

CONSTRUCTED WETLANDS FOR TREATMENT OF LANDFILL LEACHATE – EXPERIENCES FROM SWEDEN AND NORWAY

Konstruerade våtmarker för behandling av lakvatten – erfarenheter från Sverige och Norge

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Abstract

Constructed wetland systems have attracted attention as suitable methods to treat landfill leachate. Experiences are promising in several European countries and in the North America, but Swedish experiences are limited so far. There is an interest for this solution also in Sweden and a number of constructed systems have recently been established. The aim with this paper was therefore to compile experiences from some Swedish landfill sites and compare with Norwegian experiences; especially with regard to the design parameters filter materials and wetland species. Three Swedish and two Norwegian systems for leachate treatment were investigated. The results show that different filter materials have been used with varying results. The most common wetland species is *Phragmites australis*, adapted for plantation in leachate wetlands and the prevailing climate conditions. Further, the results show that Norwegian constructed wetland systems for treatment of landfill have performed well, especially during high-temperature periods, indicating that constructed wetland systems also should be an adequate solution in Sweden. Further research is however needed to increase the knowledge and to demonstrate the technique.

Key words – Bølstad, filter material, Hagby, Isätra, Löt, Spillhaug, wetland species.

Sammanfattning

Konstruerade våtmarkssystem har uppmärksammats som en lämplig metod för lakvattenbehandling. Goda erfarenheter finns från flera Europeiska länder liksom från Nordamerika, men i Sverige är erfarenheterna än så länge begränsade. Intresset är emellertid stort för den här behandlingsmetoden även i Sverige och ett antal konstruerade våtmarkssystem har nyligen etablerats vid olika deponier. Syftet med denna artikel är att sammanställa erfarenheter från några av dessa deponier och jämföra med norska dito, speciellt med avseende på filtersubstrat och våtmarksvegetation. Tre svenska och två norska lakvattenbehandlingssystem undersöktes. Resultaten visar att olika filtersubstrat använts med varierande resultat. Den vanligaste typen av våtmarksvegetation utgörs av *Phragmites australis*, som är lämpad för plantering i våtmarker för lakvattenbehandling och rådande klimatförhållanden. Vidare visar resultaten att de norska våtmarkssystemen fungerat bra, speciellt under sommartid vilket indikerar att denna typ av system också skulle vara en bra lösning även i Sverige. Fortsatt forskning är nödvändig för ökad kunskap och för att demonstrera metoden.

Introduction

The generation of leachate from landfills is an inevitable problem and the leachate production is also undesirable since it creates environmental problems such as polluted surface and ground waters. Therefore, treatment of leachate from landfills has become an important issue to protect the surrounding environment. In many places, the leachate has been led to the municipal wastewater treatment plant. This solution has however been regarded as unsuitable since the leachate might disturb the biological processes in the wastewater treatment plant due to the leachates composition that differs from that of domestic wastewater (Robinson, 1996).

Landfill leachate can be treated by means of high-tech methods such as reverse osmosis or ozonation (Robinson, 1996). These treatment methods can be both expensive and energy demanding and have therefore been rejected as suitable treatment methods at many landfill sites. In stead, natural treatment systems have been favoured since these are much cheaper and also more sustainable in the long run (Staubitz et al., 1994; Mæhlum & Haarstad, 1998; Mulamootil et al., 1999). Among the natural systems that have been adopted, aerated lagoons and constructed wetland (CW) systems can be mentioned. The latter has gained attention for the last ten to fifteen years, in North America (Johnson et al., 1999; Schwartz et al., 1999; Sartaj et al., 1999) and

in different European countries (Bulc et al., 1997; Robinson, 1996; Robinson et al., 1999; Mæhlum, 1999; Mæhlum & Haarstad, 2001).

Constructed wetlands can be designed in order to optimise the removal of a particular pollutant. Different design parameters such as choice of wetland species and special filters have attracted attention as potential treatment stages to incorporate in a constructed wetland system for treatment of landfill leachate (Mulamootil et al., 1999). The knowledge of these design parameters is though limited and further research has been suggested (Mulamootil et al., 1999).

In Sweden, the interest for constructed wetland systems for leachate treatment is growing and there are some newly established systems treating landfill leachate. The experiences from these treatment systems are limited so far, and the aim with this paper is therefore to compile the experiences from these systems and compare with similar systems established in Norway with special regard to the above mentioned design parameters.

