TREATMENT OF LANDFIL LEACHATE BY CONSTRUCTED WETLANDS

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SUMMARY: The performance of three constructed wetlands systems treating landfill leachate is described. Two are located in northern Poland (Szadolki near Gdansk and Gatka near Miastko) and one in southern Sweden (Örebro). The constructed wetlands in Szadolki consists of two parallel silty soil beds planted with reed with sub-surface horizontal flow of sewage. The constructed wetland in Gatka is a willow plantation on sandy soil, receiving leachate after preliminary sedimentation in a retention pond. The system in Örebro consists of a series of ponds with a surface flow of leachate, preceded by pre-treatment in an aerated tank with nitrogen stripping. The best treatment efficiencies were observed at Örebro. At the sub-surface flow wetlands in Szadolki and Gatka clogging problems occurred due to the unsatisfactory pre-treatment and low soil hydraulic conductivity resulting in lower treatment efficiencies.

1. INTRODUCTION

The treatment of landfill leachate has become one of the most important environmental problems due to fluctuating composition and quantity as well as high concentrations of specific pollutants (PAH, AOX, PCB, heavy metals) and very high ammonia nitrogen and COD concentrations. In the literature, considerable variations in the quality of leachate from different landfills have been reported (Kieldsen et al., 2000; Surmacz-Górska, 2001; Öman et al., 2000). The leachate from young landfills (where acetogenic biodegradation phase is active) is characterised by high COD, BOD as well as Na^+, Cl^- and NH_4^+ content, while the leachate produced in the subsequent methanogenic phase is characterised by relatively low COD, BOD and NH_4^+ content and higher pH (Jones et al., 2006; Klimiuk et al., 2007).

High-tech solutions applied for leachate treatment (i.e. reverse osmosis or ozonation) are expensive and energy consuming, thus they are not suitable at many landfill sites, especially in rural areas. Constructed Wetlands (CWs) provide an alternative method of either treating or polishing the landfill leachate, which is inexpensive, simple in operation and has potential to remove not only organic carbon and nitrogen compounds, but xenobiotics and heavy metals as well (Peverly et al., 1995; Kowalik et al., 1996; Ye et al., 1997). In Poland CWs have gained popularity for sewage treatment, however experiences with landfill leachate treatment are still at the developing stage. In some cases lack of know-how at the design and construction stage leads to future operation problems and unsatisfactory treatment results.

In this paper the design and performance of three CWs for leachate treatment, two located in northern Poland (Szadolki near Gdansk and Gatka near Miastko) and one in southern Sweden (Örebro) are discussed. The CWs differ in size, hydraulic regime, type of hydrophytic plants and type of leachate pre-treatment before discharging to the CW. Performance and operation problems of the CWs are presented.

2. STUDY FACILITIES AND METHODS

2.1. Constructed wetland in Szadolki near Gdansk (northern Poland)

The municipal landfill in Gdansk-Szadolki has been in operation since 1973. The landfill area covers around 60 ha. The quantity of collected leachate is approximately 9000-9500 m^3/year, and the daily collected leachate flow varies from 6 to 240 m^3/d. In 2001 a constructed wetland for leachate treatment was built. It consists of two parallel soil beds with subsurface horizontal flow of sewage. The area of each bed is equal to 50×50 m and the depth - 0.6 m. The beds were planted with common reed (*Phragmites australis*). Low hydraulic conductivity and clogging problems soon occurred since fine-grained soils (silt) were used as filter beds material (Wojciechowska and Obarska-Pempkowiak, 2008). Since the treatment efficiency is below expectation the solution should be described as “lessons learned”.

2.2. Willow plantation in Gatka near Miastko (northern Poland)

This facility has been constructed in 1996 to treat the leachate from municipal landfill in Miastko. The average flow of leachate is approximately 5 m^3/d. The leachate is collected by drainage into a retention tank (30×30 m) where averaging of the leachate volume and composition takes place. The leachate outflowing from the tank is directed to a soil filter (43×31 m, depth 0.8 m), composed of loamy sand planted with willow (*Salix*). Willow was covering bed only partly while the remaining area of the bed was covered by orchard grass (*Dactylis glomerata L.*). The leachate percolating through the soil filter is transpired to the atmosphere by the plants during summer and there is no outflow from the filter most of the year.

