Landfill leachate, generation, composition, and some findings from leachate treatment at Swedish plants

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Abstract

The aim of the paper is to present some fundamental conditions for the landfill leachate generation, and discuss possible variations due to the composition of the deposited refuse. Consideration is given to changes in the refuse, and its (future) influence on the leachate composition with respect to impurities. The major factors defining the composition are discussed as well as the change in time of the leachate. However, this paper is limited to what is defined as anaerobic phases inside the landfill. In an extended perspective a "second" long lasting aerobic phase is likely to occur. Some comments are given on the leachate composition as found at a number of Swedish landfills, typically contradicting a number of widespread "convictions".

Sammanfattning

Denna uppsats diskuterar några grundläggande villkor för lakvattenbildning och dess sammansättning. Speciellt belyses hur en deponis innehåll av typiska föroreningar förändras med tiden. Särskild uppmärksamhet ägnas förhållandena i deponins inre, och att deponin kan och bör ses som en anaerob reaktor, med påverkan på lakvattnets sammansättning. Särskilt betonas, att metallerna fastläggs som sulfider under anaeroba förhållanden, liksom en långtgående hydrolysering av kvävet äger rum. Slutligen visas från en anläggning, som följts noga under ett antal år, att det biologiska slammet från reningsanläggningen har låga eller mycket låga halter av de ”vanligen” diskuterade riskabla föroreningsvariablerna.

Introduction

The problem of waste handling is as old as mankind. The first written directive on waste handling is probably the statement found in Old Testimony (Deut. 23: 12 – 13), where instructions are given on how to deal with faeces. Another concern about solid waste and refuse was expressed by the north African philosopher Ibn Khaldoun in the 14-th century, stating about his fellow Arabs: *"It is the desert that follows the Arab, not the Arab following the desert"* (Free quotation) However, the waste problem resembles most of the other urban environmental problems by basic conditions such as potential health threats, odour problems (provided that organic matters were disposed), the issues of collection and transportation, and so forth.

The by far most common method to handle solid waste has been – and is still – seen in a global perspective – to collect and deposit it in various types of landfill. One inevitable problem created by the depositing the solid waste is the formation of (landfill) leachate leaving the deposit and causing potential water pollution. The problem has been identified in all industrialised countries. The problem was clearly identified during the 1970-ies in Sweden.

In the following the discussion will be limited to the landfill leachate problem linked to landfills containing organic wastes. This may be seen as obsolete from a bureaucratic point of view, as the EU has implemented a prohibition to deposit organic matter. However, as will be described in the following, a sanitary landfill will produce leachate long time after its closure, and the leachate will contain considerable concentrations of polluting agents. So, even if a landfill is abandoned the responsibility to handle the leachate will remain for a very long time.

Another aspect – easily forgotten – is that the landfill technology will be dominant for many countries around the world, independent of any EU directives! Thus the following considerations will have relevance in a wide perspective.

Objectives of the paper

The objective of this paper is to provide a short outline of leachate generation and its composition, with special relevance for outlining of relevant treatment technologies. The paper focuses on the conditions in the Swedish theatre, as the work in the US and Europe on leachate treatment is often governed by far more stringent effluent standards than found in Sweden. This fact has also resulted in a focus on very disparate treatment methods, as presented below. Another clear consequence may be that the approach to leachate treatment not always has been supported by a process engineering viewpoint.

Leachate generation

Leachates from landfill are generated by a number of factors, such as:

- Infiltration of ground water;
- Infiltration of leachate into the ground (a potential pollution of the ground water may occur);
- Rainfall (precipitation);
- Water from the deposited waste, mainly due to the static pressure;
- Evaporation from the site.

Older landfills often were operated in a rather unsophisticated way; the management and operation seldom included adequate protection devices and with large open deposit areas where the waste was disposed. This in turn means that many "old" landfills are exposed to comparatively large amounts of water, emanating from the different sources as defined above.

Some basic points that define the influence of rainwater are – apart from the magnitude and frequency of the precipitation – are the landfill area directly exposed to receive rainwater and allow it to percolate into the landfill and the shape of the landfill allowing rainwater to "run off" from the landfill area as surface water. In Figure 1 is presented a schematic picture of the water balance in a landfill. The figure is taken from a Doctoral Thesis presented by Sami Serti (2000).

