LEACHATE MANAGEMENT SESSION

SESSION CHAIR REPORT AND ABSTRACTS

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Session chair report

AIM

The session aimed at discussing leachate management of today.
The focus was intended to be on sustainability of the leachate management. In connection to this the quality of leachate would be discussed linked to the requirements for treatment. Different treatment options were also of interest.

THE SESSION

The leachate session consisted of six different papers ranging from topics of long-term leachate quality, specific organic substances in leachate, an overview of leachate treatment options to examples of leachate treatment concentration and treatment techniques. The presentations were:

- The dependence of leaching ratio on leachate quality, by Katarina Kylefors, L. Andreas & A. Lagerkvist, Sweden.
- Pesticides in solid waste leachate in Norway, by Ketil Haarstad & T. Maehlum, Norway.
- Evaluation of leachate treatment methods in perspective of the character of specific organic compounds, by Cecilia Öman & O. Cerne, Sweden.
- Leachate treatment options for sanitary landfills, by Jeff Harris, D.E. Purschwitz & C.D. Goldsmith, USA.
- Efficiency of landfill leachate treatment by freeze crystallisation and natural process of snow metamorphism, by Janusz Szpaczynski, Canada.
- Full scale performance of biological leachate treatment at low temperature, Markuu Pelkonen, K. Mikko & W. Zengzhang, Finland.

After each presentation there was time for specific questions regarding the presentation. After all presentations there was about an hour for a more general discussion. The initial out-line of the discussion was as follows:

- Sustainability
  Is the treatment of today sustainable?
  What tools can we use to decide sustainability?

- Need for leachate treatment
  Do we need leachate treatment?
  What components need to be treated?
  For how long time will leachate treatment be required?

- Treatment strategies and methods
  What kinds of treatment are preferable? Why?
  What criteria do we have for the choice of treatment strategy?
  Will the requirements for treatment methods change over a landfills lifetime?

- Research needs
  Where do we lack information?
  What activities are ongoing?

THE DISCUSSIONS

Sustainability

The opinion seems to be that the leachate management of existing landfills from the 70´s and 80´s normally is unsustainable. Landfills with bottom liner and controlled leachate collection could have a sustainable leachate management, but they seldom have.

The definition of sustainability was not clear from the discussions. However, it seems as if sustainable has to alternative criteria:

- The period of time that leachate are generated and leachate treatment are required should be less than a certain number of years (that was not defined) or
- Systems, that are reliable for an unforeseeable period of time, should exist that passively can take care of pollutants released from the landfill.

Need for leachate treatment

Beside *sum of organic material*, *ammonia nitrogen* is one major constituent that needs treatment. The need for ammonia treatment is even more evident when bioreactor landfilling is used.

The members of the session did not agree on whether *specific organic substances* are focus for treatment. Different opinions were told as *e.g.*:

"They occur in such small amounts so they are no problem. Often they are hard to detect"
"Those substances may in very small amounts give large effects on *e.g.* animals and plants in the recipients".

Metals may be a problem in the long term, but we do not have the problem right now. There may be needs for systems/barriers that can cope with metal increase in the leachate and that will not result in high effluent metal concentration to the recipients.

We do not know for how long periods of time treatment will be required. However, it may be quite some time, probably longer than the requirements by laws. For new landfills with bottom liners and leachate collection systems it may be possible to enhance stabilisation of the waste. In existing landfills without these systems, *e.g* many of the landfills started in the 70´s, enhanced stabilisation is hard to achieve. Some members of the session thought that we ought to find techniques to enhance stabilisation in those landfills too. Other members of the session were not that optimistic about the possibilities of such systems at those landfills. They thought it would be better to leave the landfill and instead put energy into finding barrier systems that can cope with expected and unexpected changes in leachate composition.

Treatment strategies and methods

The choice of treatment method is site specific.

The opinion was told that one should not only consider the effects in water quality when choosing method, but also take pollutant release to the air into consideration. Data are lacking regarding this aspect.