Materials and methods

A brief literature review was conducted in order to obtain an overview of the Swedish, and international, literature on leachate treatment by means of constructed wetland systems. Further on, personal contacts were taken with researchers and staff at waste companies in order to compile experiences from some Swedish and Norwegian landfill sites. These contacts resulted in study visits at the particular landfill sites described below.

Results

Literature review

Constructed wetlands have successfully been used worldwide for treatment of landfill leachate. In most cases, the systems have been used as a secondary treatment step after proceeding pre-treatment, commonly based on extended aeration or the activated sludge process (Robinson, 1996). Constructed wetland systems have only in exceptional cases been used for primary treatment due to the fact that the leachate at many landfill sites is too complex and contains too high pollutant concentrations (Barr & Robinson, 1999). In these cases, the removal of pollutants has failed; see for instance Bulc et al. (1997). It has therefore been suggested that constructed wetland systems for leachate treatment should be used as secondary treatment step (Robinson, 1996).

When establishing a constructed wetland system, natural conditions have to be taken into consideration. These conditions can be the geology, hydrology and

topography for instance. But constructed wetland systems can also be designed to remove particular pollutants, or mix of pollutants, depending on what kind of pollutant is to be removed (Kadlec & Knight, 1996; Mulamootil et al., 1999). One design parameter is for instance the choice of wetland plants that assimilate nutrients and/or metals. These wetland species must endure particular conditions caused by the leachate, for instance high salinity. But it must also be adapted to the climate. A common wetland species that has been used in many wetland systems is the common reed, *Phragmites australis*. This species has also been suggested as suitable for Swedish conditions (Maurice & Lagerkvist, 2000). The constructed wetland system at Isåtra landfill site was also planted with *Phragmites australis* in the summer of 2001 (Wallgren, 2001). Other wetland species suitable for Swedish conditions are *Phalaris arundinacea* and *Glyceria maxima* according to Maurice & Lagerkvist (2000).

Another design parameter that has attracted attention is the use of a filter that is incorporated into the wetland system. The filter consists of a material, or mix of materials, which is suitable for the removal of a particular pollutant. Filter materials have been investigated with regard to phosphorus and metal removal (Johansson Westholm, 2002; Färm, 2003). In a constructed wetland system intended for treatment of leachate, filters are often designed to remove metals since high phosphorus concentrations in most leachates is a minor problem (Staubitz et al., 1994). Filters for metal removal from leachate have therefore been based on materials such as sand and gravel (Sanford et al., 1995), but other materials, e.g. LECA (Light Expanded Clay Aggregates) have also been used (Jenssen et al., 1994).

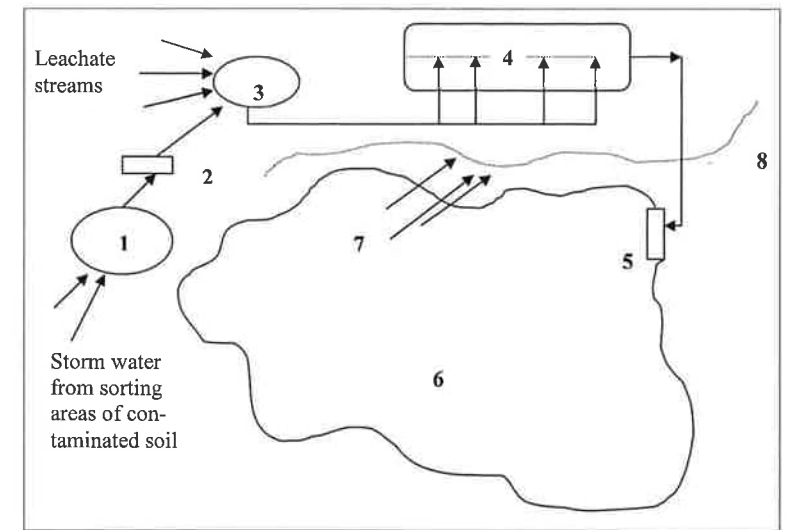
Study visits

Three Swedish CW systems for leachate treatment have been visited; Löt and Hagby landfill sites in the Stockholm region and Isåtra landfill site in the Sala region. In Norway, two landfill sites were visited, Spillhaug and Bølstad.

