Swedish Experiences of Landfill Leachate Treatment Using Sequencing Batch Reactors

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Abstract - *This paper presents experiences from operation of a SBR unit designed for treating landfill leachate from a mid-sized landfill located in central part of Sweden. A short presentation of landfill treatment options exercised in Sweden is given as an introduction. The SBR plant has been running for six years, and thanks to an ambitious control programme substantial performance data are available, allowing for presentation of both encountered initial problems, process adjustments and a successful operation. The last two years operation has consistently resulted in a complete nitrification and normally more than 90 % total nitrogen removal. The landfill leachate quality after treatment is found more than acceptable with respect to heavy metals and other potentially hazardous compounds - very low concentrations are found. Also the biological sludge has been investigated with respect to heavy metals, PCB and nonylphenol; all these hazardous pollutants are found at low to very low levels in the sludge.*

Keywords - *nitrogen removal, leachate, landfill, SBR, heavy metals*

Introduction

Concerns about the environmental impact caused by landfill leachate rose during the 1970's in Sweden. The initial concerns were focused on the heavy metal content. Traditionally the landfill leachate was either discharged directly to a receiving stream or to a municipal wastewater treatment plant (WWTP).

The formation of leachates is a result of mainly two phenomena: (1) the degradation of waste into liquid and gases, and (2) the percolation of rainwater through the landfill. The first years of landfill leachate management focused on connecting the leachate to a WWP. The alternative option was to strive to find "simple", local treatment solutions. The knowledge of the landfill leachate generation was often limited, as well as clear definitions of its content, and, perhaps most important for the technical development in those years, the absence of general guidelines and effluent standards for landfill leachate disposal. This in turn resulted in a very diverse pattern of optional treatment techniques. It also became more evident that landfill leachate management strategies called for a deeper understanding of the processes within the landfills. Therefore a good understanding of the "inner" environmental processes in a landfill would facilitate the planning of the landfill leachate management. A sanitary landfill passes through three stages with respect to the internal biological process performance as is indicated in Table 1.

Table 1. Simplified characterization of the biological performance in a landfill related to disposal time after Serti (2000).

First phase: Aerobic phase	
Duration	some weeks
Characterization of landfill leachate	pH ~ 8
	High levels of heavy metals
Second phase: Acidic (anaerobic) phase	
Duration	some years
Characterization of landfill leachate	pH ~ 5
	High concentration of VFA
	High levels of BOD
	Ratio COD/BOD is low: 1.3:1 – 2.0:1
	High levels of NH_4-N, organic N and PO_4-P,
	High levels of heavy metals
Third phase: Methane phase (anaerobic)	
Duration	> 100 years
Characterization of landfill leachate	pH ~ 7
	Low concentration of VFA
	Low levels of BOD
	Ratio COD/BOD is high 20:1 – 10:1
	High levels of NH_4-N; Moderate to low levels of organic N
	Very low levels of PO_4-P
	Low to very low levels of heavy metals, apart from Fe and Mn

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The number of phases is sometimes different, but regardless of the numbers, the key-points with respect to the leachate formation are four-fold:

1. The three phases above are the most relevant ones with respect to leachate treatment needs;
2. All phases are distinct with respect to the dominating reactions during the phase and the microbial composition;
3. They are occurring sequentially in time, and
4. They are dependent with one another, in terms of process development.

As found in ***Table 1***, a treatment management must consider the two last phases, as modern landfills are operated with a number of cells, thus producing a leachate of varying age - from less than one year to several decades. The overall picture of the landfill leachate composition is confirmed by an investigation made by Glixelli (2003). In some cases the reported data is divided into the disposal times (phases) as described above. Three major factors emerging in the mid 1980's and early 1990's contributed to the development of landfill leachate treatment methods:

1. A growing concern regarding the landfill leachate composition, inter alia heavy metals content and complex organic compounds, such as dioxins;
2. The insight of the environmental impact from non-oxidised nitrogen (especially ammonia nitrogen) became apparent;
3. The development of nitrogen removal in the Swedish theatre during the second half of the 1980's became an important source of updated knowledge that was found to be very useful when addressing the problems with landfill leachate purification.