CONCLUSIONS – RESEARCH NEEDS

The conclusions of the discussions and presentations are given below as topics for future research needs.

Sustainability

- Tools for long term prediction
- Long term leaching characteristics from existing landfills
- Long term leaching characteristics from ”new” waste compositions
- Techniques to steer leachate quality (*e.g.* the relation between nutrients as N and P in the long term)
- In situ stabilisation techniques of existing landfills
- Natural barriers that can cope with possible changes in leachate quality (in the situation of leachate migrating from landfills. There ought to be systems that makes the pollution release more safe for the surrounding environment)

Treatment needs

- Specific organic substances
  - What are the criteria for treatment requirement? Do we really need to treat those substances? If so – when?
  - Long term leaching of those substances
  - How is the leachate quality with focus on the occurrence of those organic pollutants affected by degradation phases?

Treatment systems

- Robust systems – long term performance
- Leachate treatment in combination with bioreactor landfills
  – especially focus on ammonia-nitrogen

Abstracts

Pesticides in solid waste leachate in Norway

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Abstract

It is generally assumed that landfills contain pesticides, at least in areas with a large agricultural production, or near pesticide production sites or retailers. There are about 200 active municipal landfills, but in total more than 3000 sites have been registered in Norway. The total sale of pesticides amounted to 955 ton active ingrediences pr. year in 1998, of which 68 tons, or 7%, included compounds that are not related to agricultural activities. There are about 120 approved active ingredients in pesticides sold in Norway.

The pesticide concentration in the leachate will generally depend on adsorption and degradation inside the waste body and in the leachate, which again depends on the waste characteristics, the management of the landfill, climate, topography, and geology of the site. Also the content and type of colloidal matter and suspended particles in the leachate are important, and pesticides have been reported to be associated more with colloidal mobilized shortly after precipitation events. In the liquid phase, the content and type of organic matter may significantly influence the fate of pesticides.

There are relatively few reports on pesticide concentrations in leachate. Leachate samples from a waste disposal site in Switzerland showed concentrations up to 124 µg/l of mecoprop, and down gradient groundwater with surprisingly high concentrations up to 975 µg/l (Zipper et al., 1998).

In a testing program for leachate characteristics in Sweden, it was found that 5 out of 8 leachate samples contained residues of phenoxy acid herbicides, and only one sample out of 20 of leachate particles contained pesticide residues. Analyses of leachate samples from a landfill in Denmark showed few detections of pesticides.

Here we summarize findings of pesticide residues in leachate samples from 3 major active Norwegian landfills, before and after leachate treatment. The analyses represent grab samples taken both before and after leachate treatment.

Table @. Pesticides and metabolites included in the analyses.

