

OPERATIONAL PROBLEMS OF CONSTRUCTED WETLAND FOR LANDFILL LEACHATE TREATMENT: CASE STUDY

Hanna Obarska-Pempkowiak¹, Magdalena Gajewska¹, Ewa Wojciechowska¹

¹ Faculty of Civil and Environmental Engineering,, Gdansk University of Technology, G. Narutowicza 11/12, 80-952 Gdańsk, Poland, e-mail: hanna.obarska-pempkowiak@wilis.pg.gda.pl; magdalena.gajewska@wilis.pg.gda.pl; ewa.wojciechowska@wilis.pg.gda.pl

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ABSTRACT

The present paper discusses the quality fluctuations of leachate from municipal landfill in Gdansk (Poland) over the last 5 years and the evaluation of a wetland system designed for treatment of the leachate. The research has been conducted during a 5-year period. The constructed wetland for leachate treatment was built in 2001; it consists of 2 horizontal subsurface flow reed beds, working in parallel. In the period 2005–2006 it underwent modernization due to unsatisfactory treatment results caused by bed clogging. After the modernization the treatment effectiveness is satisfactory. The effluent from bed I met Polish outflow standards, while in the effluent from bed II COD, total N and TSS exceeded the required concentrations. In spite of this, pre-treatment of leachate (iron removal) should be quickly introduced to protect the system against the reoccurrence of clogging problems.

Keywords: treatment wetland, landfill leachate, clogging.

INTRODUCTION

Treatment of landfill leachate faces a lot of problems resulting from its specific composition as well as fluctuating quantity and quality [Lo 1996]. Typically, leachate contains high concentrations of organics (BOD₅: 100 – 50 000 mg/l, COD: 5000 – 60 000 mg/l) and ammonia nitrogen (100 – 10 000 mg/l) [Lo 1996, Tasi & Zoubolis 2002]. The presence of heavy metals in the leachate is of great concern, although usually only concentrations of iron are higher than in municipal sewage [Rosik-Dulewska 2007]. Both the ammonia nitrogen concentration, pH and the BOD/COD ratio, change in time, as the decomposition processes within the landfill proceeds. The leachate from “young” landfill (younger than 5 years) contains higher concentrations of organics and ammonia nitrogen. In leachates from older landfills concentrations of pollutants decrease, however, at the same time BOD/COD ratio decreases, since the bioavailable organic fraction repre-

sented by BOD is decomposed, while the fraction resistant to biological decomposition (part of COD, organic micropollutants such as AOX, PAH, detergents) remains constant [Klimiuk et al. 2007]. Thus, effective treatment of the leachate in conventional biological methods is problematic. There are three basic methods of leachate management: (i) transportation to municipal WWTP, (ii) building on-site leachate treatment plants, or (iii) recirculation of leachate to the landfill [Robinson 2005, Rosik-Dulewska 2007]. Since discharging the leachate to municipal WWTPs often interrupts biological treatment processes, construction of on-site treatment facilities for leachate treatment is recommended instead [Robinson 2005]. Typically, conventional biological processes (activated sludge, biofilters), chemical oxidation or membrane processes (also combination of these methods) are used for on-site leachate treatment [Klimiuk et al. 2007, Rosik-Dulewska 2007]. Treatment wetlands (TWs) can be a cost-saving and simple in operation alterna-

tive to these solutions, however, it is very important that the system is designed adequately to the site-specific leachate composition. TWs have been applied with positive effects for landfill leachate treatment in several countries in Europe and North America [Bulc et al. 1997, Kadlec 2003, Maehlum 1995, Obarska-Pempkowiak et al. 2005, Robinson et al. 1999]. TWs not only remove organics and nitrogen effectively, but they are also capable of heavy metals' retention, due to plant uptake [Obarska-Pempkowiak et al. 2005, Peverly et al. 1995, Weis & Weis 2004], precipitation in the form of insoluble sulphides and hydroxides or ion exchange processes in the bottom sediments. Also retention of xenobiotics (AOX, PCB, PAHs) in TWs has been reported [Kadlec 2003].

In Poland a growing interest in CW systems for sewage treatment, especially serving individual households in rural areas, is observed over the last few years. The experiences with CWs for leachate treatment, however, are still at developing stage. In some cases, lack of know-how at the design and construction stage leads to future operation problems and unsatisfactory treatment results, which results in a kind of "bad press" regarding the application of TWs for leachate treatment.