The development of landfill leachate treatment technologies in Sweden may, somewhat simplified, be defined by five different main tendencies:

1. A co-treatment with municipal wastewater in a "classic" treatment facility;
2. Different treatment options based on "simple" methods, such as recycling the landfill leachate to the landfill, irrigation of "energy forest" areas, using constructed or natural wetlands or infiltration;
3. Adopted and modified classic biologic treatment methods, to obtain efficient landfill leachate treatment;
4. Chemical physical treatment methods; such as ammonia stripping, chemical precipitation and activated carbon filtration. An example of such a plant is presented below.
5. Use of "advanced" treatment methods, such as reversed osmosis and/or "hyper filtration".

All these methods are currently in use around Sweden. Still there are no general effluent standards established for landfill leachate discharge. Each operator has to apply for and get a "unique" environmental permit for the solid waste operation site, including the landfill leachate treatment. The permits turn out to be very disparate, related to the decision of the local or regional authority.

A number of treatment facilities for landfill leachate have been built in Sweden since the mid 1990's based on the SBR technology. The experiences presented in the US, see Irvine et al. (1982), initiated some early pilot studies in Sweden as well. Morling et al. (1989) reported from a pilot plant study in Varberg, and his work was soon followed by other attempts to operate SBR plants for landfill leachate treatment. As the pilot study at the landfill site in Varberg presented some results that guided the followers during the 1990's it is worth to summarize the findings from this study:

(a) The SBR demonstrated the ability to oxidise almost all nitrogen into nitrate. Once this was established the denitrification was efficient, thanks to the abundance of organic pollution - BOD_7: nitrogen ratio was >12:1. This in turn suggests that the sanitary landfill was in the "acidic stage";

(b) The high content of chlorides did not affect the nitrification; the Cl ranged from 5,000 to 10,000 mg/l;

(c) The water temperature is a dominating factor for the nitrification process. This is of course expected, however the tests showed that it was possible to keep the nitrifyers even at very low temperatures by lowering the load substantially.

The test operation in Varberg was not long enough to reveal some questions regarding the SRT (Solids Residence Time) and sludge quality matters found in the full scale plant in Köping as is discussed below.

Materials and Methods

Plant description

The regional solid waste handling company VMR (Västra Mälardalens Renhållningsbolag) was faced with a demand from the community of Köping to terminate the delivery of landfill leachate to the municipal wastewater treatment plant in 1998, after more than 25 years of operation. The main reasons for this decision were the apprehension that:

(1) The landfill leachate would "pollute" the sludge from the plant with considerable amounts of heavy metals;

(2) The suspicion that the landfill leachate contains high contents of complex, potentially toxic organic matters.

VMR (now VAFAB) started investigations on different options, including jar tests on the landfill leachate using SBR-technology. The tests were performed at a regional laboratory, and demonstrated promising results. Finally the chosen treatment method was based on the SBR-technology, after comparison with other options. Apart from the very encouraging jar test results on the SBR-technology, the location of the sanitary landfill close to the central heat plant for the town, as well as the proximity to the municipal treatment plant offered some opportunities, such as:

1. Heating of landfill leachate would be feasible, as hot water was easily accessible;

2. The proximity to the municipal treatment plant allowed for using some facilities not in use at the plant and also presented an option to use sludge or municipal wastewater to support the biological process in the SBR unit.

The adopted treatment train includes also other facilities, apart from the main SBR unit:

- An equalization basin 3 000 m^3.
- A pumping station feeding the main treatment facility. The flow variation on a daily base has so far been 60 – 160 m^3. This corresponds to hydraulic retention times of 2 to 5 days.
- A heat exchanger providing a lowest temperature on the landfill leachate at 15^{o}C.
- A pumping station for the addition of municipal wastewater from the adjacent Köping town treatment plant. The feed varies on a daily basis from 1 to 5 m^3.
- The SBR facility, with a maximum volume of 300 m^3; and after decant a minimum volume of 250 m^3. It was found suitable and very affordable to use a"surplus" gravity thickener at the municipal plant as the SBR unit. Only minor retrofit actions were necessary to accomplish the needed functions. The aeration is based on a jet aeration system. Decant from the reactor has been arranged by means of an automatic valve. On-line instruments in the reactor included a SS-meter, an oxygen probe and a level probe.
- The treated water passes through two units of slow speed sand filters, each of 100 m^2.
- Addition of chemicals to the SBR-process is arranged for methanol (organic carbon), alkali, anti foam agent and phosphorus.

The adopted sequences for this process are shown in ***Figure** 1*.