Pesticide	**Type**	**$\log k_{ow}$**	**pK_a**	**Sol. (mg/l)**	**pol.**	**Mol.**	**Location**	**Class**
2,4-D	H	2.7	2.64	311	-	221	be	aryloxyalcaonic acid
atrazin	H	2.5	1.7	33	-	216	fw	1,3,5-triazin
bentazon	H	5.84	3.3	570	-	240	bes, h,ww,fw	-
cypermetrin-alfa	I	7		0.01		416		pyretroid
cyprokonazole	F	2.9		93				azole
DDT	I			0.001	0	354	f	organoklorin
diazinon	I	3.3		60		304		organic P
dikamba	H	3.98	1.87	6.5	-	221		benso-syre
dikloroprop	H	1.77	3	350	-	235	bes, h, ww	aryloxyalkonic syre
dimetoat	I	0.7		23		229	fw	organic P
endosulfan	I	4.7		0.3		407		organic Cl
esfenvalerat	I	6.2		0.002		420		pyretroid
fenitrotion	I	3.4		21		277		organic P
fenpropimorf	F	2.6	6.98	4.3	+	304	b, f	morfolin
fenvalerat	I	5		<0.010		420	f	pyretroid
fluazinam	I					465		2,6dinitroanilin
fluroksypyr	H	-1.2	2.94	91	-	255		aryloxyalkonic syre
ioksynil	H		3.96	50	-	371		OH-benzonitril
iprodion	F	3		13		330	f	dicarboximid
klorfenvinphos	I	3.85		145		360		org.fosfor
lindan	I			7		291	f	org.klorin
linuron	H	3		81		249	ww	urea
mankozeb	F	1.75	<<0	8.4		279	h, ww, fw	acylalinin
MCPA	H	2.75	3.07	734	-	201	be, h, ww	aryloxyalkonic acid
mekoprop	H	1.29	3.78	860	-	215	bes, fw	aryloxyalkonic acid
metalaksyl	F	1.75	<<0	8.4		279	h, ww, fw	acylalinin
metamitron	H	0.83		1.7		202	ww	1,2,4-triazinon
metribuzin	H	1.58		1		214	h, ww, fw	1,2,4-triazinon
penkonazol	H	3.72	1.51	73	-	284		azole
permetrin	I	6.1		0.2		391		pyretroid
pirimikarb	I	1.7	pkb	3000	+	238		carbamat
prokloaz	F	4.38	3.8	34	-	377		azole
propaklor	H	2		613		212	ww	kloracetanilide
propikonazol	F	3.72	1.09	100	-	342	fw, f	azole
simazin	H	2.1	pkb	6.2	-	202		1,3,5-triazin
tebukonazol	F	3.7		32		308		azole
terbutylazin	H	3.04	pkb	8.5	-	230		1,3,5-triazin
tiabendazol	F		4.73	30 (ph 5)	-	201	e, fw	benzimidazole
vinklozolin	F	3		3.4		286		dicarbox-imid

Location: b...bølstad landfill, e...Esval landfill, s...Spillhaug landfill, f...forest production landfill, fw...farmland well, ww...water work

Results and discussion

Leachate samples with positive detection of pesticides have concentrations between 0.03 – 30.01 µg/l (Table @). Some substances have detection in all samples, such as the phenoxy acids mecoprop and dichloroprop, and bentazone

Table @. Pesticides (µg/l) found in MSW leachate samples in Norway

Compound	**B Oct. 97**	**B Oct. 98**	**B Sep. 99**	**E Oct. 97**	**E May 99**	**E Oct. 99**	**S Oct. 97**	**S Oct. 98**	**Type**
fenpropimorph		0.04							F
tiabendazole				0.4					F
mecoprop	1,00	0,58	1,40	1,00	8,70	9,70	0,17	0,03	H
MCPA			1,50		0,35	0,84			H
dichloroprop	0,40	0,10	0,22	0,04	9,10	13,00	1,10	0,04	H
2,4-D		0,05	0,08	1,80	0,04	0,57			H
bentzone	0,50	0,41	0,87	0,56	5,60	5,90	1,00	0,18	H
klopyralid					0,39				H
Sum pesticides	**1,90**	**1,18**	**4,07**	**3,80**	**24,20**	**30,01**	**2,27**	**0,25**	

B=Bølstad, E=Esval, S=Spillhaug Landfills

Table @. Pesticides (maximum concentrations) found in leachate or leachate-polluted groundwater at waste sites in the forest trees nurseries (µg/l)

Pesticide	**Max. C**
fenvalerate	0,20
fenpropimorf	0,15
iprodion	0,13
lindan	3,31
propikonazole	0,25
tolylfluanid	1,80
DDT	5,00

Evaluation of leachate treatment methods in perspective of the character of specific compounds

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Background

A large number of hazardous compounds posing an environmental threat has previously been identified in landfill leachates (Öman 1993, Öman et al. 2000 and others). The treatment of landfill leachates may be practised at local treatment plants or at municipal treatment plants. Ahnert and Ehrig (1992) assumed that the amount of metals in the sewage from the municipal treatment plants would increase if landfill leachates were treated together with other types of discharges. This would obviously reduce the value of sewage as fertilisers in agriculture. In addition, the risk of persistent pollutants included in the leachates disturbing microbial processes and an inadequate treatment effect of landfill leachates in municipal treatment plants (not optimised for landfill leachates) was discussed by Ahnert and Ehrig (1992).

