Impacts of filter media, temperature and nutrient conditions on treatment of airport runoff

Impact des matériaux filtrants, de la température et des nutriments sur le traitement des eaux de ruissellement des aéroports

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RÉSUMÉ

Les aéroports dans des conditions climatiques froides représentent un défi de gestion des eaux pluviales en raison de la grande quantité de surfaces imperméables et des produits chimiques uniques utilisés pour minimiser les effets défavorables des conditions verglacées sur la sécurité des passagers. Ces produits sont très mobiles et posent des risques graves pour les eaux réceptrices. Pour remédier aux problèmes de qualité de l'eau dans les aéroports, marais filtrants d'écoulement souterrain (SSFW) sont de plus en plus proposées comme solutions de traitement en raison de leurs relativement bas coûts de construction et de maintenance. Toutefois, ces systèmes ont eu un impact environnemental considérable ; elles ont eu des vastes zones de terres réservées et des longs temps de séjour hydraulique. En plus, l'ajout artificiel de nutriments est généralement nécessaire. Dans cette étude, des expériences à l'échelle de laboratoire ont été menées afin de comprendre l'influence de types différents d'éléments filtrants sur les performances de ces systèmes dans des conditions défavorables. La recherche sur l'élimination des charges organiques et des nutriments, ainsi que sur les facteurs influant sur la performance des filtres, est nécessaire pour développer des solutions optimales pour le traitement des eaux de ruissellement urbaines. Tous les matériaux ont montré des résultats prometteurs, mais aération était nécessaire pour optimiser les filtres. Les résultats peuvent être utilisés pour augmenter la performance des systèmes de traitements et pour réduire l'impact environnemental des aéroports. Les résultats de l'étude seront utilisés dans la planification du SSFW à l'aéroport d'Helsinki, en Finlande.

ABSTRACT

Airports in cold climatic conditions represent a stormwater management challenge due to the large amounts of impervious surfaces and the unique chemicals used to minimize the unfavourable effects of icy conditions on safety. These chemicals are highly mobile and pose severe risks to receiving surface and ground waters. To tackle the water quality problems at airports, subsurface flow wetlands (SSFW) have been proposed as treatment solutions due to their relatively low construction and maintenance costs. However, these systems e.g., in Paris, London, and Edmonton, have had a large footprint; in addition to large reserved land areas and long hydraulic retention times, the artificial addition of nutrients is commonly needed. In this study, laboratory-scale experiments were carried out with the aim to understand the influence of different filter media (gravel, expanded clay, biochar) on the performance of these systems under unfavourable cold conditions. The investigation of both nutrient and organic load removal, as well as the factors influencing filter performance, is required to develop optimal solutions for the treatment of urban runoff. All materials showed promising results, yet aeration was needed for optimal filter performance. The results can be used to increase the overall performance of the treatment systems and reduce the environmental footprint of airports. The results of the study are utilised in the planning of the SSFW at the Helsinki Airport, Finland.

KEYWORDS

Birch biochar, Biological treatment, Cold climate, De-icing chemicals.

1 INTRODUCTION

Airports represent a unique land use type that typically produces high volumes of runoff due to large extent of impervious surfaces. In cold climatic conditions, de-icing treatments are used in airports to counteract the effects of ice and snow on airplane and runway surfaces. The treatments include substances such as formates for runway anti-skid treatment and propylene glycol (PG) for airplane de-icing treatment. These substances are miscible in water and thus highly mobile in the environment. Although they are not classified as hazardous, they have a severe impact on receiving waters due to high biological oxygen demand reaching up to 1.68 g O_2/g PG (Toscano et al., 2013).

To overcome the water quality challenges triggered by the de-icing treatments, airports such as Orly (Paris), Heathrow (London), and Edmonton (Canada), have implemented solutions similar to subsurface flow wetlands (SSFW). These solutions are favoured due to their low construction, operation and maintenance costs. Typically, the focus of these systems has been the reduction of high organic loadings. The systems are commonly designed to have long hydraulic residence times (1-60 days) and operated with an artificial feed of nutrients (Freeman et al., 2015)

A SSFW has been proposed to reduce environmental risks of de-icing at the Helsinki Airport. Due to the large stormwater volumes and limited vacant space available at the airport, contaminated stormwater needs to be treated more efficiently in terms of area and time, and in conditions with low stormwater nutrient concentrations and temperature. The aim of this study was to test in laboratory conditions the influence of different filter materials, ambient temperature, nutrient concentrations, air injection, and flow regime on the treatment performance of alternative SSFW configurations, with the main focus on the removal of nutrient and organic loads.