The paper discusses the fluctuations of leachate composition and performance of a CW for leachate treatment, consisting of two parallel horizontal subsurface flow reed beds, over the years 2004–2008. The design errors and attempts of TW modernization are described

EXPERIMENTAL

Study TW

The municipal landfill in Gdańsk-Szadółki has been in operation since 1973. The landfill area covers around 60 ha. The quantity of generated leachate is approximately 9000–9500 m³/year. In 2001 a constructed wetland for leachate treatment was built. It consists of two parallel HF-CW beds (subsurface, horizontal flow of sewage). The area of each bed is equal to 50×50 m and the depth is 0.6 m. The beds were planted with *P. australis*.

Methods

The samples of leachate were collected at the CW in Szadółki at the inflow (raw leachate RL),

after bed I and bed II and in the collection tank, were treated, leachate from both beds is collected. Four series of analyses were made in autumn 2004 and five series were performed after modernization of the beds in August – October 2008. The following parameters were analysed: organic matter expressed as BOD, COD, TSS, total N, ammonia N, nitrate as well as organic N. Additionally, in both types of wastewater COD was also analysed, after filtration through membrane filter with pore size 0.45 *pim* (Millipore nitrocellulose filters), in aqueous phase. The content of volatile suspended solids in the total suspended solids was determined as losses on ignition. The procedure was adopted by Hach Chemical Company (Hach, Loveland, CO) and Dr Lange GmbH (Germany). All the analyses were carried out according to the European Standards and recommendations given in the Polish Environment Ministry Regulation of 24th July 2006/137 item 984. Filtration coefficient analyses were performed according to standard procedures [Geotechnical Engineering Handbook 2002].

RESULTS AND DISCUSSION

Fluctuations of raw leachate composition

The concentrations of pollutants in municipal landfill leachate fluctuate in time. The leachate composition is affected by rainfall, which dilutes the leachate, but on the other hand, washes out the pollutants from landfilled wastes. Also, the concentration of pollutants in the leachate change due to biodegradation processes taking place at the landfill [Klimiuk et al. 2007]. The composition of the leachate from Szadółki landfill is very unstable, which is reflected by high SD values. Generally, average concentrations of pollutants in the raw leachate at the inflow to TW were lower in 2008 than in 2004, which resulted from mixing of the leachate with rainwater, which was started in 2005. However, the concentrations of pollutants fluctuate. The only significant tendency is BOD₅ depletion, due to biodegradation processes and the consumption of easily available carbon. Also BOD₅/COD ratio decreased, although the value of this parameter was changing.

Hydraulic conductivity of the beds

According to the project assumptions, the maximal hydraulic loading of both beds should

Table 1. The changes of Szadólki landfill composition in the years 2004–2008

| Parameter | 2004 | | 2005 | | 2006 | | 2007 | | 2008 | |
|--------------------------------|--------|---------|--------|---------|-------|--------|--------|--------|-------|--------|
| | mean | ±SD | mean | ±SD | mean | ±SD | mean | ±SD | mean | ±SD |
| pH | 7.5 | 0.06 | 7.6 | 0.21 | 7.8 | 0.31 | 7.7 | 0.41 | 7.2 | 0.10 |
| TSS | 150.5 | 134.05 | 242.7 | 218.78 | 145.5 | 194.26 | 82.0 | 34.00 | 84.2 | 44.54 |
| COD | 1616.2 | 1645.06 | 2259.0 | 2520.35 | 615.5 | 589.87 | 1010.9 | 800.36 | 445.2 | 77.95 |
| BOD ₅ | 792.1 | 968.92 | 395.5 | 417.10 | 243.8 | 327.75 | 235.0 | 248.42 | 115.9 | 15.08 |
| N _{tot} | 433.3 | 92.45 | 245.0 | 198.87 | 72.0 | 46.08 | 341.4 | 439.92 | 395.8 | 54.55 |
| N-NH ₄ ⁺ | 302.5 | 205.69 | 235.18 | 197.87 | 55.3 | 32.03 | 320.7 | 423.82 | 325.9 | 56.03 |
| N-NO ₃ ⁻ | – | – | 1.0 | 1.50 | 0.5 | 0.71 | 0.1 | 0 | 2.7 | 0.28 |
| N | – | – | 8.7 | 0.50 | 13.4 | 19.51 | 20.6 | 17.23 | 67.2 | 77.95 |
| Cl ⁻ | 749.4 | 162.61 | 440.7 | 277.40 | 430.0 | 455.92 | 607.5 | 558.34 | 863.1 | 234.32 |
| SO ₄ ²⁻ | – | 34.05 | 60.6 | 64.92 | 521.0 | 478.10 | 220.7 | 92.52 | 25.9 | 8.54 |
| Fe _{tot} | 22.6 | 13.95 | 0.1 | 0.01 | 4.3 | 3.03 | 4.4 | 4.69 | 16.4 | 1.32 |
| BOD/COD | 0.49 | – | 0.17 | – | 0.40 | – | 0.23 | – | 0.26 | – |