A number of operating treatment methods have previously been studied. These may be summarised as; i) biological methods, ii) physical-chemical methods, iii) methods requiring reduced technical support and, iv) combinations of these. The efficiencies of reducing organic pollutants of the methods has often been measured and evaluated using parameters describing the total amount of organic carbon. The parameters include; the biological oxygen demand (BOD), the chemical oxygen demand (COD), the total organic carbon (TOC), the dissolved organic carbon (DOC) and/or the purgeable organic carbon (POC). Parameters describing the total amount of organic carbon however do not always give the most relevant information about the actual environmental risks involved.

Purpose

The purpose of this study was to suggest a method for evaluation of the efficiency of landfill leachate treatment methods in perspective of the character of specific compounds.

Method

Identification of organic compounds in landfill leachates

A methodology for the characterisation of landfill leachates has previously been developed (Öman et al. 2000) and 15 landfill leachates have been characterised (Öman, in manuscript). The results showed that a large number of organic compounds are present in leachates including: volatile halogenated hydrocarbons, benzenes and alkylated benzenes, phenol and alkylated phenols, polycyclic aromatic compounds (PAH), phthalic compounds, chlorobenzenes, chlorophenols, phenoxyacids, chlorinated pesticides, polychlorinated biphenyls (PCB), polychlorinated dibenzo-p-dioxines (PCDD), polychlorinated dibenzofuranes (PCDF) and bromated flame retardants.

The character of specific organic compounds

Emissions of organic compounds from landfills depend on the character of the specific compounds (Öman, in press). Consequently one can assume that also the fate of organic compounds in leachate treatment systems depend on their compound character. Previous results have shown that processes which significantly affect the compounds inside landfills are sorption, dissociation, evaporation and transformation (Öman 1995). These processes could be described by the octanol/water coefficient, K_{ow}, the acid dissociation constant~~s~~, pK_a, the Henry's law constant~~s~~, H, and the potential of the compounds to be biologically transformed. The use of a ranking score system was suggested as a tool for interpreting the predicted fate of specific compounds caused by several simultaneous processes (Öman, in press). A good correlation could be found between the measured emissions and the theoretically evaluated fate.

It is proposed that the ranking score system previously used inside a landfill (Table 1) can also be used for leachate treatment methods. Obviously, the scoring values may need to be adjusted in perspective of the different treatment methods.

Table 1. Ranking of the characters of specific organic compounds (adjusted from Öman, in press).

Ranking	Sorption	Evaporation		Anaerobic microbial transformation *	
Score	log K_{ow}	H, Pa m^3/mole	Description	Rate $t_{1/2}$	Description
0	<1	< 0.1	not volatile	> 10 years	Persistent
1	1-2	0.1-100		100 days-10 years	Medium degradability
2	2-3	100-1000		1 - 100 days	Good - medium degradability
3	>3	>1000	volatile	< 1 day	Good degradability

* The microbial transformation data may vary significantly due to different experimental conditions.

Transformation stages

One obvious concern is that the leachate character changes with time. In landfills containing organic waste, biological, chemical and physical processes proceed which affect the state of the solid waste, leachate and produced gas (Öman 1991, Öman 1998). Based on earlier literature results an idealised classification of these processes in five sequential transition stages which cover the lifetime of the landfills was made. The transformation of waste, leachate and landfill gas with time have been classified into five transition stages; the initial stage, the oxygen and nitrate reducing stage, the acid anaerobic stage, the methane forming anaerobic stage, and the humic forming stage. The descriptions given refer to only certain volumes of the waste since different parts of real landfills can exist at different stages at the same point in time. The classification of the different transition stages is based on microbial degradation of the organic material in the waste.