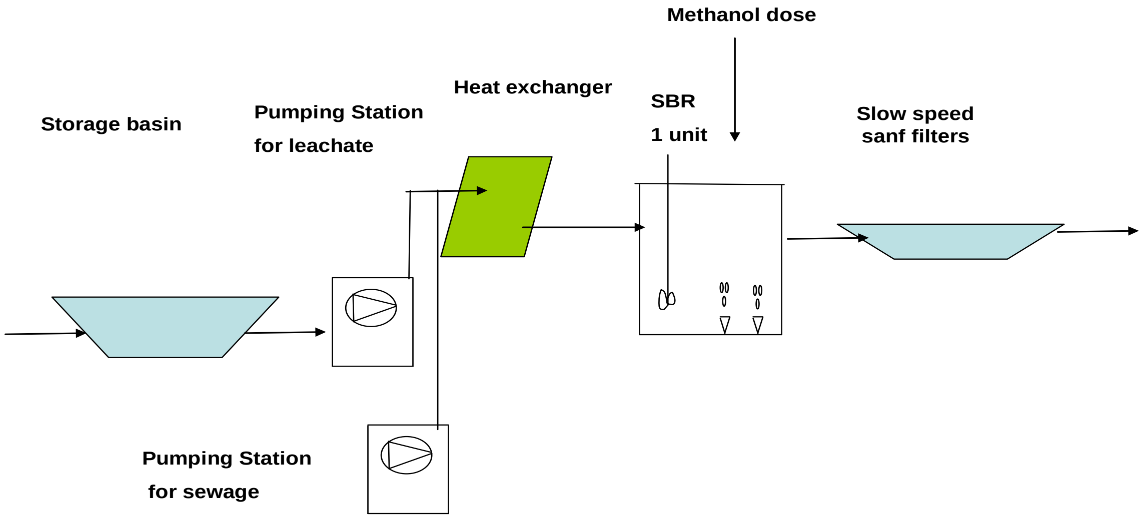

Figure1. **Schematic process train for the treatment of landfill leachate in Köping**

Design data

The local authority decided to put rather stringent effluent standards on the plant, which are summarized in Table 2, together with the adopted design values for the landfill leachate treatment.

Table 2 **Design data for the landfill leachate treatment plant in Köping, Sweden**

Variable	Consent values		Concentration		Amount	
Flow					85	m^3/d
pH			7.5			
Alkalin.			1,000	mg/l		
BOD_7	< 15	mg/l	25	mg/l	2.125	kg/d
COD_{cr}			500	mg/l	42.5	kg/d
Total P	< 0.5	mg/l	1	mg/l	0.085	kg/d
Total N	< 30	mg/l	200	mg/l	17	kg/d
NH_4-N			180	mg/l	15.3	kg/d

Plant Operation

The operation of the plant started in 2000. The SBR-plant was typically operated with an eight, ten or twelve hour cycle as shown in ***Figure 2***.

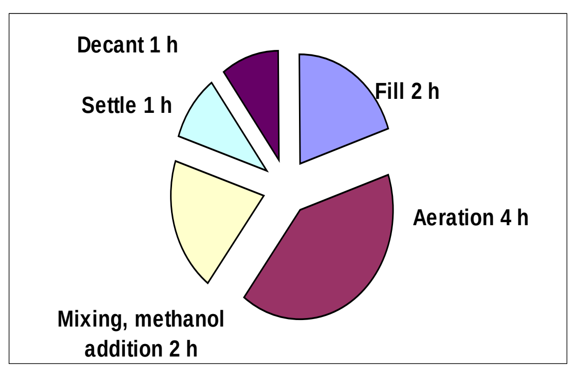

Figure 2 Typical operation cycle for the SBR-plant in Köping (10 hour cycle)

Results and discussion

All analysis results presented in this paper are based on reports from accredited laboratories in Sweden, using the Swedish Standards, which comparable with the relevant EU standards. The plant performance history may be divided into two periods, both providing useful information both with respect to improvements of the plant operation, and guiding operation for design and operation of other plants. The first period covers 2001 through 2003 when the plant was operated in its initial configuration. The second period started early 2004, after a re-arrangement of the final slow speed filter stage. .