Löt landfill site

The Löt landfill site is situated about 45 km north-east of Stockholm. The landfill site has been in operation since 1995 and has since then received domestic and industrial wastes. The wastes are deposited in separate cells creating several leachate streams with various compositions depending on the wastes deposited. Nutrients (N and P), BOD₇, TOC and metals are the major pollutants found in the leachate streams. These are collected in a collection pond that is regarded as the pre-treatment step in the CW system that was taken into operation in 1998 (see Figure 1).

Figure 1. Principle overview of the constructed wetland system at the Löt landfill site with collection pond for storm water (1), peat filter (2), collection pond for leachate and storm water (3), aerated lagoon (4), filter system (5), wetland pond (6), overflow area (7) and collection ditch leading to recipient (8).



Soils contaminated with organic substances and metals have also been treated at the landfill site. Storm water from the deposition areas is collected in another collection pond than the one mentioned above and passes thereafter a peat filter before being introduced into the same collection pond as the leachate streams.

The CW system, that is dimensioned to treat 60 000 m³ of leachate per year, consists of an aerated lagoon, a peat filter, a wetland pond and an overflow area. The hydraulic retention time (HRT) in the aerated lagoon is approximately two months, but can be prolonged if necessary. The leachate is thereafter pumped from the lagoon to the wetland pond. When entering the pond, the leachate is passing through a filter system consisting

of two filters that can be used separately or in parallel. The filters are composed of a mixture of peat and sand. Natural wetland species have invaded the pond area, but vegetation has also been planted (Hanna Bergman, personal communication, September 2003). The depth of the pond is about 1 meter and the surface area is 15 000 m². The retention time in the pond is about three weeks. The leachate is leaving the wetland pond and enters the overflow area leading to a collection ditch. From this, the treated leachate is transferred to the recipient, a small stream leading to a shallow and eutrophicated lake.

The efficiency of the CW system to reduce different pollutants has proved to be good. The data for the first 6 months in 2003 are presented in table 1. All values, ex-

Table 1. Reduction of pollutants in the leachate after treatment in the CW system at the Löt landfill site (January–June 2003). (Hanna Bergman, personal communication, September 2003; Söderhalls Renhållningsverk AB, 2002.)

Pollutant	Average concentrations after treatment in CWS	Discharge limits	Reduction (%)
BOD ₇ (mg/l)	5	15	77
TOC (mg/l)	31	120	74
NH ₄ (mg/l)	0.08	10	99
N-tot (mg/l)	6	15	89
P-tot (mg/l)	0.06	0.2	85
Fe (mg/l)	0.5	1.5	—
Zn (µg/l)	23	80	–35
Ni (µg/l)	9.9	50	24
Hg (µg/l)	0.008	0.1	60
Pb (µg/l)	0.7	5	—
Cd (µg/l)	<0.05	0.4	90
Cu (µg/l)	5.8	15	19
Cr (µg/l)	10	20	52
Cl (mg/l)	193	150	6

cept for chloride (Cl), are below the allowed discharge limits. The high concentration of chloride in the leachate is, according to Hanna Bergman, due to the reason that slag materials have been deposited at the landfill site. Slag materials deposited at the landfill site will in the future be washed to reduce the chloride concentration. The washing water will be mixed with ashes that will be stabilized and deposited as cement. The organic material and the nitrogen are reduced in the aerated lagoon while the metals are reduced in the lagoon, the filters, the wetland pond and in the overflow area (Söderhalls Renhållningsverk AB, 2002).

Hagby landfill site

The Hagby landfill site is a closed down landfill situated about 20 km north of Stockholm. The landfill was in operation between 1948 and 1995; the present activities going on at the landfill is recycling and sorting of wastes. The wastes that cannot be recycled are transferred and deposited at the Löt landfill site. Municipal, demolition and bulky wastes were deposited at the Hagby landfill site during the period of operation. In the older parts of the landfill, the wastes were mixed while they were separated in the younger parts. Municipal wastes were sent for combustion from 1984 to the close down of the landfill.

