INFLUENCE OF TRANSIENT HYDRAULIC LOADING RATE ON THE PERFORMANCE OF HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLANDS

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ABSTRACT

Hydraulic loading rate (HLR) is a critical parameter for constructed wetlands operation. A Filtralite-based horizontal subsurface flow (HSSF) bed under transient hydraulic loading conditions was monitored during one year. The results show that the bed received variable HLR over time, which compromised the removal of BOD_5 and nitrogen, but seems to have had a minor effect on the removal of TSS and phosphorous. It was observed a linear relationship with statistical significance between the applied and removed loads for COD, phosphorus and TSS, which seems to indicate that the applied loads influenced the respective removal rates. This study shows that the use of bed media with high void ratio, porosity and specific surface area does not bring benefits if the HLR is not properly controlled.

KEY WORDS

Constructed wetlands; horizontal subsurface flow; bed media, hydraulic loading rate; pollutants removal

INTRODUCTION

The dispersion of small population agglomerates, especially in rural areas or around big cities, makes the operation of conventional wastewater treatment systems (WWTS) very expensive. Constructed wetlands (CW) are considered economic, technical and sustainable alternative solutions for wastewater treatment (Kadlec *et al*. (2000)). Besides providing secondary treatment, the system deals well with variable pollutant loads (Albuquerque *et al*. (2009)) and may also be used for polishing treatment, which is especially useful when receiving streams are considered sensitive or water reuse is an option (Kadlec *et al.* (2000), Vymazal and Kropfelova (2008)).

The use of light–expanded clay aggregates (*e.g.* Filtralite) is pointed out as an alternative solution to minimize the clogging problem or to increase the treatment capacity, since it presents both higher porosity and specific surface area, which allows a better biofilm adhesion. As the material is light also stimulate a quickly development of plants. This material has been used in CW to improve the removal of organic matter and nutrients with very good results as reported in the studies of Vilpas *et al.* (2005) and Albuquerque *et al.* (2009). According to Kadlec *et al.* (2000) and Vymazal and Kropfelova (2008) nitrogen removal in HSSF beds is low when compared to organics and solids, varying between 40% to 55% and can rarely be higher because of their inability to provide oxic conditions for nitrification and anoxic conditions for denitrification simultaneously.

The main objective of the work was to evaluate the influence of the HLR variation on the removal of organics, nitrogen, phosphorus and solids in a Filtralite-based HSSF bed.

MATERIAL AND METHODS

The HSSF-CW of Vila Fernando (Portugal) was used for this study. The bed has 23x18 m (length x width), a water depth of 0.5 m and was colonized with common reeds (*Phragmites australis*). It was sized for 400 p.e. and for the following conditions (maximum values for 2023): maximum flow rate of 26 m^3 d^{-1}, maximum HLR of 12 cm d^{-1}, maximum HRT of 9 d, BOD_5 from 200 to 400 mg L^{-1} (maximum OLR of 25 g BOD_5 m^{-2} d^{-1}) and COD from 500 to 700 mg L^{-1} (maximum OLR of 44 g COD m^{-2} d^{-1}).

A one year monitoring campaign was set up in 2008, which included the measurement of the flow-rate (entrance) and the collection of samples each 15 days at the influent and effluent of the bed to determine pH, temperature, BOD_5, COD, TN, NH_4-N, NO_2-N, NO_3-N, TP, TSS and VSS. All the measurements were analysed according to standard methods.

RESULTS AND DISCUSSION

The results are presented in Table 1.