First operation period

Although the plant showed very good performance figures during the long periods during the early operation period, some distinct problems were encountered:

1. The fine grade intermittent slow speed sand filters clogged frequently due to discharge of sludge from the SBR-facility. The average SS-content in the decanted water was 86 mg/l, the max value 231 mg/L and the min value 17 mg/l during 2003;

2. As the SRT (Solids Retention Time) was not controlled accurately during this period, sometimes very high SRT occurred, possibly resulting in an excess of pin point sludge, with very poor settling characteristics. Tests with flocculants indicated that a very high dosage was needed to substantially reduce the SS content in the effluent, > 450 mg/l of aluminium sulphate;

3. From time to time the nitrification was affected. The time to overcome this disturbance was sometimes considerable. In Figure 3 is illustrated the nitrogen removal performance. As found from the figure there were two distinct periods with unacceptable nitrogen performance. It was never clearly discovered the true causes for the nitrification inhibition, but for the second period – in fall 2003 – it was suspected that high concentrations of H_2S may have contributed to the situation.

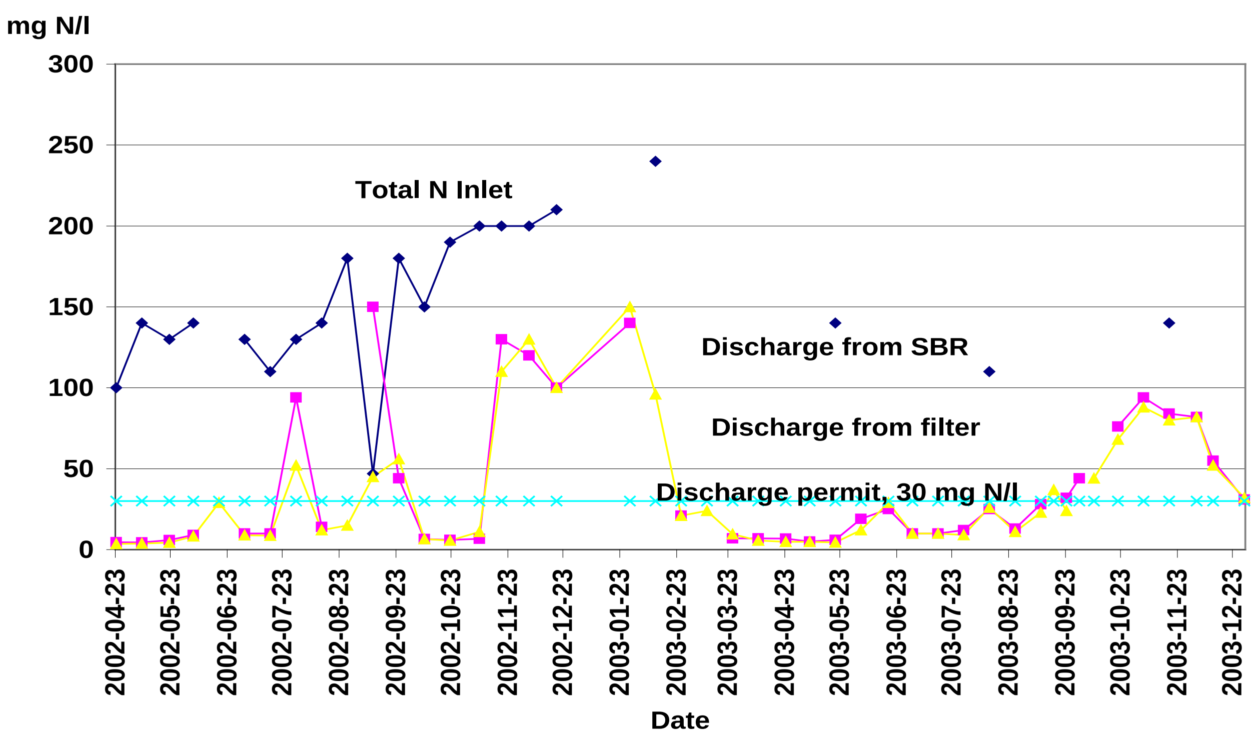

Figure 3 Nitrogen removal performance at Köping leachate treatment, 2002 and 2003

4. The COD-removal was found rather modest, in the range 30 – 45 %. This fact was to a certain extent attributed to the high Cl content, from 2,100 to over 3,000 mg/l. The other consideration in this context was that parts of the COD was "humus", and thus even relevant to reduce. The actions to overcome these problems concentrated on three issues:

a. To replace the sand in the filters by coarser material;

b. To accurately control the SRT (Solids Retention Time) and operate the plant at an SRT value of 25 to 30 days.

c. Not to use the COD as a consent parameter for the plant.

