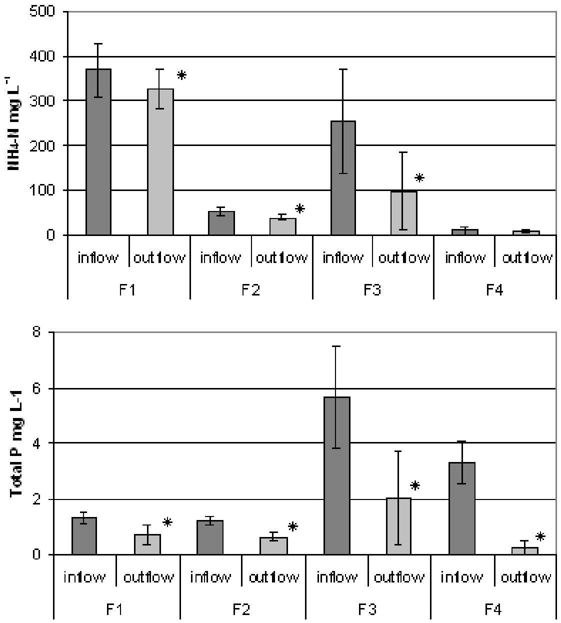

Figure 2: Average inflow and outflow concentrations of NH_4-N and total P in all filters. * - $p<0.05$, the inflow value is significantly different from outflow values, according to the pairwise t-test.

3.3 Composition of peat

The initial concentrations of Ca, Mg and K in the well mineralised peat are relatively high (Table 3). Before the experiment, the content of organic matter in peat was almost twice lower (37%) than on average, which could be due to the small stones that were found in the peat. During the experiment there was a slight increase in the content of organic matter. After the experiment, Ca, Mg and especially K concentrations increased significantly (96%).

Table 3: Composition of peat in filters 1 and 2 before and after the first experiment. Units are mg kg^{-1} (unless otherwise noted).

	pH_{KCl}	N (%)	P	K	Ca	Mg	Organic matter (%)
Before	6.7	0.5	23	93	8294	1416	37.2
After	7.1	0.6	37	2177	9178	2149	36.9

The removal of contaminants from leachate can be linked to chemical changes in the peat. The results are affected by interactions between peat type, water quality, loading rates, duration of treatment etc. The removal of total P with the filters may be caused by the high content of Mg- and Ca-compounds in peat.

4 Conclusions

In Estonia, the use of peat as a filter material has good potential. It has shown sufficient purification efficiency and can be considered to be an ecologically sound and economically beneficial material in leachate treatment.

The pre-treatment of landfill leachate considerably reduces the pollutant load on the peat filter, which increases its performance. A smaller flow rate and respectively longer retention time will be required for the optimal performance of peat filters.

We can conclude that peat filters are well suited to the reduction of Total P from raw leachate (up to 81%), as well as from pre-treated leachate (up to 70-99%).

The remarkable efficiency of well-mineralised peat in the reduction of BOD values (up to 95%) and NH_4-N concentrations (up to 93%) encourages us to use peat filters in combination with conventional treatment methods, e.g. as soil filters of subsurface flow constructed wetlands for secondary or tertiary treatment of landfill leachate.

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