Table 1 – Results of the monitoring campaign (average, confidence interval and range of values)

Parameter	Influent	Effluent	Removal Efficiency (%)
Flow-rate (m^3 d^{-1})	16 ± 9 (5-50)	—	—
Temperature (° C)	15 ± 2 (10-21)	16 ± 3 (9-21)	—
pH	6.7 – 7.3	7.2 – 7.6	—
BOD_5 (mg L^{-1})	146 ± 56 (51-344)	36 ± 16 (7-80)	74.1 ± 12.1
COD (mg L^{-1})	365 ± 138 (125-750)	100 ± 25 (52-167)	64.6 ± 13.7

TSS (mg L^{-1})	73 ± 26 (31–139)	18 ± 14 (6–68)	76.6 ± 8.7
VSS (mg L^{-1})	61 ± 22 (26–121)	13 ± 9 (4–44)	79.2 ± 9.1
TN (mg L^{-1})	77 ± 20 (46–131)	61 ± 9 (40–79)	26.4 ± 12.3
NH_4-N (mg L^{-1})	63 ± 14 (41–113)	52 ± 7 (32–64)	25.2 ± 8.3
NO_2-N (mg L^{-1})	0.1 ± 0 (0.1)	0.3 ± 0.1 (0.1–0.4)	—
NO_3-N (mg L^{-1})	0.1 ± 0 (0.1)	2 ± 0.5 (1.3–4)	—
TP (mg L^{-1})	8 ± 3 (4–13)	6 ± 2 (4–10)	26.4 ± 9.2

High flow-rates were registered in the rainiest months (January to May) of the monitoring period, with values close to 50 $m^3 \cdot d^{-1}$ (more than the double predicted for 2023), which means that high infiltration of stormwater occurred into the sanitary sewer network. The HLR, in those months, reached 25 cm d^{-1}, twice the maximum allowed value. In the driest months (July to November), the HLR varied between 2.2 and 5 cm d^{-1}, i.e. 58% to 81% lower than the maximum allowed value, which is justified by the lack of connection of part of the Vila Fernando sanitary sewer network. Those variations in the HLR originated very variable HRT over time (4 to 45 d), with an average value (21 d) much higher than the maximum value allowed for the bed (9 d).

The removal efficiencies are, except for TN and NH_4-N, according to the values observed in Kadlec *et al*. (2000) and Vymazal and Kropfelova (2008). The low removal of nitrogen it seems related to the variable HLR entering the bed that caused a weak development of both the plants and the biofilm. The homogeneous development of plants through the bed allowed an adequate biofilm development in the media as well as in roots and rhizomes, promoting the removal of organic matter and nitrogen and the uptake of nitrogen and phosphorus by plants (Vymazal and Kropfelova (2008)).

After a regression analysis between the applied loads and the removed loads, it was observed a linear relationship with statistical significance ($p<0.05$) for BOD_5, COD, TP and TSS (*i.e.* the applied OLR, PLR and SLR seems to have influenced the respective removal rates). However, there was no statistical significance for the relationship between nitrogen applied loads and nitrogen removed loads. The removal rates observed for COD are even higher than the ones reported by Vilpas *et al*. (2005) in similar HSSF beds in Finland (3 a 10 g COD m^{-2} d^{-1}), while the removal efficiencies are within the interval observed by those authors (60 to 80%).

The use of Filtralite, with higher void ratio, porosity and specific surface than the ones for conventional materials (gravel and sand), in spite of the advantages pointed in some studies (Vilpas *et al*. (2005), Albuquerque *et al*. (2009a), it seems to not contribute for the improvement of HSSF beds performance if the HLR is not stabilised.

CONCLUSIONS

The bed received higher flow-rates than the maximum predicted value for 2023. The high variation of the HLR was responsible for the instability in the HRT and for the weak development of both biofilm and plants in the bed, which negatively affected the removal of BOD_5 and especially nitrogen. However, the removal of TSS and TP seem to have not been significantly affected by the variation on the HLR, since they were mainly removed by physical-chemical mechanisms (filtration and adsorption). The removal of organic matter, phosphorus and solid matter seems to have been proportional to the applied loads. Therefore, Filtralite, besides presenting good properties that may promote high removal of pollutants, only can contribute for a good performance of HSSF beds if the HLR is properly controlled.

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