The control of the leachate temperature showed to be a major factor for the good results. As a comparison the operation of a similar plant in Sala, some 100 km north east to the Köping plant reveals the importance of temperature control; see also Johansson Westholm (2003). The Sala plant is operated without any temperature adjustment, and consequently the nitrification is lost for about three months during winter time.

Apart from these operation problems the plant performed satisfactorily, with good to excellent removal of phosphorus and BOD. Other potential pollutants linked to landfill leachate have been studied at the plant from year 2001. The findings and conclusion regarding these pollutants are found below.

Second operation period

The operation from 2004 has showed very good process stability, with virtually a complete nitrification in the reactor. The only noticeable problem has sometimes been an insufficient dosage of Methanol used as carbon source for denitrification. This in turn resulted in higher than wanted nitrogen discharges. This matter is illustrated in ***Figure 4*** that shows the 1st quarter 2006 performance. A summary of the performance 2004 through 2006, 1st quarter is found in Table 3. The leachate strength with respect to nitrogen is comparatively low, in relation to other reports; see for instance Spagni et al. (2008), who operated a bench scale reactor at ammonia levels of NH_4-N > 1,000 mg/l. Other Swedish plants report levels of 100 – 500 mg NH_4-N/l; see Morling (2007).

Table 3 Nitrogen removal at the Köping SBR landfill leachate treatment 2004 through 2006, 1st quarter

Parameter*[mg/l]*/spec.	Total N, in	Total N, out	NH_4-N, in	NH_4-N, out	NO_3-N, in	NO_3-N, out
Number of obs.	*55*	*54*	*55*	*55*	*54*	*55*
Max value	200	66	180	25	17	56
Mean value	122.1	15.7	105.7	0.8	9.4	9.9
Median value	110	9.9	100	0.033	11	4.8
min value	72	3.2	61	0.005	0.01	0.01
Standard deviation	28.4	13.9	25.2	3.7	5.3	12.1
Standard error	3.83	1.90	3.40	0.50	0.73	1.64
Removal efficiency, % On median values		91		> 99		

The other consent parameters, BOD_7 and total P, have been kept with a good margin throughout this period of more than 2 years. BOD_7 is normally < 6 mg/l and total P < 0.2 mg/l. The SBR-process has been operated with cycle times of 8 to 12 hours, related to the amounts of landfill leachate and pollution loads. The average SS-concentration in the SBR unit during mixing was about 3.0 kg SS/m^3.Needs for chemical addition has been limited to methanol, to provide a sufficient denitrification and anti foam agent.

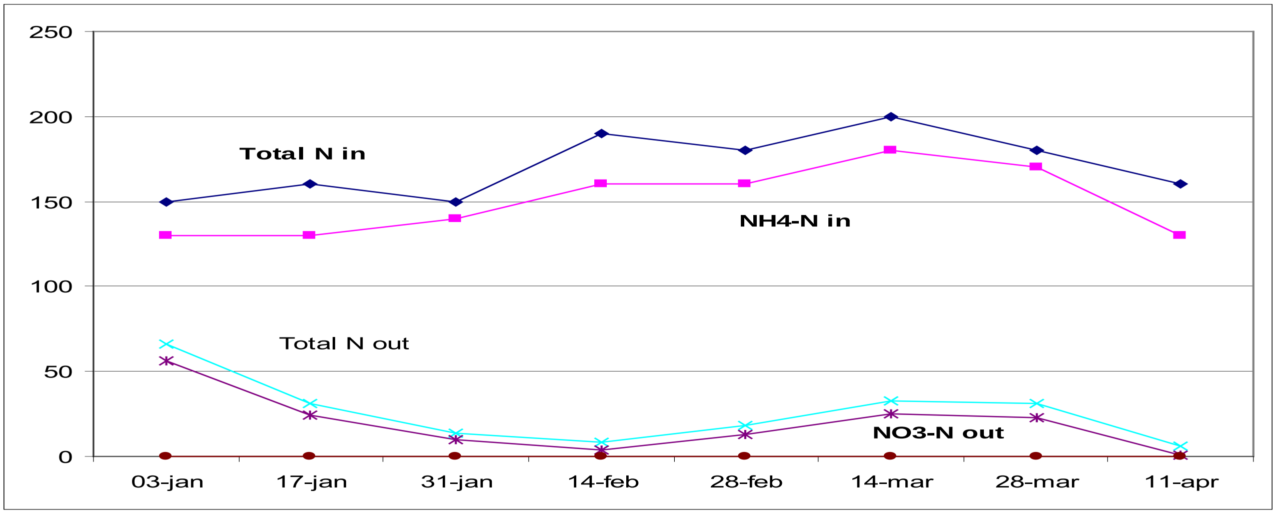

Figure 4 N inlet and outlet from the Köping landfill leachate SBR-plant 1st quarter 2006

