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Comparative Study on the Landfill Leachate Treatment in a Vertical Flow Wetland System With/Without Phragmites australis

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Abstract: The landfill leachate treatment efficiency in a vertical-flow wetland system with and without planted *Phragmites australis* was investigated. The BOD/COD ratio of the landfill leachate was 0.38. Water samples were taken daily for determination of the COD, BOD, [NH_4-N], [NO_2-N], [NO_3-N] and orthophosphates values. High COD and BOD removal efficiencies and discharge limits in both laboratory systems were achieved. Complete elimination of the ammonium nitrogen from the leachate in the nonvegetated wetland for 13 and 14 days was obtained at a recirculation ratio of 1:1 and 1:2, respectively, and for 9 and 7 days - in the vegetated wetland, at the same recirculation ratios. The initial nitrite nitrogen concentration in the landfill leachate was 17.2 ± 1.1 mg/L, which is 430 times over the discharge limit for these ions. After landfill leachate treatment in the nonvegetated wetland system at the recirculation ratios 1:1 and 1:2, nitrites removal efficiencies of 98.8% and 92.5%, respectively, were achieved. In the vegetated wetland system at the same recirculation ratios, nitrites removal efficiencies of 96.5% and 76.2%, respectively were achieved. Nitrates removal was not observed. The results show that the orthophosphates were assimilated better from the *Phragmites australis* at longer water resting period.

Key words: Landfill leachate, vertical flow constructed wetland, *Phragmites australis*.

Introduction

The landfill leachate is a liquid, which is formed as a result of degradation processes of deposited wastes. The quantity of the leachates depends on the wastes composition, the used deposition method, the precipitations amounts, as well as the landfill age. The landfill leachates contain a large variety of contaminants and because of this they have harmful effect on the environment. This is the main reason for their preliminary treatment before discharge. The Landfill Directive and Waste Framework Directive directly influence the practices for leachate management and especially their collection and methods for treatment. This in turn affects the concentrations of BOD and ammonium nitrogen (Brennan *et al.*, 2016). The most common practice of the landfill leachates disposal is their mixing with domestic wastewater and their co-treatment in the wastewater treatment plants. Advanced oxidation methods, which are able to degrade wide range of the compounds, contained in the leachates were also used. They are very effective but quite expensive. Therefore, it is necessary to use a combination of chemical and biological methods that complement each other and lead to effective landfill leachate treatment. There are integrated systems including different processes like biochemical oxidation, coagulation, sedimentation and photo oxidation (Silva *et al.*, 2017). The so-called constructed wetlands for wastewater treatment are used over the past few decades

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in Europe and US (VYMAZAL, 2010). The constructed wetlands can provide effective wastewaters treatment but for longer period of time because of contained toxic and persistent organic pollutants in landfill leachates, which inhibit the biochemical reactions (KADLEC & ZMARTHIE, 2010). Different types of plants in these systems are used. They contribute for treatment efficiency by accumulation of the pollutants in their tissue (LAVROVA & KOUMANOVA, 2008). One of the most important requirements for the effectiveness of these systems is the right choice of vegetation (LAVROVA & KOUMANOVA, 2013). The type of filler media in the systems also plays significant role in the purification process. Materials such as gravel, sand, zeolite, organic matter and other are used for filling the wetlands body (LI *et al.*, 2010; PELISSARI *et al.*, 2016; MOJIRI *et al.*, 2016; DE ROZARI *et al.*, 2016). The removal of organics, nitrogen and phosphorus containing substances and other pollutants in these systems is of a particular interest in research.

The aim of this research was to study the landfill leachate treatment efficiency in vertical-flow wetland system with and without planted *Phragmites australis*.

Materials and Methods

Wastewater characteristics

The landfill leachate was taken from a 10-15 years old landfill situated in the north-western part of Bulgaria. The characteristics of the landfill leachate used in the experiments are presented in Table 1. The values show that the cell from which the leachate was generated is in the methanogenic phase.