Leachate originating from the waste heaps and storm water from the sorting areas were until June 2002 collected in a collection pond and transferred to the Käppala sewage treatment plant in Stockholm. The treatment at the landfill site has since then been complemented with a CW system consisting of an overflow area in three sections, a constructed wetland, a peat filter, a system of ponds and ditches and a second collection pond, see Figure 2. The treatment steps were taken into operation in July 2002 and are dimensioned to treat 90 000 m³ leachate per year.

The leachate is pumped from the first collection pond to the overflow area where the leachate is discharged intermittently to each section for 8 hours followed by 16 hours drying. The leachate then enters the meandering constructed wetland. Thereafter the leachate is pumped back to the pump station from where it is pumped to the top of the landfill. The leachate passes through a filter

(peat and sand) before entering the system of ponds and ditches. The leachate is flowing through the system to the second collection pond situated at the base of the waste heap. If the leachate is sufficiently treated, it is discharged into the recipient Stora Värtan, part of the inner archipelago of the Baltic Sea, and if not, it is transferred to the Käppala sewage treatment plant.

The system has in the first place been constructed in order to reduce nutrients, metals and BOD₇. Nutrients (ammonia) are expected to be reduced in the overflow area and in the constructed wetland pond, while metals are expected to be reduced in the filter. A monitoring programme of the treatment started in July 2002, but the results available at the moment are limited due to the recent establishment. Available results are presented in table 2, but interpretation should be made with caution keeping in mind that a new CW system does not show true results the first years of operation.

The CW system at Hagby landfill site is not only a treatment system for landfill leachate; it is in addition intended as a recreational area for the public. The waste heaps are covered with vegetation, groups of trees have been planted and footpaths are constructed. The above mentioned pond and ditch system have been constructed not only with regard to reduction of pollutants, but also with regard to aesthetical views. Information boards have been installed along the footpaths. The recreational park was officially opened in June 2003.

Isättra landfill site

The Isättra landfill site is situated 7 km east of Sala, Sweden. The landfill has been in operation since 1973 and has since then received municipal and industrial wastes, but also sludge and demolition wastes. The landfill site covers an area of 10 ha. On a yearly basis, approximately 85 m³ leachate/day is produced at the landfill site.

Until 1999, the leachate produced at Isättra was transferred to the municipal sewage treatment plant, but in the same year, a Sequencing Batch Reactor (SBR) was installed at the landfill. The SBR has been in operation since then and was supplemented with a subsequent CW system in the year of 2000. The CW system consists of a collection pond, an overflow area and a root zone, see

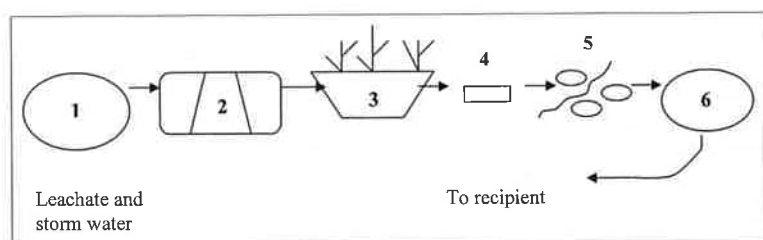


Figure 2. Principle cross-section of the Hagby landfill site with collection pond (1), overflow area (2), constructed wetland (3), peat filter (4), pond and ditch system (5) and collection pond (6).

Table 2. Reduction of pollutants in the leachate after treatment in the CW system at the Hagby landfill site (July–October 2002). (Emma Breitholtz, personal communication, September 2003.)

Pollutant	Average concentrations after treatment in CWS	Discharge limits	Reduction (%)
BOD ₇ (mg/l)	6	—	65
TOC (mg/l)	144	100	—
NH ₄ (mg/l)	19	—	69
N-tot (mg/l)	56	35	42
P-tot (mg/l)	0.29	0.5	23
Zn (µg/l)	30.5	100	22
Ni (µg/l)	59	15	—
Hg (µg/l)	0.0232	0.2	61
Pb (µg/l)	2.9	7	36
Cd (µg/l)	0.13	0.5	98
Cu (µg/l)	15.1	25	—
Cr (µg/l)	11.58	15	33

figure 3. Both the overflow area and the root zone are planted with *Phragmites australis* and *Typhoides arundinacea* (Wallgren, 2001).