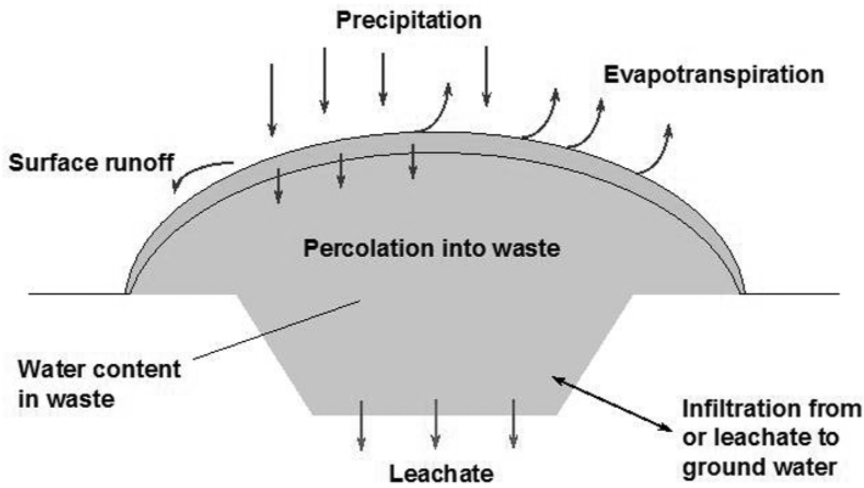


Figure 1. Shematic scheme of how leachate is genarete

Even if the water balance over a defined period of time – normally a year – shows that the evaporation from the area is bigger than the precipitation it may be essential to focus on a shorter time when studying the water balance. As an example: In normally dry areas very heavy rainfalls with short duration may cause a large amount of leachate from the landfill. This "run off" must be addressed in a proper technical way – either by storage lagoons or a "simple technique" for treating the leachate. The latter alternative may be interesting if there is a potential to treat the leachate is such a way that it may be used for irrigation. A crude leachate is highly susceptible to be unfit for irrigation purposes.

By and by it has become more apparent that landfill leachate management called for a deeper understanding of the processes within the landfills. A good understanding of the "inner" environmental processes in a landfill would facilitate the planning of the landfill leachate management. It would also provide needed knowledge of the short term and long term composition of the leachate composition. And finally this would provide "input" data for leachate treatment design.

Processes defining the leachate composition´

A sanitary landfill passes through four stages with respect to the internal biological process performance. The first three phases may be defined and characterised as follows; see Table 1. The fourth phase that is labelled the "humic phase". The knowledge of this phase is limited as very few observed landfills have entered this phase, see Serti (2000), as it is expected to occur more than 100 years – perhaps many centuries after the closure of a sanitary landfill. Thus as Serti has described in (3) most of the outlined (future) changes of the leachate composition is based not on observations but on analogies and rational hypotheses based on chemistry. In the following the discussion will be refined to the three first phases in a land fill with special attention to the conditions during the second and third phases.

First phase: Aerobic phase	
Duration	some weeks
Characterisation of landfill leachate	pH ~ 8
	High levels of heavy metals
Second phase: Acidic (anaerobic) phase	
Duration	some years
Characterisation 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
Characterisation 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

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

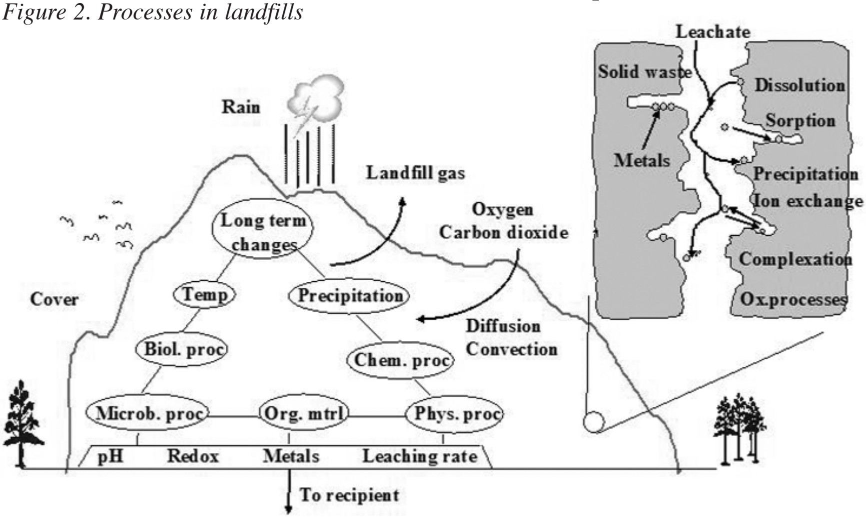
It would be kept in mind that this "phasing" of the sequential processes in landfill is related to a number of conditions, such as:

- The solid waste composition – especially if the solid waste contains large or small amounts of organic matters, more or less easily degradable would influence the velocity in the aerobic/ anaerobic reactions;
- The formation of leachate, and its ability to transport matters within the landfill;
- The ambient temperature – climatic conditions. As an example may be mentioned a newly opened landfill site in Oujjda, Maroc, where – according to observations by SWECO engineers - the Methane phase seems to have started within half a year from the opening of the deposit.
- The arrangement of the landfill – if the landfill is arranged with rather small deposit cells that are closed and sealed after only one or two years the anaerobic conditions would most likely be accelerated. This in turn would "convert" the landfill cell into an anaerobic reactor.

As found in the table a landfill leachate treatment management must consider the two last phases, as modern landfills are operated with a number of cells, thus producing a landfill leachate of varying age - from less than one year to several decades.

Another way to illustrate the complex reactions in a landfill is found in Sami Serti (2000). The Figure 2 present an illustration of a landfill with macro and micro conditions in a landfill. The figure presents both the short term and long term influences on the solid waste, and thus the conditions for the leachate creation and composition.

Figure 2. Processes in landfills



A typical modern landfill design scheme is presented in Figure 3, showing a cross section of a landfill cell. It would be kept in mind that the cell will be covered after completion, and anaerobic processes will be enhanced.

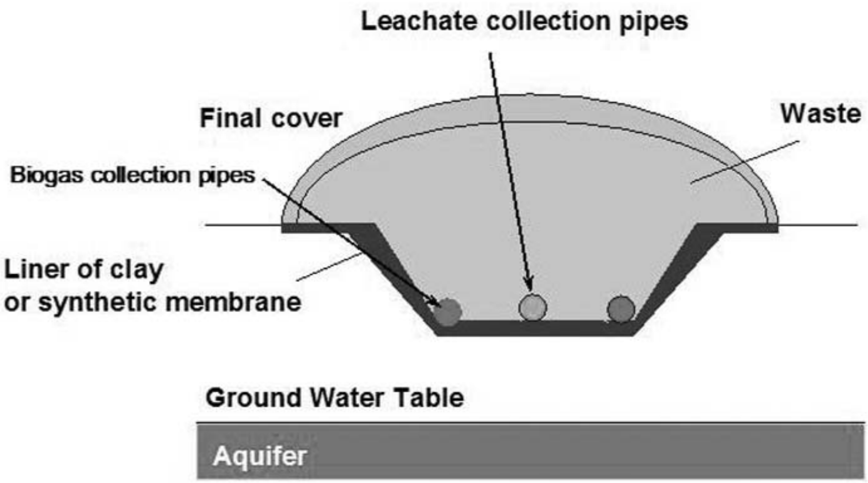


Figure 3. Typical modern landfill design scheme

Some outlines of treatment technologies

Three major factors emerging in the mid 1980-ies and early 1990-ies contributed to the development of landfill leachate treatment methods:

- A growing concern regarding the landfill leachate composition, inter alia heavy metals content and complex organic compounds, such as dioxins. To what extent such a concern was well-founded may be disputed;
- The insight of the environmental impact from non-oxidised nitrogen (especially ammonia nitrogen) became apparent;

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

- A co-treatment with municipal wastewater in a "classic" treatment facility;
- 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;
- Adopted and modified classic biologic treatment methods, to obtain efficient landfill leachate treatment;

- Chemical physical treatment methods; such as ammonia stripping, chemical precipitation and activated carbon filtration.
- Use of "advanced" treatment methods, such as reversed osmosis and/or "hyper filtration".

All these methods are currently in use around Sweden. The methods will not be discussed in detail in this paper; only one aspect with respect to treatment technologies will be discussed. Some of the very profound considerations with respect to leachate composition are discussed and questioned.