not exceed 50 m³/d. The treatment wetland in Szadólki was first built using fine-grained filtration material (filtration coefficients 5.77·10⁵ m/s and 2.55·10⁵ m/s for beds 1 and 2, respectively) (Table 2). It was designed according to the guidelines of [Kickuth 1981], where fine-grained soils were recommended as filter bed materials. The initial low hydraulic conductivity was supposed to increase due to root penetration. The total hydraulic capacity of the TW system (the sum of flow rates of both beds), calculated on the basis of hydraulic conductivity, was equal to 1.72 m³/d. Whereas the hydraulic loading of the beds, evaluated basing on the pump capacity and pump working period for the years 2002–2004, varied from 6 to 240 m³/d [Obarska-Pempkowiak et al. 2004, Obarska-Pempkowiak et al. 2005]. Due to excessively high hydraulic loading, the beds were flooded. Since the discharged leachate contained, among other pollutants, relatively high concentrations of iron (Table 1), the clogging processes contributed to the decrease of hydraulic conductivity of the beds. The *P. australis* died off, especially in bed II. The treatment effectiveness, especially in the bed II, was low. In bed I the removal of BOD₅, COD and nitrification of ammonia N took place, despite of excessively high hydraulic

loading. However in bed II, the treatment processes failed. Only Fe and Mn removal was observed (Table 2).

According to the technical opinion of the researchers from Gdansk University of Technology [Obarska-Pempkowiak et al. 2004], it was advised to modernize the TW. The researchers insisted on replacing the clogged fine-grained beds filling material into coarse sand or gravel and introducing preliminary leachate treatment, in order to remove iron from the leachate before it is discharged into the beds. In the years 2005–2008 CW was not working. The leachate was collected and then redirected to one of landfill compartments. At the same time modernization of the CW was completed. The clogged filtration material was partially removed and replaced. New *P. australis* seedlings (eight seedling per m²) were planted. Also, the quantity of leachate discharged to the CW was decreased to about 4.5 m³/d. No leachate pretreatment was introduced. The results of the permeability coefficient analyses of the filling material in 2008 are presented in Table 1. Despite of the technical opinion and past experiences (bed clogging in 2004), the fine-grained material, with low hydraulic conductivity was used again. The natural soil containing partly decomposed landfilled wastes with addi-

Table 2. Filtration coefficients of the beds filling material before (2004) and after (2008) modernization of the TW Szadólki

| Parameter | Bed I | | Bed II | |
|------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| | 2004 | 2008 | 2004 | 2008 |
| Filtration coefficient [m/s] | 5.77 · 10 ⁻⁵ | 4.80 · 10 ⁻⁵ | 2.55 · 10 ⁻⁵ | 1.03 · 10 ⁻⁵ |
| Filtration coefficient [m/d] | 4.98 | 4.15 | 2.20 | 0.89 |



tion of straw was used. The filtration coefficients were even lower in 2008 than in 2004.

The total hydraulic capacity of the TW (both beds), calculated on the basis of filtration coefficients and the beds dimensions, was equal to 0.994 m³/d for bed I and 0.213 m³/d for bed II. The total hydraulic capacity of both beds was equal to 1.207 m³/d. The average hydraulic loading in the period 1st August – 15th October 2008 was 4.41 m³/d. In the years 2006–2007 the flow of leachate was higher: 7.9 m³/d in 2007 and 16.1 m³/d in 2006. The leachate quantity fluctuated, reaching the maximum of 20 m³/d. Then, the hydraulic conductivity of the beds after modernization was still too low. A prior leachate retention tank would allow for averaging the quantity of the leachate discharged to the beds.

The TW performance

The quality of treated leachate improved significantly in 2008 in comparison to 2004, although bed II continued to perform worse than bed I. The average concentrations of pollutants in the effluent of bed I met Polish outflow standards, while in case of bed II the concentrations of TSS, COD and the total N exceeded the out-flow requirements.

Both beds removed BOD₅ effectively (the removal effectiveness was equal to 95.7% for bed I and 79% for bed II), while the removal effectiveness of COD was lower (78.5% for bed I and only 32% for bed II). This difference can be explained by high amount of refractory compounds present in the leachate, which is also indicated by low BOD₅/COD ratio (0.27). Further decrease of the BOD₅/COD ratio took place during the treatment – the ratio in the effluents of beds I and II was only equal to 0.05 and 0.06, respectively.