The pre-treated leachate from the SBR treatment tank enters the collection pond, which has an area of 500 m² and a depth of 1 meter. From the pond, the leachate is distributed to the overflow area through a distribution ditch filled with gravel. The overflow area has an area of 800 m². The root zone area is the third and last step of the system. It has an area of 800 m² and consists of a 0.5 metre deep bed composed of a mixture of sand and clay. The hydraulic retention time in the CW system is several days allowing nitrification and denitrification and also assimilation of nutrients to take place. The leachate is flowing horizontally through the constructed wetland system. When the leachate has passed through the root zone, it can either be pumped back to the SBR-reactor or be discharged into the recipient, the small stream Isättrabäcken.

Results from the Isättra landfill site shows that the SBR treatment tank as well as the CW system work adequately (Johansson Westholm, 2003). In the CW system, removal of BOD₇ and phosphorus occurred even during the autumn and winter seasons however too a limited extent. It has proved that the CW has performed better during the summer season when temperatures are higher. Also in the longer run, the performance of the

CW is suggested to increase due to maturation of the vegetation cover and root system.

A monitoring programme is carried out on a regular basis in order to survey the performance of the wetland system. It is important to continue this programme to achieve a better understanding of the function of the treatment system.

Bølstad landfill site

The Bølstad landfill is situated in Ås, approximately 40 km south of Oslo, Norway. The landfill was taken into operation in 1962 and is a municipal sanitary waste (MSW) landfill. On a daily basis, about 80 m³ of leachate is produced.

In 1994, a leachate treatment system was established close to the landfill site. The system consists of an extended aerated lagoon, a sedimentation pond and four parallel subsurface horizontal-flow CW cells. The latter were part of a mesocosm pilot project run in 1996–1997. For further details, see Mæhlum et al. (1999). The filter media in the wetland cells consisted of washed gravel and the lightweight aggregate Filtralite™. The vegetation consisted of *Phragmites australis*, *Typha latifolia* and *Phalaris arundinacea*, all plants taken from a nearby natural wetland. The mean HRT in the lagoon was 30 days, but it proved to vary during wet and dry periods (Mæhlum et al., 1999).

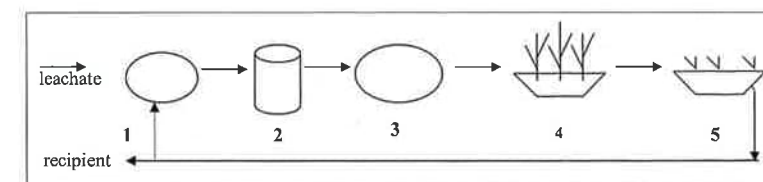


Figure 3. Cross-sectional view of the Isättra landfill treatment system with collection pond (1), SBR treatment tank (2), collection pond (3), overflow area (4) and root zone (5).

The total treatment efficiency of the system (aerated lagoon and constructed wetland cells) for COD varies between 38–78 %; the corresponding values for BOD₇, TOC, Tot-N and Fe are 40–80 %, 40–65 %, 2–65 % and 68–96 % respectively. For further details, see Mæhlum et al. (1999).

Mæhlum et al. (1999) however stress that only during periods with temperatures above 14°C, low input of water flow and sufficient oxidation; the system satisfied the treatment requirements. Based on the experiences from the Bølstad landfill site, Mæhlum et al. (1999) suggested improvements that also can apply to other treatment systems. Among the measurements suggested, intermittent use of constructed wetlands under aerobic and anaerobic conditions, insulation of aerobic pre-treatment and the use of a free-water surface flow wetland in combination with a subsurface flow wetland can be mentioned.

Spillhaug landfill site

The Spillhaug landfill site is situated about 60 km west of Oslo, Norway. It was taken into operation in the early 1970's and since then; municipal wastes have been deposited at the site. Approximately 112 m³ of leachate is produced each day (Mæhlum & Haarstad, 2001).

In the late 1990's, iron (Fe) precipitations downstream the landfill became an aesthetic problem and the authorities decided to construct a treatment system at the site. A constructed wetland system was established in 1998 and it consists of a pre-treatment step in form of a natural sandy aquifer, an aerated lagoon for oxidation and three free-water CW's in series. For further details, see Mæhlum & Haarstad, (2001). In the CW cells, *Phragmites australis* and *Typha latifolia* have been established (Aurskog-Høland kommune, 1999).