Results

Based on previous results the following four-step methodology was suggested for the evaluation of leachate treatment methods.

1. Identify specific organic compounds in the leachate prior to treatment. The sampling, treatment and analysis may be performed according to the previously developed method (Öman et al. 2000).
2. From the compounds present in the leachate, a suitable number of compounds are selected, in order to represent different characters according to Table 1.
3. The chosen compounds are then analysed before and after each treatment step. The results can be evaluated in relation to the total ranking scores.
4. The results are evaluated in relation to the actual transformation stage of the landfill.

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LEACHATE TREATMENT OPTIONS FOR SANITARY LANDFILLS

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LEACHATE TREATMENT OPTIONS FOR SANITARY LANDFILLS

Abstract: At the dawn of the new millennium, sanitary landfill remains an environmentally sound and cost-effective option for disposing of the debris of modern civilization. It is a technology that can be successfully utilized by both developed and developing countries. Improvements in sanitary landfill design and operation parameters over the last decade have concentrated on lining systems and residuals management (gas, liquids). Improved lining systems have minimized the threat of groundwater contamination while simultaneously resulting in higher leachate recovery. Environmental protection demands that these liquids, typically high in organic content, be treated before discharge. The cost of managing these liquids is substantial in both the active and post-closure period. Numerous schemes have been developed to treat leachate. Most are based on traditional sanitary wastewater treatment technologies, but numerous innovative technologies or new applications of existing technologies, are now available for leachate treatment.

Several of the more promising of these treatment options (biological, physical, chemical, thermal) are described along with the associated advantages and disadvantages. The impetus for finding alternative leachate treatment technologies include:

- Reduced costs of managing leachate and other landfill liquids,
- Utilizing processes that are more amenable to changes in leachate quality over time,
- The ability to remove recalcitrant contaminants such as total dissolved solids (TDS) and,
- The ability to deal with higher ammonia concentrations as recirculation becomes more common.

The paper also addresses the emerging issue of leachate composition changes as a function of recirculation and bioreactor operation techniques. One of the most promising of the advanced landfill operating models is bioreactor, which uses moisture control (via recirculation and other methods) to optimize the degradation of organic compounds in a landfill. One potential concern is the concentration of ammonia in recirculated leachate. Cost effective and efficient ammonia control is one of the key requirements for successful bioreactor operations. The control of ammonia has not traditionally been addressed at on-site leachate treatment systems in the U.S. This is an area where concentrated research effort is required.

A case history of an U.S. East Coast landfill is presented to illustrate one method of on-site ammonia control. This landfill has recirculated leachate for several years. Concentrations of NH_3-N range from 300 to 550 mg/L. An enhanced biological process for the elimination of nitrogen from the landfill MSW and leachate was tested. Preliminary data suggests that the nitrification process was successful during the field trial and would be successful on a full-scale application.

Key Words: ammonia, bioreactor, evaporation, landfill, leachate, membrane treatment, nitrification, recirculation, reverse osmosis, treatment

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Efficiency of Landfill Leachate Treatment by Freeze Crystallization and Natural Process of Snow Metamorphism

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ABSTRACT

In the past, various attempts have been made to apply, in full-scale, the beneficial effect of the freeze crystallization phenomenon. However, in most of the studies, the process has not been widely accepted because of its high-energy consumption of the refrigeration system, or, in the case of freezing in natural conditions, because of the problem with distribution and freezing of large volumes of wastewater. These problems can be avoided by freezing the wastewater in the form of man-made snow.