The outflow concentrations of ammonia N were quite low. The ammonia N represent only 0.5% and 1% of the total N in the effluents of beds I and II, respectively, which proves that nitrification took place at the beds. The effluent concentration of the total N was quite low for bed I (13.14±3.68 mg/l), whereas for bed II it was high (112.98±38.13 mg/l). At the same time, the nitrate N at the outflow of bed II was high (92 mg/l), which represented approx. 82% of the total N. In the effluent of bed I, nitrate N represented only 57% of the total N. These results indicate the denitrification took place at bed I. The increase of pH (from 7.23 in the raw leachate

to 7.8 in the effluent of bed I) also confirms this. However, denitrification process at bed II failed.

The TSS concentration in the effluent of bed II was even higher than at the in-flow. On the other hand, bed I removed TSS effectively.

The leachate inflowing to TW in 2008 were well aerated, which is indicated by low share of Fe²⁺ (about 3%) in the total Fe and the presence of nitrates (Tables 1, 3). The treated leachate outflowing from both beds contained very low concentrations of total Fe, which indicates that insoluble trivalent Fe precipitated in the beds. This process will end up with beds clogging unless preliminary Fe removal is introduced.

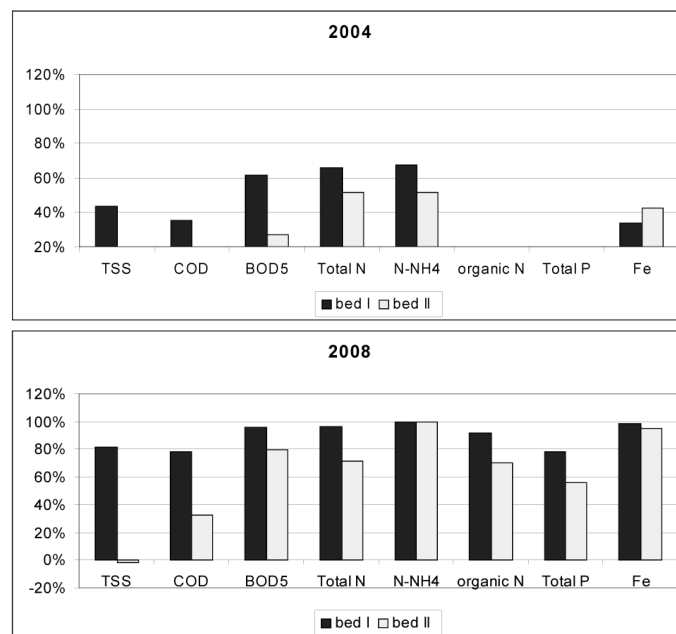
Effectiveness of leachate treatment in CW Szadólki was similar to the effectiveness reported by [Maehlum 1995] for the TW for leachate treatment in Esva, Norway: 91% for BOD₅ and 88% for COD. The CW in Esva had similar construction to CW Szadólki (two HF-CW beds working in parallel), but in Esva the leachate was pretreated in an aeration lagoon and the effluent of HF-CW beds was polished in a surface flow bed. The major difference between Esva and Szadólki was the bed filter material – in Esva gravel (10–20 mm diameter) was used. In Dragonja (Slovenia) removal effectiveness of COD, BOD₅, ammonia nitrogen and iron were as follows: 68%, 46%, 81% and 80%, respectively [1], while [Kinsley et al. 2006] reported 93–99% BOD₅ and 97–99% N-NH₄⁺ removal efficiencies.

In 2008 relatively high concentrations of SO₄²⁻ ions were present in the effluent from the beds. The SO₄²⁻ concentrations in the treated leachate were significantly higher than in the raw leachate (two times for bed I and five times for bed II). This was due to degradation of organic matter (natural soil containing partly decomposed landfilled wastes, straw) used for the beds filling during modernization works

In 2008 the effluent from beds I and II was discharged to a retention tank, where it was collected and periodically pumped to a landfill compartment. The effluents from beds I (better quality) and II (worse quality) were mixed, what is reflected in pollutants' concentrations (Table 3). It was found that the decrease of ammonia nitrogen concentration took place in the retention tank, what must have resulted from denitrification and release of gaseous nitrogen to the atmosphere. The pH increase, which usually takes place in the denitrification process, was also observed in the retention tank.