2 METHODS

2.1 Experimental design

Twelve cylindrical columns with an individual area of ~0.07 m^2 were constructed in an environmental chamber and filled with three different filter media (Figure 1). The filter materials were expanded clay (Leca Ø 3- 8 mm), crushed stone (Gravel Ø 5-16 mm) and birch biochar (Biochar Ø 0-10 mm). Leca and biochar were each mixed 1:1 by volume with gravel. Structural details of the columns are shown in Figure 1. The vegetation was taken from the airport with the purpose of conditioning the columns with an indigenous microbial community. An aeration system was installed in all columns, but only used on half of the columns during the experiments. The columns were fed with synthetic runoff formulated on a 1 m^3 tank with tap water based on historical data about water quality at Helsinki Airport. The de-icing chemical was Type I Propylene Glycol (PG), and nutrients were $NaNO_3$ and K_2HPO_4. The ratio of C:N:P in the synthetic runoff was thus based on median (~120:6:0.1) and mean (~120:13:0.3) historical values, which differed from the optimal C:N:P value (120:15:1.4) for PG degradation (Toscano et al., 2013).

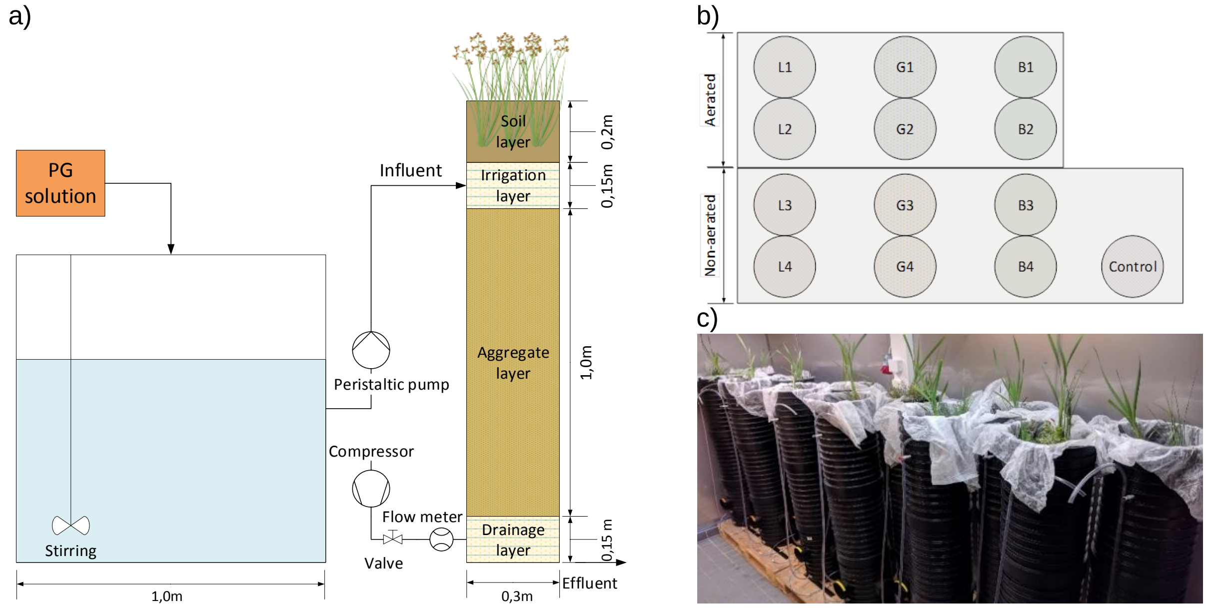

Figure 1. A a) cross-sectional and a b) top view illustration of the setup utilised as well as c) the finalised columns.

The experimental period was divided into Phases I-IV with varying conditions (Table 1). Each Phase consisted of 3 irrigation periods per column under the same conditions, hence most results are given as averages of six values (3 irrigations x 2 columns). The hydraulic retention time (HRT) remained constant in all Phases (HRT = 16±1 h).