The BOD/COD ratio of the landfill leachate was 0.38 which means that the wastewater is fairly biodegradable and can be effectively treated biologically. The landfill leachate contains ammonium ions with high concentration which is directly dependent with the organic matter decomposition (BURTON & WATSON-CRAIK, 1998; LEE *et al.*, 2010). The wastewater contains nitrites and low concentration of nitrates, which is evidence for presence of slight nitrification of the generated ammonium ions.

Table 1. Landfill leachate characteristics.

Parameter	Value (mean ± SD)
COD (mg/L)	2031.3 ± 9.2
BOD (mg/L)	762.2 ± 5.1
NH_4-N (mg/L)	332.3 ± 32.4
NO_2-N (mg/L)	17.2 ± 1.1
NO_3-N (mg/L)	0.3 ± 0.2
Orthophosphates (mg/L)	1.9 ± 0.1

Laboratory system

Two identical laboratory systems (Fig. 1) were used in the experiments. They have one significant difference – in the first laboratory system the reactor type subsurface vertical-flow wetland (SVFW) was unplanted and in the second laboratory system this reactor was planted with *Phragmites australis*. The reactor type SVFW was a column with dimensions 123 mm in diameter and 900 mm in height. It was filled with 35 ÷ 55 mm round gravel as a bottom layer with a height of 300 mm and top layer with a height of 500 mm of 5 ÷ 25 mm gravel.

After clarifying into a sedimentation tank the landfill leachate flows into the SVFW reactor. Peristaltic pump ensures the water movement through the reactor with flow rate 60 ml/min. The system operated continuously in recirculation regime. The recirculation was performed at ratio of 1:1 and 1:2, giving 1 h water movement through the filter media and 1 (2) h resting period of the water into the reactor (contact between the wastewater and the bed matrix). Water samples were taken daily for determination of the COD, BOD, NH_4-N, NO_2-N, NO_3-N and OP values. In a similar laboratory system young *Phragmites australis* (common reed), obtained from comparatively clean area, was planted.