The process responsible for segregation of chemical elements and nutrients in the snow pack, as well as its concentration, is snow metamorphism. Snow, as a thermodynamically unstable material, has the ability to change its physical characteristic even at very low temperatures. Fresh man-made snow is a composition of frozen droplets and in macro scale, is dissimilar to natural snowflakes. However, the process of metamorphism is governed by the same mechanisms. Based on this process, as well as the phenomenon of ions elution and its concentration in melt water, authors of the following paper hypothesized that the snow metamorphism process could be applied to treat/concentrate landfill leachate.

After wastewater atomization, the ice crystals first form from the pure water at the surface of each droplet, and trap dissolved compounds such as salts and gases, as well as solid particles in the ice globule. Growing further ice crystals, incorporate water molecules and concentrate compounds in the remaining liquid inside the droplet. As the ice crystal grows, the free space for liquid decreases and the concentration at the growing ice front is higher than in the bulk water. When the solubility of the gaseous compounds reaches the maximum and oversaturation takes place, gas bubbles nucleate and are trapped between the growing ice crystals. An analogous situation occurs with other compounds and some salts may precipitate. The pressure of liquid inside the ice droplet increases with the decreasing volume of remaining liquid. The ice globule may fracture and the concentrate could be released outside. This gives additional benefit for further concentration because the concentrate is removed from the inside of the droplets on their surface. At that moment, the separation and concentration is in macro scale of each droplet and the contaminants are equally distributed in the snow pack profile. However, soon after the man-made snow is deposited on the ground, the temperature gradient is established in the snow pack profile. The mechanism of snow metamorphism, based on vapor pressure gradient, takes place and is enhanced by fluctuations in ambient temperatures. Some ice grains or portions sublimate and the water vapor condenses as pure ice on the surface of the ice grains located in the area with lower vapor pressure. As a result, solid particles and ionic compounds, as well as gas bubbles (volatile compounds of wastewater) are easily excluded and released from the ice. Most of the contaminants are deposited on the surface of the ice grains in the pores of the snow pack. When the melting begins, the rejected and accumulated soluble impurities on the ice crystals are similarly washed down as "cake" in a filtration process. Volatile compounds are stripped away during atomization and/or separated in frozen droplets as gas bubbles, and slowly released during snow metamorphism and melting.

The efficiency of concentration for non-volatile compounds is described as follows:

$$E_{(i)} = 1 - a(1 - V_c) - bd(e^{(-V_c/d)} - e^{(-1/d)});$$

Where: a, b, d = coefficients of concentration (based on experimental data).

Concentration of compound "i" in the effluent melt water and in the concentrate (Figure 1) can be calculated from the following equations:

$$C_{E(i)} = \frac{1 - E_{(i)}}{1 - V_c} C_{0(i)} \qquad C_{C(i)} = \frac{E_{(i)}}{V_c} C_{0(i)}$$

Where:

$C_{E(i)}$ = Average concentration of compound (i) in effluent [mg/l];

$C_{0(i)}$ = Concentration of compound (i) in raw wastewater [mg/l].