Table 3. Mean concentrations of pollutants in landfill leachate in CW Szadólki in 2004 and 2008

| Parametr | Unit | Raw leachate | | | | Bed I | | | | Bed II | | | | Collection tank | | Regulation of Polish Env. Ministry |
|--------------------------------|-----------------------------------|--------------|---------|-------|--------|--------|--------|-------|-------|--------|--------|-------|--------|-----------------|-------|------------------------------------|
| | | 2004 | | 2008 | | 2004 | | 2008 | | 2004 | | 2008 | | 2008 | | |
| | | mean | ±SD | mean | ±SD | mean | ±SD | mean | ±SD | mean | ±SD | mean | ±SD | mean | ±SD | |
| pH | – | 7.5 | 0.06 | 7.2 | 0.10 | – | – | 7.8 | 0.15 | – | – | 7.3 | 0.14 | 8.3 | 0.06 | 6.5–9.0 |
| TSS | mg/dm ³ | 150.5 | 134.05 | 84.2 | 44.54 | 84.80 | 17.16 | 15.3 | 5.79 | 124.1 | 36.76 | 85.9 | 44.29 | 38.6 | 25.01 | 50 |
| COD | mgO ₂ /dm ³ | 1616.2 | 1645.06 | 445.2 | 77.95 | 1045.0 | 281.22 | 95.3 | 37.24 | 1422.0 | 425.88 | 299.9 | 162.28 | 183.5 | 53.74 | 150 |
| BOD ₅ | mgO ₂ /dm ³ | 792.1 | 968.92 | 115.9 | 15.08 | 303.0 | 68.88 | 4.9 | 82.46 | 576.0 | 115.87 | 23.7 | 96.15 | 11.2 | 3.75 | 30 |
| N _{tot} | mg/dm ³ | 433.3 | 92.45 | 395.8 | 54.55 | 148.4 | 23.11 | 13.1 | 2.15 | 208.6 | 45.09 | 112.9 | 13.50 | 11.4 | 4.37 | 30 |
| N-NH ₄ ⁺ | mg/dm ³ | 302.5 | 205.69 | 325.9 | 56.03 | 98.4 | 11.17 | 0.6 | 3.68 | 146.1 | 27.07 | 1.4 | 38.13 | 0.7 | 0.10 | 6 |
| N-NO ₃ ⁻ | mg/dm ³ | – | – | 2.7 | 0.28 | – | – | 7.6 | 0.72 | – | – | 92.6 | 0.23 | 3.3 | 1.00 | 1 |
| N _{org} | mg/dm ³ | – | – | 67.2 | 77.95 | – | – | 5.6 | 1.70 | – | – | 19.9 | 39.25 | 7.5 | 3.29 | – |
| P _{tot} | mg/dm ³ | – | – | 2.1 | 13.08 | – | – | 0.5 | 1.68 | – | – | 0.9 | 2.37 | 0.6 | 0.08 | 5 |
| Cl ⁻ | mg/dm ³ | 749.4 | 162.61 | 863.1 | 234.32 | – | – | 111.6 | 0.41 | – | – | 847.5 | 55.82 | 232.6 | 35.69 | 1000 |
| SO ₄ ²⁻ | mg/dm ³ | – | 34.05 | 25.9 | 8.54 | – | – | 77.2 | 52.21 | – | 4.56 | 162.9 | 100.99 | 143.5 | 34.48 | – |
| Fe _{tot} | mg/dm ³ | 22.6 | 13.95 | 16.4 | 1.32 | – | 8.81 | 0.3 | 32.43 | – | – | 0.8 | 0.69 | 0.3 | 0.13 | 10 |
| Fe (+2) | mg/dm ³ | – | – | 0.5 | 0.26 | – | – | 0 | 0 | – | – | 0.1 | 0.04 | 0 | 0 | – |
| BOD/COD | – | 0.49 | – | 0.26 | – | – | – | 0.08 | – | – | – | 0.08 | – | 0.06 | – | – |

**Fig. 1.** Pollutants removal efficiencies in 2004 and 2008

CONCLUSIONS

In 2004 the quality of leachate inflowing to the TW Szadólki was very unstable. The beds received too high loads of pollutants. Low hydraulic conductivity lead to clogging processes and water stagnation. In spite of clogging problems, TW Szadólki provided quite good treatment efficiencies of BOD₅ (bed I), total N and ammonia N.

Modernization of the beds was successful in terms of treatment results. The leachate treated at bed I met the requirements concerning sewage outflowing to surface water defined in Polish Environmental Law. In case of the outflow from bed II, concentrations of TSS, COD and total nitrogen exceeded the admissible values. Nitrogen transformations took place at both beds: ammonification and nitrification. Denitrification only took place in bed I.

In spite of good treatment results, clogging risk factors are present in TW, due to high concentration of trivalent iron in raw leachate. In both beds precipitation of iron took place, what may lead to beds' clogging in a short period of time. Pre-treatment of raw leachate at sedimentation tank would allow for removal of iron before the inflow to TW.

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