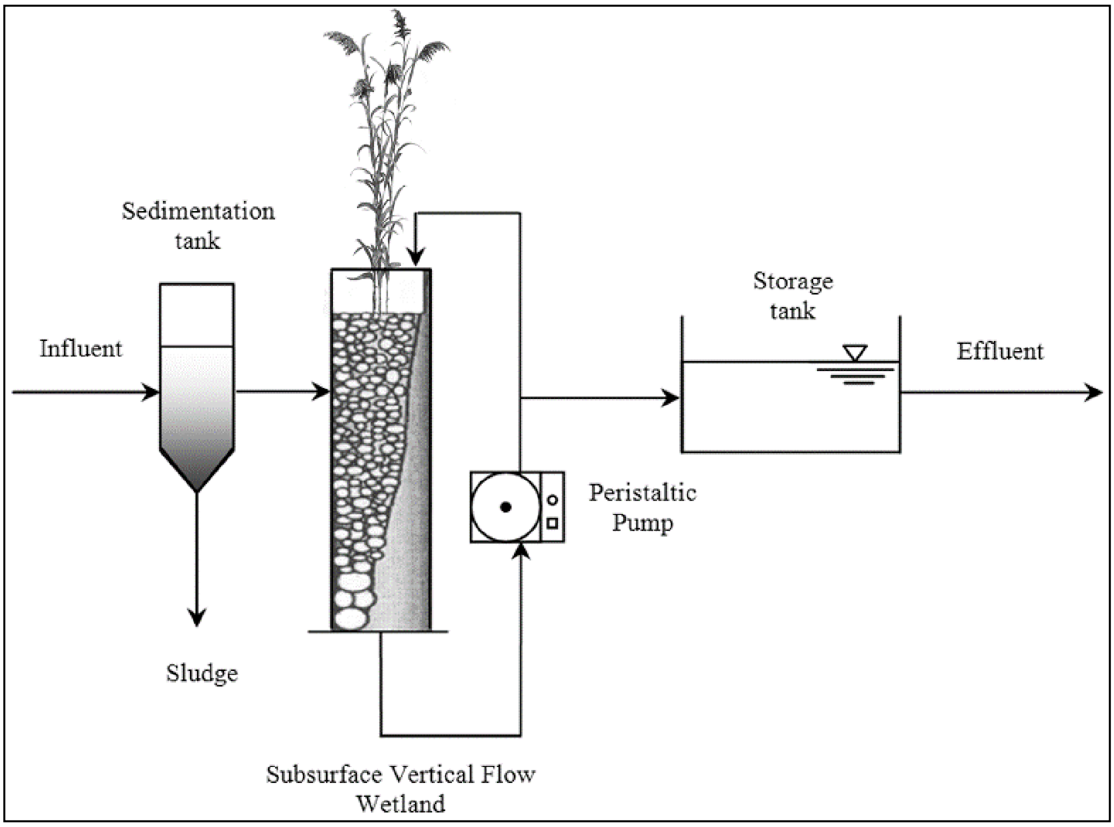

Fig. 1. Scheme of the laboratory system used in the experiments.

Analytical methods and chemicals

The parameters Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Ammonium Nitrogen [NH_4-N], Nitrite Nitrogen [NO_2-N], Nitrate Nitrogen [NO_3-N] and Orthophosphates (OP) were determined by standard methods, using pure reagents for analysis (APHA, 1992).

Removal efficiency

The removal efficiency was determined by using the following formula:

$$E = \frac{C_0 - C_t}{C_0} \times 100, \%$$

where C_o is the initial concentration in mg/L and C_t is the concentration at time t.

Results and Discussion

COD removal

The landfill leachates used in the experiments has high initial COD values (2031.3 ± 9.2 mg/L). The obtained results show that the leachate resting period and the plants presence in the system are important for the treatment efficiency (Table 2).

For 15 days leachate treatment in the laboratory system, consisted of reactor type subsurface vertical-flow wetland without *Phragmites australis*, COD removal efficiency of 81.6% and 92% was achieved at recirculation ratio 1:1 and 1:2, respectively. The longer contact time between the leachate and the reactor's package leads to better results probably due to the vital activity of the microorganisms attached on the gravel surface. For this period of time the COD discharge limit was not met. During the leachate treatment in the system with *Phragmites australis*, faster decreasing of COD was observed. In this system COD discharge limit was achieved with removal efficiency of 96.2% and 96.8% for 12 and 10 days at recirculation ratio 1:1 and 1:2, respectively. The plant presence in the laboratory system contributes to the faster removal of contaminants from the leachate probably due to the well-developed microbial community and root system which release oxygen in the surrounding media. It is also well known that the plants have ability to accumulate different compounds from the aquatic environment in their tissue which also contributes for the COD decreasing.

Table 2. COD and BOD removal efficiency (%).

Days	SVFW without *Phragmites australis*		SVFW with *Phragmites australis*	
	Recirculation ratio			
	1:1	1:2	1:1	1:2
		COD		
3	28.4	38.5	45.8	56.9
6	45.6	63.2	76.1	87.9
10	63.7	80.4	93.9	96.8
		BOD		
3	49.6	55.8	65.1	81.2
5	61.0	69.8	81.5	90.9
8	74.1	79.2	96.5	98.3

BOD removal

The landfill leachate used was with high BOD initial concentration (762.2 ± 5.1 mg/L). During the experiments the BOD values flowingly decreased as in the laboratory system without vegetation the process becomes slower in comparison with laboratory system with *Phragmites australis* (Table 2). In the SVFW without *Phragmites australis* the BOD discharge limit was not met for 15 days treatment. This period of time was insufficient for complete leachate polishing because of high contaminants concentration in it, although the BOD/COD ratio of 0.38, which is an indicator for slight biodegradable compounds. During the experiments in the laboratory system with common reed, the BOD discharge limit was achieved for 9 and 8 days at recirculation ratio 1:1 and 1:2, respectively.