Landfill leachate composition

The following Table 2 illustrates typical composition of landfill leachate from Swedish plants. The Table includes both a large landfill in the western part of Sweden (called Trestad, operated by TRAAB) and new and old landfills.

	Large landfill (old)	New landfill	Old landfill
Number of observations			
p	7.2	5 - 6	8 - 9
Conductivity, mS/m	543	50 – 1,400	50 – 1,400
Alkalinity, mekv/l	543		
Cl^-, mg/l	920	(5) – 1,300	1,000 – 6,000
BOD_7, mg/l	27	1,000 -2,000	10 - 800
COD, mg/l	480	1,000 -30,000	500 – 4,000
Total P, mg/l	1.1	< 24	0.1 – 4.0
NH_4-N, mg/l	240	150 - 560	80 -370
Total N, mg/l	330	800	100 - 400
Suspended Solids, mg/l	5	n.a.	n.a.

Table 2. Typical composition of leachates, from Swedish landfills

The overall picture of the landfill leachate composition is confirmed by an investigation made by Glixelli (2003). The report presents literature documentations, covering reports from Germany, Great Britain, Poland and Turkey on leachate composition. These reports show a vide range in concentrations of the pollutants. In some cases the referred figures are divided into the disposal times (phases) as described above.

<u>Organic content</u>

As discussed above is the organic content in the leachate "time dependant". The most striking difference between the leachate composition from a "new" and "old" landfill is the ratio COD/BOD, and also the content change of BOD. This is related to the anaerobic decomposition.

As pointed out this stage will normally change into the methane phase after a rather limited time, when most of the degradable organics are decomposed of organics into methane gas and carbon dioxide. The ratio COD/BOD increases and ends up being very high – often in the vicinity of 20/1. These circumstances will in turn influence the selection of adequate treatment methods for the leachate. The anaerobic conditions also support the creation of metal sulphides, being one important reason for the long term leachate composition with respect to heavy metal content.

Nutrient content in leachate

Most leachates are rich in nitrogen and also normally contain low to very low concentrations of phosphorous. The nitrogen content may, as shown above be in the range 100 – 800 mg total N/l– typical levels found in Swedish leachate investigations. Spinoza and others report substantially higher levels for leachates, according to Magnus Montelius (1996) is the range 50 – 50 000 mg/l of total N. The nitrogen ammonium part of the total nitrogen increases by time, mainly due to anaerobic hydrolysis of organic nitrogen into ammonia. Already during the acidic phase in the landfill the ammonia content represents the major part of the total nitrogen. For an old landfill operated at methane phase the ammonia nitrogen represents 85 to 95 % of the total nitrogen content in the leachate.

The phosphorous content on the other hand is found to be low to very low in most leachates; see ***Table 2***. The phosphorous is to a large extent hydrolysed, and found as phosphates. The content is normally not sufficient to support an aerobic biological treatment; when such a treatment is preferred an addition of phosphoric acid is arranged.

Chloride and other salt components

Leachates from most landfills have a rather high salt content, especially when compared with municipal wastewater in Europe. For arid areas, such as Northern Africa the matter is even more relevant. The salinity in crude municipal wastewater in the city of Sfax, Tunisia is about 5 000 to 7 000 mg/l.

The high salinity in leachates represents problems in at least two ways:

- If the receiving stream is very poor (small water flow) and a very limited dilution is expected especially the chloride content in the leachate may constituent a discharge problem;
- High salinity and especially high chloride content create a very corrosive environment, and when a treatment plant is built it becomes essential to chose non corrosive materials for the process equipment and adequate protection for the concrete, provided that the plant is built with concrete reactors.
- The high chloride content will also affect the COD analysis. This has been handled by adding mercury to the sample when analysing the COD. Never the

less at very high chloride content the COD analysis will be severely affected and the result may be dubious.

Other salinity components, such as SO_4^- will add to concrete corrosion.

Heavy metal content

In Figure 4 is illustrated in a graphical way how some of the constituents in the leachate change by time, especially worth is looking at the heavy metal content in the leachate. An often not well founded statement regarding the leachate composition is that the heavy metal content is high. As illustrated above this statement is not true when it comes to leachate emanating from a landfill in the "methane stage". The figure illustrates these conditions further. A number of observations at leachate treatment plants in Sweden also support the statement that heavy metals are not found at high concentrations in the leachates.