Table 1. Key characteristics of different experimental phases

Phase	Reactor type	No. of columns	Materials and replicates	Aeration rate (l/h/m²)	Temperature °C	Nutrients concentration
I	Batch reactor	12	• 3 Materials ○ 2 aerated ○ 2 non-aerated	~1360	21±1 °C	Historical mean values
II	Batch reactor	12	• 3 Materials ○ 2 aerated ○ 2 non-aerated	~1360	3±1 °C	Historical mean values
III	Batch reactor	5	• Best performing materials	~680	2±1 °C	Historical median values
IV	Continuous reactor	5	• Best performing materials	~180-450	1.4±0.6 °C	Historical median values

The synthetic runoff was sampled before and after each irrigation treatment. The main parameters monitored included PG, BOD_5, DO, N_{tot}, P_{tot}, heterotrophic bacteria, pH, conductivity and temperature. The water quality analyses were performed by an external certified laboratory and at the Aalto University Water Laboratory according to international standards. Additionally, a degradation experiment in tank was performed before the experiments to understand the natural rate of PG degradation (24±1 °C) and to test (Pearson) correlations between different surrogate analyses for PG, such as COD_{Cr}, TOC and $BOD_{5\text{-}7}$. Unpaired t-test was used to compare the differences.

3 RESULTS AND DISCUSSION

3.1 Degradation experiment

The results from the degradation experiment showed that PG correlated significantly ($r=0.94$, $p<0.05$) with BOD_5, thus demonstrating the suitability of BOD_5 as surrogate variable. After a period of 72 h, a ~77% decrease in PG was observed. BOD_5, BOD_7 and COD_{Cr} showed smaller decreases of ~52%, ~51% and ~47%, respectively. TOC reduction followed a linear trend ($R^2=0.99$) with a reduction of ~35% after the period of 72 h. The TOC trend predicted a ~57% TOC degradation after 5 days, which is in line with similar studies of 50% reduction (Lindseth, 2016). Additionally, a bacterial count increased from $1{,}6\times10^4$ to $2{,}0\times10^6$ CFU/ml and DO was depleted after only 24 h.

3.2 Column irrigations

The average BOD_5 removal for the alternative treatment methods showed significant ($p<0.05$) performance differences between aerated and non-aerated columns collectively, as well as by filter material (Figure 2). All aerated columns achieved >96% BOD_5 removal regardless of filter media type (Figure 2a). However, significant performance differences ($p<0.05$) were observed between the non-aerated columns. Non-aerated biochar columns tended to perform better than the other alternatives and non-aerated gravel columns showed the worst performance. As a result, neither non-aerated gravel columns nor aerated Leca columns were further studied during the last two Phases III and IV. During the Phases III and IV of low temperature and low nutrient conditions, the performance of the non-aerated columns was significantly ($p<0.05$) poorer than during the earlier Phases I and II, however, the performance of the aerated columns was not affected. Therefore, these results demonstrate that adequate performance is achievable in poor environmental conditions, if aerobic conditions are kept within the filter media. Hence, aeration appears to be necessary to achieve consistent and efficient results with the planned HRT.

The DO saturation [%] in the effluent (Figure 2b) was significantly ($p<0.05$) lower in the non-aerated columns, being in all non-aerated cases well under the minimum recommended levels of 4 mg O_2/l by Carter (2005) for freshwater adult salmonids such as trout and salmon. Furthermore, the non-aerated gravel and Leca effluents produced strong odours associated with anoxic degradation of PG. Despite showing similar anoxic conditions, biochar columns did not produce any odours, suggesting that biochar acted as an odour adsorbent like activated carbon (Rowe, 1963). Additionally, gravel and Leca were found to respond better than biochar to aeration rate changes and needed overall less aeration to reach a similar DO saturation level. However, the reduced saturation level, as compared with gravel and Leca, did not seem to affect the BOD_5 removal performance of Biochar.