NH_4-N removal

The ammonium nitrogen concentration was reduced gradually in each experiment (Fig. 2). The results show that the concentration of these ions was reduced as slowly as in the wetland system without vegetation at recirculation ratio of 1:2, and most rapidly in the wetland system with vegetation and at the same recirculation ratio. Generally, the natural NH_4-N oxidation by the air has a fundamental influence on the process. In the vegetated wetland it was noted that the process occurs faster than in the nonvegetated system. This is probably due to the release of oxygen from the *Phragmites australis* root system into the rhizosphere. The fact, that the ammonium nitrogen decreases more rapidly at a recirculation ratio 1:2 in the wetland with growing vegetation means that, thelonger the leachate resting period in the system is, the longer the influence of the aerobic environment, formed in the rhizosphere is. Complete elimination of the ammonium nitrogen from the leachate in the nonvegetated wetland for 13 and 14 days was obtained at a recirculation ratio of 1:1 and 1:2, respectively, and for 9 and 7 days in the vegetated wetland at the same recirculation ratios.

NO_2-N removal

The initial nitrites concentration in the landfill leachate was 17.2 ± 1.1 mg/L, which is 430 times over the discharge limit for these ions. As a result of the ongoing nitrification in both laboratory systems, the concentration of these ions reaches even higher values (Fig. 3). For example, the maximum nitrites concentration of 20.9 ± 0.9 mg/L and 24.9 ± 2.2 mg/L at recirculation ratio 1:1 and 1:2, respectively, was achieved at the second day after the treatment process beginning in the vegetated wetland. Then their concentrations are decreasing, reaching values of 0.6 ± 0.25 mg/L and 4.1 ± 0.12 mg/L, at recirculation ratio 1:1 and 1:2, respectively, in the vegetated wetland. Significantly lower are the concentrations of these ions in the nonvegetated system. Perhaps this is due to the weaker nitrification. In the nonvegetated wetland an increase of these ions concentrations was not observed.

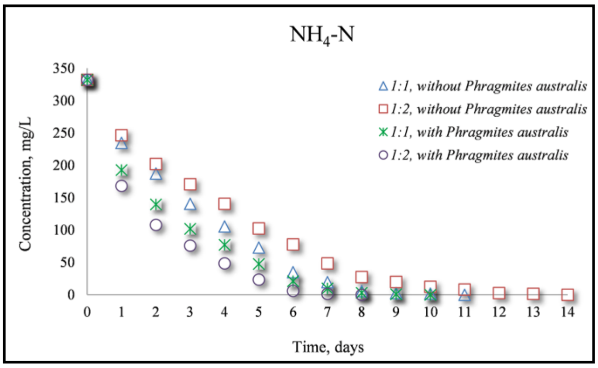

Fig. 2. Ammonium ions concentration decrease in all experiments.

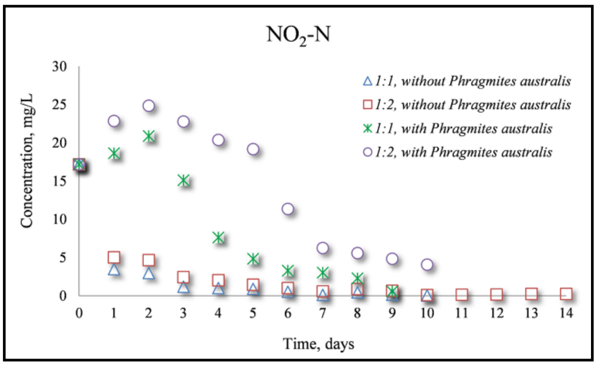

Fig. 3. Nitrite nitrogen concentration decrease.

In the first twenty-four hours in this system a sharp decrease of the nitrite nitrogen concentration was observed, and at recirculation ratio of 1:1 and 1:2 their values reach up to 3.5 ± 0.16 mg/L and 5.03 ± 0.17mg/L, respectively. Thereafter, the concentrations slightly decreased and after 13 days at recirculation ratio of 1:1 the values reach up to 0.2 ± 0.2 mg/L and after 14 days at a recirculation ratio of 1:2 - up to 0.3 ± 0.04 mg/L. In the nonvegetated wetland system at the recirculation ratios 1:1 and 1:2, treatment efficiencies of 98.8% and 92.5%, respectively were achieved. In the vegetated wetland system at the same recirculation ratios, treatment efficiencies of 96.5% and 76.2%, respectively were achieved.