The addition of methanol during year 2004 has been 12,000 kg; equivalent to a specific dosage of 2.8 kg methanol/kg total N in the landfill leachate. Addition of anti-foam agent was 240 kg during year 2004.The SS-discharge from the SBR unit has changed significantly: The average SS-content in the decanted water was 18.6 mg/l, the maximum value 44 mg/l and the minimum value 5.6 mg/l from January 2004 through April 2006. Throughout the operation – from the starting year 2001 until Summer 2006 the phosphorus addition from the municipal wastewater contribution has been sufficient for the process, and no further addition of P has been necessary.

Other pollution parameters

As mentioned above the heavy metal content in landfill leachate has been a concern. Thus the content has been analysed at a number of times throughout the operation time. The results of 11 different analyses show the following: Only at very few occasions have heavy metal concentrations been found to exceed the level for potable water in Sweden. A noticeable exception is Mn with concentrations exceeding the consent value for drinking water. Apart from this observation only few analysis are found with values exceeding the potable water quality consent value. This statement may be illustrated for Cd; see Figure 5:

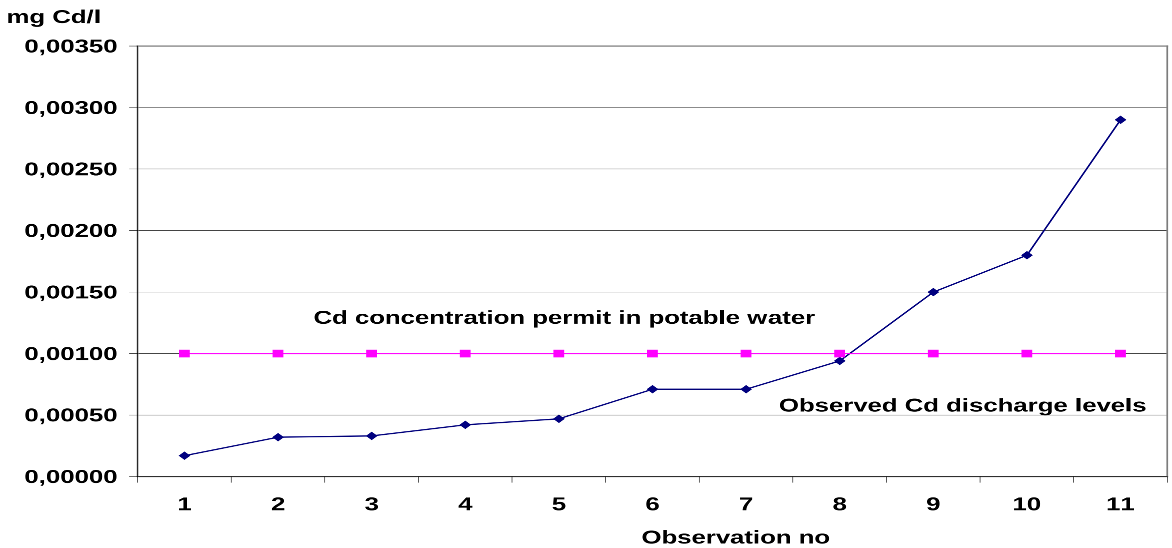

Figure 5 Cd content in treated landfill leachate at Köping SBR plant shown in increasing concentration not by time

The biological sludge in the SBR was investigated with respect to the heavy metal content. Also in this case was found low to very low concentrations of the "most susceptible" metals. In Table 4 the measured concentrations are compared with the Swedish guidelines for sludge quality related to agricultural use:

Table 4. Sludge content of heavy metals compared with reuse requirements for agricultural use

(mg/kg TS)	Sludge from landfill leachate treatment	Swedish EPA guidelikes
Lead	5.1	< 100
Cadmium	1.0	< 2
Copper	99	< 600
Chromium, tot	7.7	< 100
Mercury	0.06	< 2.5
Nickel	7.7	< 100
Zinc	71	< 800

Also complex organics were analysed in the bio sludge, such as PCB and nonylphenol. Seven different PCB-compounds regarded as potentially hazardous – have been analysed at three occasions. The concentrations on these PCB-compounds were found low to very low. The analyses showed that the sum of these seven compounds were < 0.02 mg/kg TS at all three occasions. The Swedish EPA guidelines for agricultural use stipulates PCB < 0.4 mg/kg TS.