2.3. Hydrophyte system in Örebro, southern Sweden

The municipal landfill in Orebro was established in 1979. In 2003 waste segregation was introduced. At the same time the waste quantity decreased from approximately 100 000 t/year during 1979 to 15 000 t/year after 2003. The landfill leachate generated at the site is pre-treated and stored in an aerated lagoon with a volume of 20 000 m^3 with a maximum depth of 5 m. During 2001 a free surface flow treatment wetland was constructed downstream the aerated lagoon for further treatment of the leachate upon demands from Swedish Authorities to shift treatment method from the municipal waste water treatment plant to on-site methods. The wetland covers an area of 8 h and has a total volume of 52.200 m^3. The wetland is intermittently loaded when the $N\text{-}NH_4$ concentration is below 100 mg/l in the pretreated water from the aerated lagoon. This level is generally obtained in April-May when temperature allow biological transformation of the nitrogen to occur and may continue to October-November. The total quantity of landfill leachate pumped into the wetland 2006 was 81 235 m^3 and the total outflow by gravity was 68 577 m^3. The dilution of the leachate in the system has been estimated to approximately 20 % during 2003-2006 (Waara et al. 2008). The wetland consists of a series of 10 ponds covering an area of 8 ha. The first pond has a depth of 1 m and the others are 0.4-0.6 m deep. The ponds contain aquatic and hydrophyte plants, predominantly species of duckweed (*Lemna*), common reed (*Phragmites australis*), bulrush (*Scirpus palla*), reed-mace (*Typha latifolia*) and sedge (*Carex sp*). At the inlet of the first pond sediment traps have been constructed to trap some of the particulte material before entering the wetland system.

2.4. Monitoring

Monitoring of the analysed CWs performance relied on the quality analysis of the leachate inflowing to and outflowing from the CW systems. In case of the CW at Gatka the soil pore water samples were collected instead of the outflow (no outflow due to high evapotranspiration). In case of the CWs working as the final treatment stage, the raw leachate quality (before pre-treatment) was also assessed. The leachate samples were collected in the period from 2004 to 2005 at Szadolki, from December 2005 to November 2006 at Gatka, from January 2004 to October 2006 at Örebro. The concentrations of the following pollutants were measured: TSS, BOD_5 (i.e. BOD_7 in Örebro), COD_{Cr}, $N\text{-}NH_4$, $N\text{-}NO_3^-$, N_{tot}, P_{tot}, total alkalinity, and Cl^-. All measurements were performed according to Swedish Standards (Örebro study), US Standard Methods as well as EU norms. Polish Standard Methods are similar to US Standards. The data from Örebro has been obtained from the monitoring program of the treatment facility.

Removal efficiency (η) was calculated as a removal of pollutant loads (flow of leachate multiplied by concentrations). It gives concentration difference between the influent (C_{inf}) and the effluent (C_{out}) divided by the influent concentration (C_{inf}):

$$\eta = (C_{inf} - C_{out})/C_{inf}.$$

3. RESULTS AND DISCUSSION

3.1 Raw leachate composition and pre-treatment

The composition of leachates from the analyzed landfills is presented in Table 1. In case of the sites where the leachate is pre-treated before discharging to the CW, both the quality of raw leachate before pre-treatment and the leachate after pre-treatment inflowing to the CW units is presented.

A measure of bioavailability of organics in the leachate is the BOD_5/COD ratio. According to Surmacz-Górska (2001) at young landfill sites (landfilled wastes not older than 3-5 years) the BOD_5/COD ratio is high, reaching even 0.7, indicating high bioavailability of organics in the leachate. In such cases, COD and BOD_5 concentrations are very high (over 4000 mg O_2/l

Table 1. The composition of raw leachate from the analyzed landfill sites (means and data ranges)