NO_3-N removal

As a result of the nitrification in both laboratory systems an increase of the nitrates concentrations was observed (Fig. 4). From the results it is particularly evident that the vegetation significantly affects the concentration of these ions. As it can be seen from Figure 4, the NO_3-N concentrations in the laboratory system with vegetated wetland rapidly increased as early as the first day of the treatment process and reached values of 14.4 ± 0.4 mg/L and 16.3 ± 0.9 mg/L at recirculation ratio of 1:1 and 1:2, respectively. Then the concentration of these ions began to decrease gradually and after the seventh day almost did not change. The final concentrations of 10.4 ± 0.3 mg/L and 11.4 ± 0.2 mg/L, respectively, were achieved in this laboratory installation during one-hour and two-hour leachate resting. In the nonvegetated wetland a gradual increase of the nitrate nitrogen concentration was observed and from the ninth day until to the end of the experiment almost constant concentration of 8.2 ± 0.1 mg/L and 5.2 ± 0.3 mg/L was observed at recirculation ratio 1:1 and 1:2, respectively. The results show that in both systems at these experimental conditions denitrification was not achieved. In the nonvegetated wetland it could be achieved by increasing of the leachate resting period and additional organic carbon source as a food for denitrifying bacteria.

Orthophosphates removal

The initial orthophosphate concentration in the landfill leachate was 1.9 ± 0.01 mg/L. During the experiments a slight change in their concentration was observed (Fig. 5). In the reactor without vegetation the treatment efficiencies 16.8% at recirculation ratio of 1:1 and 25.9% - at recirculation ratio of 1:2, respectively, were achieved. In the wetland with vegetation, treatment efficiencies of

29.3% and 38.3% were achieved at recirculation ratios 1:1 and 1:2, respectively.

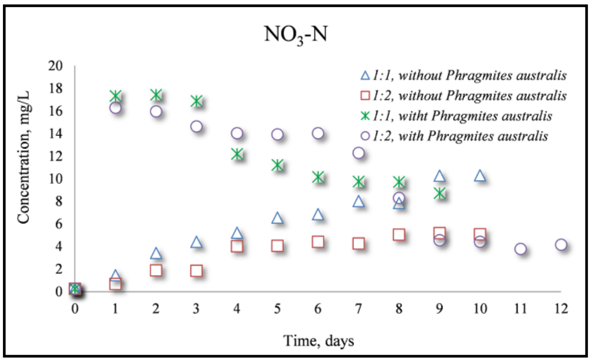

Fig. 4. Nitrate nitrogen concentration variation.

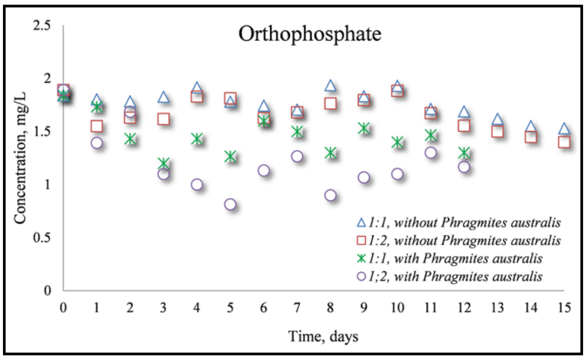

Fig. 5. Orthophosphate concentration variation.

The results show that the orthophosphates were assimilated better from the *Phragmites australis* at longer water resting period (recirculation ratio 1:2).

Conclusions

The landfill leachate treatment efficiency was compared in laboratory systems with and without planted *Phragmites australis*.

The obtained results show that the vegetation significantly affects the treatment process. The concentrations of COD and BOD decreased much faster in the vegetated wetland compared to the nonvegetated wetland. Complete elimination of ammonium nitrogen from landfill leachate was achieved in both wetlands. Complete nitrate nitrogen denitrification was not observed because of the aerobic conditions in both laboratory wetlands. The orthophosphate concentration decreasing in the wetland system with growing *Phragmites australis* was two times faster than that in the nonvegetated system. The presence of *Phragmites australis* significantly increases the treatment efficiency of the vertical-flow wetland systems.

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