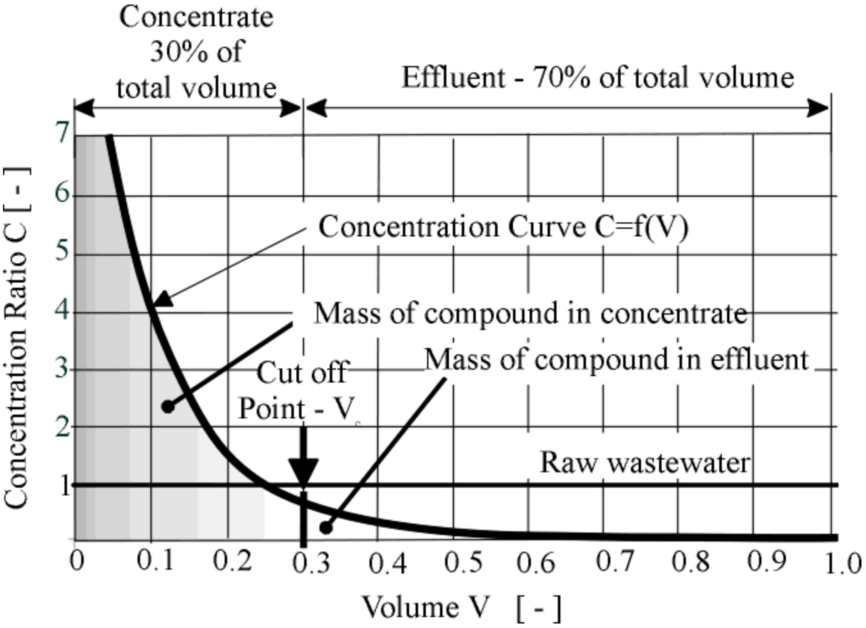

Figure 1 Concentration Curve

Selected results from concentration of landfill leachate in lab scale experiments are presented. An elution of anions and cations, as well as other parameters during the melting process, were monitored. A high concentration of contaminants was reported in the initial runoff of melt water. Most toxic elements and organics were concentrated in the first melt water runoff. The efficiency of the process was different for different elements. Sulphate was generally not detectable in the melt effluent. Very high efficiency of the treatment was also noted for chloride and such compounds as Boron, Potassium and Sodium. More than 95% of these elements were removed from the leachate. An increase in BOD, COD, DOC and TOC, in the first melt was very high and reached values of 92%, 94%, 95% and 97%, respectively. Satisfactory concentration efficiency of Barium was also reported (94%). Other elements such as Aluminum, Chromium, Nickel, Zinc and Iron were concentrated to 93%, 90%, 93%, 89% and 92%, respectively. Mercury, in raw leachate was 0.0007mg/L and was concentrated in the first 20% of melt to the value of 0.003 mg/L .In further samples of effluent, Mercury was below Method Detection Limit. The concentration efficiency of Copper was at the range of 77%. Lower concentration of 21% was reported for Fluoride. Fluoride is easily incorporated into the ice structure and thus its concentration was restricted.

The freeze crystallization process improves clarity of effluent. The colloidal particles undergo natural agglomeration and are easily separated from the melt water stream. The atomizing freeze crystallization process can be an excellent pre-treatment unit system in winter operation or may work as a separate independent unit.

Full scale performance of biological leachate treatment at low temperature

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The aim and background

The aim of the study was to examine the performance of a new full scale biological leachate treatment plant in demanding Nordic winter conditions and to study factors affecting the process, especially nitrogen removal, and its feasibility including economical aspects.

The treatment unit consisted of an activated sludge process with pre-denitrification and nitrification stages. The process configuration and design values were based on the pilot scale results found earlier (Pelkonen et al.1999). The construction of full-scale plant started in summer 1999 and was taken in operation at the end of November 1999. The water taken into the process consisted mainly of leachate from a 2.5 ha landfill (age 7 years) and from an approx. 1 ha windrow composting area. The water was led to a balancing tank, from where it was pumped to the treatment process. During the winter and spring period the water temperature was around 2-4 °C, the hydraulic retention time 1.5-3.8 days and the sludge age over 30 days. Phosphorus was added to the process to maintain the nutrient balance.

Results and discussion

The loading of the process was increased stepwise during the first two months after the start of the process to allow the adaptation of the biomass. Results after this period representing winter and spring conditions with snow melting period (length approx. 3 months) are shown in table 1.

Table 1. Treatment efficiency during the winter and spring period

	Influent					Effluent					Removal efficiency
	Unit	Avg	std	Min	Max	Avg	std	min	max	N	avg [%]
COD_{tot}	Mg/l	619	101	540	820	189	23.8	154	224	7	69.4
BOD_7	Mg/l	227	48.3	170	290	11.2	3.5	6	15	5	95.0
Ntot	Mg/l	84	11.4	66.4	97.6	38.3	9.1	32.2	56	6	54.4
NH_4-N	Mg/l	77	8.7	61.7	90.8	1.2	2.5	0.1	7.4	8	98.5
NO_2+NO_3-N	Mg/l					25.0	10.8	16	50.7	8	
Temperature	°C					6.6	2.3	4.7	11.4	8	