Parameter	Szadolki	Gatka*		Örebro*	
		Raw leachate	Inflow to the CW	Raw leachate	Inflow to the CW
pH	7.5 7.4–7.5	8.4 8.2–8.7	8.4 8.3–8.6	8.0 7.8–8.1	7.9 7.8–8.0
BOD_5 [mg O_2/l]	792 41–2118.5	76 51.4–100.6	60 51–72	275 215–334	79 74–82
COD [mg O_2/l]	1616 723–4380.2	804 600.1–1110.8	648 579–711	1338 1071–1510	716 690–734
BOD/COD	0.49	0.10	0.09	0.21	0.11
P_{tot} [mg/l]		5.0 4.5–5.4	5.2 4.9–5.6	4.65 4.25–4.78	4.22 4.02–4.30
N_{tot} [mg/l]	433 342–551	182 101.2–269.9	116 96–135	497 401–568	286 230–332
N-NH_4^+ [mg/l]	302 40.3–523	85 55–147.5	75 68–79	415 384–451	134 112–150
N-NO_3^- [mg/l]		4.4 2.7–6.2		2.29 1.89–2.45	96 78–117
TSS [mg/l]	150 63.2–380	2714 2560.5–2830.1	2596 2340–2780	99 88–119	234 184–260
total alkalinity [mval/l]	58 39.5–71.7				1253 1164–1340
Cl^- [mg/l]	749 531.8–922	446 333.3–574.3	320 287–358	679 613–728	579 545–620
pH	7,5 7,4–7,5	8,4 8,2–8,7	8,4 8,3–8,6	8,0 7,8–8,1	7,9 7,8–8,0

*raw leachate before and after pre-treatment

and over 6000 mg O_2/l, respectively). The pH is acidic (<6.5) indicating that the acetogenic fermentation phase products (volatile fatty acids) are present.

The analyzed landfills have been in operation for several years with the acidogenic fermentation phase still going on. The decomposition processes within the landfill have not yet finished. The leachate from Szadolki is characterized by the highest COD and the highest BOD/COD ratio (0.49), whereas the pH of the Szadolki leachate is the lowest of the analyzed leachates (7.5). In view of the landfill leachate characteristics given above, these parameters correspond to leachate from mature landfill, with partly decomposed organic wastes. Leachate from the Örebro site has the second highest COD concentration as well as BOD/COD ratio (0.21), and pH 8.0. The ammonia nitrogen concentration of the Örebro leachate is even higher than this of Szadolki. The quality of raw leachate from the Gatka landfill is much better than that of the other two sites.

Apart from the organics, ammonia nitrogen is a typical pollutant of landfill leachates. The concentrations of ammonia nitrogen in the municipal leachates fluctuate from several hundred to over 10 000 mg/l (Lo, 1996; Klimiuk et al., 2007). The concentrations of ammonia nitrogen in the analyzed leachates were typical, as were the chloride concentrations.

3.2. Treatment efficiency

The data presented in the Table 2 allows for analysis of pre-treatment efficiency. At Gatka, pre-treatment in the retention tank was not effective at all.

At Örebro the pre-treatment took place in the aeration tank with nitrogen transformation. High removal efficiencies were observed: 71% for BOD_5, 46% for COD and 68% for N-NH_4^+, however the TSS concentrations increased by over 100%. At Szadolki, raw leachate was discharged directly to the CW.

Due to lack of sedimentation tank upstream CW at Szadolki, the leachate inflowing to the CW contained very high concentrations of BOD and COD as well as ammonia nitrogen, which had a remarkable impact on the treatment results. A sedimentation tank would enable not only partial elimination of TSS and probably organics or volatilization of ammonia nitrogen, but it would allow for averaging the concentrations of pollutants and the leachate inflow as well.

The concentrations of pollutants in the treated leachate (after CW systems) are presented in Table 2. In case of the CW in Gatka the values given in the Table 2 refer to soil pore water samples, since there was no outflow from the vegetated filter due to intensive transpiration. Among the analysed CWs, the most successful in terms of pollution reduction was the CW at Örebro. At the other sites operational problems connected with clogging (Szadolki, Gatka), fluctuations of the leachate amount and quality (Szadolki) and excessive pollutant concentrations in the leachate discharged to the CWs (due to lack of or unsatisfactory pre-treatment) occurred, influencing the treatment results (Wojciechowska and Obarska-Pempkowiak, 2008).