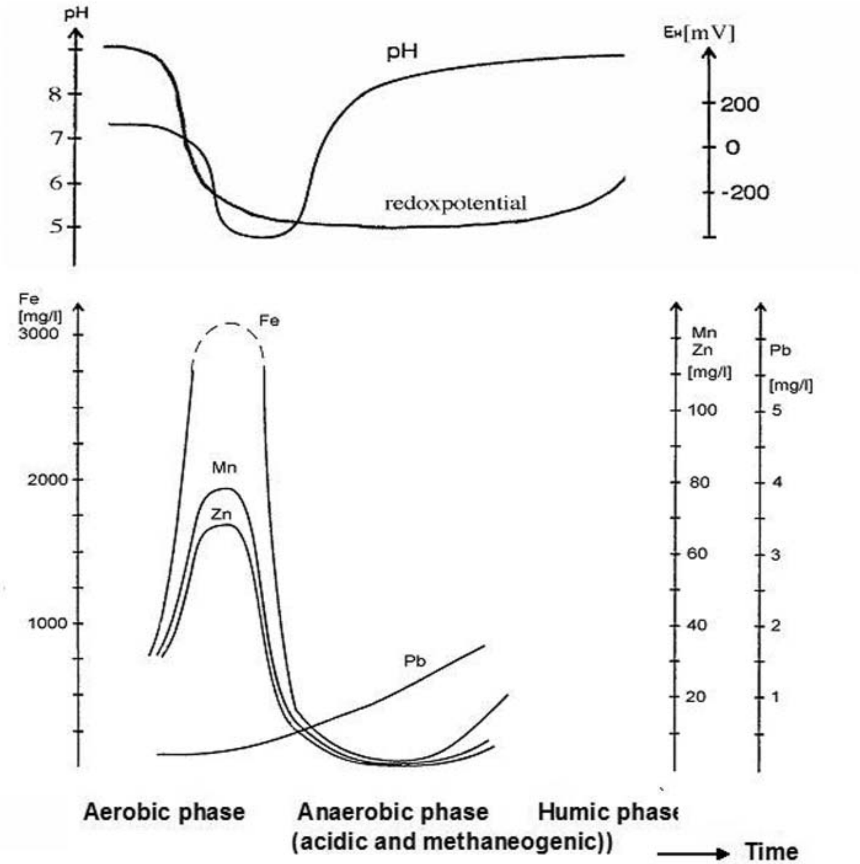


Figure 4. Development of leachate quality, pH and redox potential

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 are heavy metal concentrations been found that exceeds the level for potable water in Sweden. Noticeable exceptions are Fe and 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.

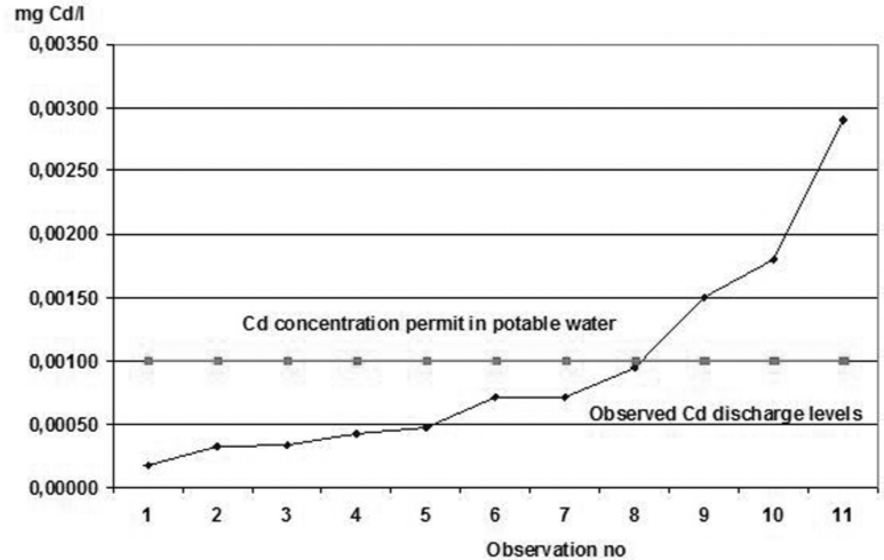


Figure 5. Cd content in treated landfill leachate at Köping SBR plant shown in increasing concentration, not by time

This statement is further illustrated by a summary of analysis at the Isätra landfill, town of Sala, some 120 km north west of Stockholm; see Table 4.