Avg = average, std = standard deviation, min = minimum, max = maximum, N = number of observations

The results show a nearly complete nitrification, the ammonia removal was in average over 98 %. A reasonable denitrification was found; in average the total nitrogen removal was approx. 55 %. The lowest monthly process temperature was 4.5-5 °C, which can be characterised extremely low. It is obviously first time, when a full and stable nitrification has been reported in a leachate treatment process in this temperature range in full scale.

Removal of BOD_7 was in average 95 % and of COD approx. 70 % indicating efficient degradation of biodegradable organic matter. The residual COD was in average 190 mg/l. The COD- and BOD_7- concentrations in the influent were lower than during the previous pilot tests mainly due to obvious increase in gas production in the landfill and decrease of organics in the water phase.

The specific nitrification rate was 0.009-0.02 g NH_4-N (g VSS) $^{-1}$. This did not differ considerably from the pilot tests, in which the temperature range was approx. 7-11 °C. These results support to extend the feasible temperature range for nitrogen removal down to 4.5-5 °C. An important factor to take into consideration is the possible inhibition of nitrification due to heavy metals or other toxic compounds, which can have a synergetic effect with the decreasing temperature. These results (and other test results not shown here) indicate that at least in this case this phenomenon did not have a remarkable role.

Of importance is, in spite of carbon and nitrogen removal, the solids separation efficiency, because excess solids deteriorate the effluent quality. Results in table 1 and other test results (not shown here) confirm a reasonable bioflocculation and that the solid particles can also be removed without serious problems in an activated sludge process in these temperature conditions.

The operation and investment costs were estimated in the pilot study and the real data from this full-scale plant confirms that the costs of local biological treatment per m^3 and per kg nitrogen removed are competitive. An important factor was that no extra heating was used and the energy consumption was low. The good treatment results at low temperatures aid also the process economy.

Conclusions

A biological process was applied successfully to treat cold leachate in winter conditions in full scale. A complete ammonia nitrogen oxidation was maintained, obviously first time in full scale at process temperature 4.5 – 5 °C in combination with a reasonable denitrification efficiency.

The process was not considerably affected by inhibition due to heavy metals and toxic compounds in these extreme conditions. In addition, the solids removal was reasonable.

The treatment results together with economical evaluation show that the application of biological processes in leachate treatment at low temperatures is worth considering and the feasible temperature range can be extended down to 4.5 – 5 °C.

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The dependency of leaching ratio on leachate quality

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Many small and big scale experiments have been made in the landfill research in recent years. One thing all of them have in common is the lack of a tool to interpret the results for a full-scale landfill. Some authors *e.g.* Reitzel et al. (1992), Kylefors (1997) used the ratio between liquid and solids (L/S) to transfer the time scale. However, in most cases only concentration trends over the duration time of the lab test were shown. Yet it is not only of scientific interest to know when *e.g.* the leachate concentrations will reach an environmentally sound level but rather very important from a leachate management perspective. For example, there is a need to predict the extension of time when leachate treatment will be needed.

Here we focus on the possibilities of using L/S as a tool for predictions. It will show differences in leachate quality at certain L/S ratios between simple leaching tests versus model simulations and model simulations versus field observations. These comparisons are made for different kinds of wastes ranging from a compostable fraction of municipal solid waste (MSW), a typical MSW, MSW mixed with ashes, and pure ashes.

Differences in the leaching performance between simple leaching tests and model simulations as well as between model simulations and field observations will be discussed. The differences are *e.g.* dependent on factors like the particle size and the residence time of the water.

Conclusively L/S is a tool that may be used to estimate the time required for leachate treatment. However, the L/S is not a complete tool, i.e. it will not solve all the problems of predicting full-scale performance from small-scale experiments.

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