The low DO levels present in the effluent of the non-aerated columns, together with the significantly higher ($p<0.05$) removal rates than their aerated counterparts (Table 2), suggested that the main mechanism for nitrogen (N) removal in non-aerated columns was denitrification. Additionally, there was no significant ($p>0.05$) difference between alternative filter media of the non-aerated columns. Biochar was the only material that consistently removed most N regardless of the oxygen conditions, thus suggesting other removal mechanisms as well. During the low nutrient and temperature Phases (III-IV), aerated gravel achieved good performance, indicating that in poor conditions N might become a limiting factor. Removal of phosphorus (P) appeared to require almost opposite conditions to N removal, since the highest removal performances were seen in the aerated setups (Table 2). In terms of reliability, gravel columns together with biochar columns tended to be more consistent in the removal of P. However, non-aerated biochar and Leca columns appeared to be leaching P during continuous steady state flow.

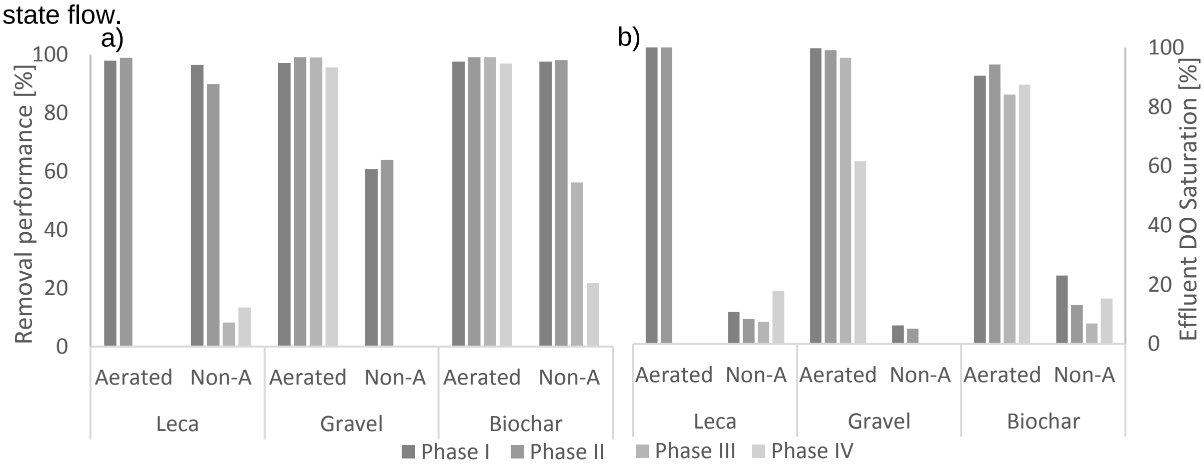

Figure 2. Removal performance for a) BOD_5 and b) DO saturation [%] in effluent. Non-A = Non-aerated

Table 2. Nutrient removal performance for each Phase. Best performing setups with >70% removal in bold.

	Ntot removal [%]				**Ptot removal [%]**			
	Phase I	**Phase II**	**Phase III**	**Phase IV**	**Phase I**	**Phase II**	**Phase III**	**Phase IV**
Leca aerated	32,8	70,3	-	-	28,2	**85,1**	-	-
Leca non-aerated	**93,8**	**97,0**	82,3	**93,9**	50,0	74,4	50,9	-106,2
Gravel aerated	51,8	75,6	**93,3**	88,7	**79,5**	**86,6**	**72,4**	**83,9**
Gravel non-aerated	**96,1**	96,8	-	-	32,7	27,8	-	-
Biochar aerated	91,8	**98,1**	**95,7**	**94,7**	45,5	**81,1**	**82,7**	**81,3**
Biochar non-aerated	**94,0**	**98,3**	**95,6**	**96,4**	41,0	75,0	55,9	-344,7

4 CONCLUSIONS

The results showed that a SSF wetland would clearly improve the quality of airport runoff. Additionally, it was possible to achieve satisfactory performance with the tested materials under disadvantageous environmental conditions. Biochar showed promising performance in most metrics utilised. However, the high cost of biochar, technical difficulties in its use and the possible leaching of P are the negative side of biochar application. Gravel on the other hand had a good and consistent performance throughout the experiments. Additionally, this study showed the inevitability of an aerated system for these conditions for securing adequate performance of SSFW. The holistic approach for both organic load and nutrient retention, as well as the factors influencing their performance, provide valuable insights into the development of optimal solutions with different filter media for the treatment of urban runoff.

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