The nonylphenol concentration has been measured in the sludge at three occasions. The results found were the following: 12 mg/kg TS (2000-08-16); 3.6 mg/kg TS, (2001-05-04) and 3.1 mg/kg TS, (2002-04-19). Again these levels would be regarded as low, or even very low in comparison with the Swedish EPA criteria for nonylphenol; < 50 mg/kg TS.

Conclusions

Landfill leachate treatment is today applied in most of the Swedish sanitary landfills. This paper presents results from the operation of a rather small facility based on the SBR-technology, in Köping, west of Stockholm. The plant has been operated for six years, and provides comprehensive analysis and results, allowing for some considerations and conclusions regarding biological treatment of landfill leachate. These are:

- The landfill leachate composition was typical for an "old" landfill in the Methane phase;
- The use of small amounts of municipal wastewater possibly saved costs for phosphoric acid addition;
- The causes of initial difficulties on the ammonia oxidation performance were never accurately established. However, seasonal variations of the landfill leachate quality may have contributed to these difficulties. The difficulties were apparent during the late summer and fall periods;
- A seldom systematically investigated perspective may be the "relation man-machine": The improved knowledge of the plant performance and has enabled the operator to "meet" the variations in due time.
- As expected the water temperature has a paramount influence on the nitrification rate. The rate is found to be at least 52 g NH_4-N_{ox}/kg VSS/d at T = 15 ^oC, however, the maximum rate may be higher, as the nitrification in all cases was complete;
- The SRT was kept in the range 25 – 30 days that resulted in a complete nitrification, to a large extent the same result as presented by Le et al. (1990);
- The results from Köping do not support the indications given by Britain et al. (1999), that the ammonia concentration in untreated landfill leachate is growing with the landfill age;
- The heavy metal content in the treated landfill leachate is found low –to very low, as opposed to the normal assumption that the content is high!
- The sludge quality with respect to polluting agents, both heavy metals and complex organic compounds would be regarded very well.

Acknowledgements

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References

[1] Serti Bozkurt, S. (2000) "Assessment of the Long-Term Transport Processes and Chemical Evaluation in Waste Deposits", Doctoral Thesis, Royal Institute of Technology, Stockholm

[2] Glixelli, Thomas M. (2003) "Treatment of ammonium-rich waste streams with deammonification process", Master of Science Thesis, Cracow University of Technology, Cracow and Royal Institute of Technology, Stockholm.

[3] Irvine, R. L. Sojka, S. A. and Colarutolo, J. F.(1982) "Treating landfill landfill leachates by pure strain inoculations of SBRs" Paper presented at a Symposium held at the University of Notre Dame, May 24 – 26th 1982

[4] Morling, S., Persson, T. and Johansson, B. (1989) "Sequencing Batch Reactor (SBR) Test on Concentrated Landfill leachates at Low Temperature, Varberg, Sweden" VATTEN 45:3, 1989

[5] Quarterly environmental reports from VMR 2001 through 2005.

[6] Le, A., Arand, J., Liu, B., and Urek, J. (1990) "Biologic Treatment of Hazardous Waste Landfill leachate: Fate of Toxic Organics and Metals in a Full-Scale Biological Sequencing Batch Reactor (SBR)"

[7] Butler, P. G., Kitchin, J. E. and Parry, C (1999) "Characterisation of a sequencing batch activated-sludge process for treatment of high ammonia landfill leaches" IWM Proceedings, March 1999.

[8] Johansson Westholm, L. (2003)"Leachate treatment with use of SBR-technology combined with a constructed wetland system at the Isätra landfill site, Sweden" Proceedings of the 9th International Waste Management and Landfill Symposium

[9] Spagni A., Marsili-Libelli S. and Lavagnolo M. C. (2008) "Optimisation of sanitary landfill leachate treatment in a sequencing batch reactor", Proceedings, 4th of IWA Specialised Conference on Sequencing Batch Reactor Technology, Rome April 2008

[10] Morling, S. (2007) "Landfill leachate, generation, composition, and some findings from leachate treatment at Swedish plants" VANN No 2 2007