The most "problematic" of the CWs was the pair of beds at Szadolki, where all of the above operational problems appeared, caused by errors in the design and construction stage (Wojciechowska and Obarska-Pempkowiak, 2008). Using fine-grained silty soil for bed construction resulted in very low hydraulic conductivity of the beds. Since there was no pre-treatment of the leachate discharged to the CW, the beds were particularly exposed to clogging problems, not only because of the average TSS concentration in the leachate in Szadolki (150 mg/l) but also due to high organics content (792 mg/l BOD and 1616 mg/l COD). The recommended values to avoid clogging risk are 5.4 g $TSS/m^2 \cdot d$ (Vymazal, 2003), 6 g $BOD_5/m^2 \cdot d$ (Garcia et al., 2005) and 15-20 g $COD/m^2 \cdot d$ (Vymazal, 2003). According the TSS concentration, some authors and the German Guideline ATV-A62 recommend that the incoming concentrations should be below 100 mg TSS/l. Beyond any doubt the organics loads discharged to the CW Szadolki were too high and the TSS load contributed to the beds clogging as well. Another contributor to the poor hydraulic capacity was related to high concentration of Fe in the raw leachate (mean 22.6 mg/l; range 11 to 38 mg/l) (see:Randerson, Slater, 2005). Another problem at Szadolki was connected with unstable leachate composition and lack of any collecting tank prior to the CW, that would enable averaging of the leachate composition. It is a bad example of engineering design. Finally, high Cl^- concentration was present in the leachate (mean 749 mg/l; range 530 to 922 mg/l). The combination of these factors led to flooding of the beds and reed die-off, with consequently poor treatment efficiency (Figure 1). The leachate at Szadolki cannot be discharged to surface waters and is recirculated to the landfill site.

The concentrations of pollutants measured in the pore water samples collected at the vegetated filter at Gatka were quite low in terms of the BOD, total nitrogen and ammonia nitrogen concentrations. In contrast, the COD and TSS concentrations are very high.

Table 2. The treated leachate characteristics (means and data ranges) for the landfill leachate treatment CWs

Parameter	Szadolki		Gatka[1)]		Örebro
	bed I	bed II	point III[2)]	point IV[3)]	
BOD_5 [mg O_2/l]	303 196 – 460	576 446 – 704	44 37 – 48	54 45 – 61	7 6 – 9
COD [mg O_2/l]	1045 832 – 1160	1422 1125 – 1785	788 720 – 936	576 498 – 645	246 202 –278
P_{tot} [mg/l]	–	–	1.1 0.8 – 1.4	1.7 1.3 – 2.2	0.1 0.1 – 0.2
N_{tot} [mg/l]	148.4 121.4 – 180.9	208.6 167.5 – 285.5	34.2 29.2 – 38.9	25.9 19.6 – 31.1	27.6 22.3 – 30.6
N-NH_4^+ [mg/l]	98.4 76.5 – 115.7	146.1 99.2 – 179.6	16.5 15.2 – 18.8	8.8 6.8 – 9.6	0.62 0.54 – 0.68
N-NO_3^- [mg/l]	–	–	1.4 1.1 –1.9	1.3 0.8 – 1.6	19 16 – 22
TSS[mg/l]	84.8 74.3 – 95.6	124.1 94.8 – 140.5	311.9 256 – 357	412.5 367 – 478	4.8 4.4 – 5.2
Cl^- [mg/l]	–	–	581.4 523 – 620	17.8 16.7 – 18.3	–
pH	7,2 7,1 – 7,4	7,3 7,2– 7,3	7,2 7,2 – 7,3	7,4 7,3 – 7,5	7,8 7,1 – 8,5

[1)] willow plantation without outflow; analysis of pore water samples from the vegetation filter

[2)] pore water sampling point in the vegetation filter; the part of filter covered by willow

[3)] pore water sampling point in the vegetation filter; the part of filter covered by orchard grass

Nevertheless, the leachate discharged to the vegetation filter was transpired to the atmosphere by *Salix and Dactylis glomerata L.* plants and there was no problem with the effluent quality. The BOD and COD removal in the vegetation filter was below expectations, however good efficiencies of N and P removal were observed. The ammonia nitrogen removal efficiency was about 70–78%, indicating quite effective nitrification process.

The leachate outflowing from the CW in Örebro contained very low BOD and N-NH_4^+ concentrations. However, the total nitrogen concentrations were similar to the treated leachate from Gatka. The predominant form of nitrogen in the effluent from Örebro was nitrate nitrogen. The CW in Örebro was characterized by the highest treatment efficiency among the analyzed facilities. This resulted from (i) an effective pre-treatment of leachate before it was discharged to the CW, (ii) the CW type – with surface flow of leachate and (iii) the long retention time. The raw leachate from the Örebro landfill site contained the highest concentration of N-NH_4^+ of the analyzed leachates. The biological transformation processes in the aerated tank prior to the CW system was quite effective and allowed for the average N-NH_4^+ concentration decrease from 415 to 134 mg/l . In spite of this high removal efficiency, the discharge permit of an average value of 20 mg/l N_{tot} was exceeded during 2006 while an attempt to treat 100 % of the generated leachate volume at the site was made (Waara et al. 2008). Also BOD and COD concentrations decrease in the aerated tank and in the wetland. In