The sandy aquifer has proved to efficiently remove pollutants from the leachate before it enters the constructed wetland system (Mæhlum & Haarstad, 1998). The leachate entering the wetland system can therefore be characterised as low-strength. The further removal of pollutants has therefore proved to be successful, especially during the summer period (Aurskog-Høland kommune, 1999). According to Trond Mæhlum (personal communication, May 2002), monitoring of the leachate is not carried out on a regular basis. Samples are taken a couple of times a year, but not within a monitoring programme.

Discussion and conclusions

Constructed wetland systems are, according to the literature, adequate methods for treatment of landfill leachate if used as a secondary treatment step after a pre-treatment step. These experiences have so far been based

on CW systems in the UK and in North America, but also in Norway. The Swedish experiences are so far limited, but there is a growing interest for leachate treatment by means of CW systems also in Sweden, and several systems have been constructed within the last few years.

The results from the Swedish CW systems presented in this paper are limited so far, but they show that the reduction of pollutants is sufficient with regard to discharge limits permitted by the authorities. These results therefore indicate that CW systems are adequate as secondary treatment step also in Sweden. It is however important to keep in mind that the results presented are relatively scarce; i.e. the data is originating from a few years of monitoring in the newly constructed treatment systems. These are, for other types of wastewater known to stabilise after some years (Kowalik et al., 1995) and there are reasons to believe that this also will apply to CW systems treating landfill leachate. Mæhlum (1995) mentions for instance that a newly established wetland system most probably will perform much better when the vegetation cover and root system have matured.

Based on the experiences from the literature as well as from the study visits, CW systems can look very different depending on what leachate is to be treated at the specific landfill site. One important design factor has been the capacity to reduce the desired pollutants from the leachate, i.e. sufficient surface areas available for nitrogen removal for instance. Other factors of importance are the given conditions at the specific site, for instance the geology, hydrology and topography. These conditions have been utilised at some of the visited landfill sites; at Löt, the topography is utilised for the overflow area, at Spillhaug, the natural occurring sandy aquifer is used as a natural filter removing pollutants from the leachate on its way from the landfill to the wetland system.

Special filters have been incorporated into the constructed wetland systems at the Löt and Hagby landfill sites. There are no results from the sand/peat filters at Löt landfill site since the filters have not been included in the monitoring programme. In order to obtain more knowledge on the efficiency of the filters, further investigations should be undertaken. At the Hagby landfill site, the monitoring programme started in July 2002 and sampling has been undertaken at several places within the treatment system. Sampling should also at this site be taken in the sand/peat filter to achieve more data on the filter function. Norwegian experiences using LECA as filter materials showed that the filter clogged after three years of operation because of insufficient pre-treatment and overloading of the filters (Mæhlum et al., 1999). These results indicate that an adequate pre-treatment of the leachate is necessary and even though other types of materials are used in the Swedish treatment systems, the same might occur also in these filters. Färm

(2003) has for instance showed that peat has a capability to migrate making the filter less useful.

Phragmites australis and *Phalaris arundinacea* are commonly occurring natural wetland species in Scandinavia. Maurice & Lagerkvist (2000) suggested these species as suitable for constructed wetlands in Sweden since they can endure conditions caused by landfill leachate as well as the climate conditions prevailing. At the Swedish landfill sites studied, it could be observed that *Phragmites australis* had been planted at the Hagby and Isåtra landfill sites, thus confirming the findings of Maurice & Lagerkvist (2000). *Phragmites australis* is also present in the wetland system treating the landfill leachate from the Gärstad landfill site in Linköping (Lindahl, 2000). Also in Norway, *Phragmites australis* has been a common wetland species in constructed wetland systems for leachate treatment (Mæhlum, 1998).

Important to notice is that monitoring programmes are implemented at the above described Swedish landfill sites in order to observe changes in the leachate composition and quality. No monitoring programmes have been adapted at the Norwegian landfill sites described above, which probably is due to the fact that these landfill sites were partly constructed for research purposes. The systems still works as treatment systems, but no regular monitoring is performed and this makes it much more difficult to survey eventual changes in the leachate composition and quality. A regular monitoring programme makes it easy to take measures if needed in case of changes of the landfill leachate.

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