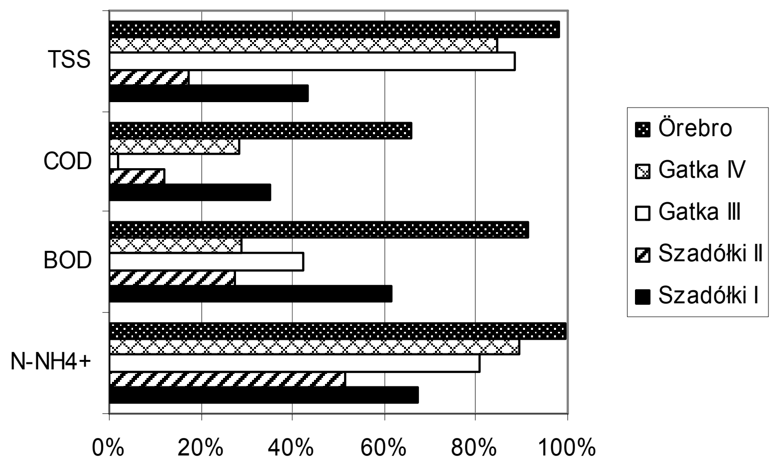

Fig. 1. Average leachate treatment efficiencies at the analyzed CW systems

contrast, the average TSS concentrations increased from 99 to 234 mg/l in the areated lagoon but decreased to a low level in the wetland. The increase in TSS in the aerated tank can be due to sampling of the raw leachate for analysis when no actual pumping occurs or to problems with sampling techniques. The latter problem also sometimes occurs when sampling within the wetland (Waara et al. 2008) and this is now counteracted by building platforms to avoid sampling close to the shoreline. Clogging problems inside the wetland did not occur however, since this was the wetland with surface flow of leachate, which is generally less exposed to clogging problems than the sub-surface flow wetlands. The amount of N loss in the aerated pond at Atleverket has been estimated based upon measurements during spring and summer of 2006 that the loss of from the aerated pond is approximately 2.2 ton N/year. Their recommendations are to minimize aeration during summer months when temperature is generally high and also to minimize the retention time of the leachate in the aerated pond (Rohde et al., 2008).

In Figure 1 the BOD, COD TSS and ammonia nitrogen removal efficiencies for the three analyzed CWs are given. For the CW Szadolki, removal efficiencies for both parallel working beds (I and II) are presented. In case of the CW Gatka the removal efficiencies were calculated separately for soil pore water sampling points in the area covered by willow (Gatka III) and by orchard grass (Gatka IV). Although the treated leachate quality from the sites Gatka and Szadolki is worse than at Örebro, the treatment efficiencies observed at Gatka and even at Szadolki (especially at bed I) are quite good.

4. CONCLUSIONS

Analysis of the operation results of three CW systems for leachate treatment located in northern Poland (2 sites) and southern Sweden (1 site) shows that constructed wetland systems can be used to efficiently treat landfill leachate. The hydrophytes are tolerant to the high concentrations of COD, BOD, $N\text{-}NH_4^+$ and Cl^- present in the leachate, however there may be problems with huge fluctuations in the composition and quantity, typical of the landfill leachates. Thus retention tanks ought to precede the CW systems. Another role of retention tanks would be the removal of TSS, in order to avoid clogging of wetland cells, which is especially important in case of sub-surface flow wetlands. Since high concentrations of Fe (III) contribute to the clogging, Fe (III) removal prior to the wetland systems should be considered. Although constructed wetlands can deal even with raw leachate, using the two-stage leachate treatment systems with CW as the final stage, achieves high quality effluent that can be discharged to surface waters (Örebro). The pre-treatment can occur in a combination of aeration and sedimentation units. The design and construction stage of the CW systems is very important, which is apparent in the case of the CW at Szadolki. As leachate composition, volume and quality fluctuations are site specific, the system design should be adapted to these site specific conditions. Otherwise, future problems with the operation of CW systems and poor treatment results will cause that landfill operators to reject the idea of leachate treatment with CWs in favour of some other more costly treatment method.

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