Heavy metal	Maximum value	75 %:s percentil	Median-value	25 %:s percentil	Minimum value	Limit value for potable water, Swedish standards
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Iron, Fe	***13.0***	***8.5***	***6.5***	***5.1***	***3.5***	1.0
Manganese, Mn	***1.9***	***1.4***	***1.3***	***1.2***	**0.5**	0.3
Zink, Zn	0.44	0.21	0.16	0.12	0.08	0.3
Cobalt, Co	0.008	0.006	0.006	0.005	0.004	
Chromium, Cr	0.03	0.02	0.02	0.02	0.01	0.05
Cadmium, Cd	0.00041	0.00028	0.00021	0.00012	0.00005	0.001
Copper, Cu	0.027	0.014	0.012	0.009	0.007	0.20
Nickel, Ni	0.03	0.02	0.02	0.02	0.02	0.05
Led, Pb	***0.019***	0.008	0.004	0.003	0.002	0.010
Arsenic, As	***0.380***	0.006	0.004	0.003	0.001	0.01
Mercury, Hg	0.0002	0.0002	0.0002	0.0001	0.0001	0.001

Table 4. Heavy metal concentrations in leachate at Isätra landfill, Sweden. Water into leachate treatment facility, observation period October 2001 through September 2002 (10 observations).Values exceeding the limit values for potable water are presented in ***Italian bold.***

The sludge in the biological facility, based on SBR (Sequencing Batch Reactor technology) was accordingly 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 5 the measured concentrations are compared with the Swedish guidelines for sludge quality related to agricultural use. The results are found at the Köping leachate treatment facility, some 180 km west of Stockholm.

	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
Zink	71	< 800

Table 5. Sludge content of heavy metals at a small Swedish leachate treatment facility, see Morling (2006) compared with reuse requirements for agricultural use (mg/kg TS)

Other pollution parameters

Leachate is normally regarded as a potentially toxic matter. This statement may be confirmed or rejected for each leachate by toxicity tests. For the case in Köping, Sweden and the leachate planning toxicity tests were conducted. It was found that the untreated leachate was toxic. Reference: Laboratory tests conducted at a municipal water laboratory, see Dahl (1998). After biological treatment by nitrification it was found that the toxicity was substantially lower, or even not easily detectable (communication from Anita Höglund-Eriksson, at VAFAB, the owner and operator of the plant). The toxicity has often been related to the presence of complex organic matters, such as chlorinated organics (PCB dioxins). A problem connected with this issue is that the concentration of these compounds is often found to be lower than the accuracy of the analysis method. This in turn does not imply that the leachate is not toxic, only that the analysed compound can not be detected with accuracy. A normally met concern is that the sludge would be contaminated by these complex compounds. At the Köping plant the biological sludge has been analysed with respect to some of these compounds. The outcome from three tests shows the following:

"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 < $\sum$ 0.02 mg/kg TS at all three occasions. The Swedish EPA guidelines for agricultural use stipulates $\sum$ 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.", see Morling (2006).

Discussion and conclusions

A good understanding of the conditions for landfill leachate treatment starts in an understanding of the leachate generation and the processes inside the landfill. The identified process phases inside the landfill –aerobic, acidic (anaerobic), methane (anaerobic) and humic (aerobic) will all determine different compositions of the leachate. By these four phases the two intermediate are of central importance for the decisions on leachate management. Some central points with respect to leachate generation and its polluting potentials are summarized as follows:

- It is essential to establish a model for water balance for a land fill and from this model try to estimate the short term and long term leachate generation. Among the most important factors are the annual and peak precipitation figures, the evaporation. When planning a new landfill it would be indispensable to prevent the transportation of ground water into the landfill and the percolation of leachates into the ground.
- The understanding of the methane phase is crucial both

with respect to the potential of energy content in the generated gas and how to address leachate management;
- The crucial question regarding leachate handling with respect to environmental protection is how to quantify potentially hazardous compounds. The complex organic matters, such as dioxins are often found at concentrations below the accuracy level of the analysis method.
- The often advocated standpoint that the heavy metal content in leachates is "high" is often found disputable, apart from Fe and Mn. These metals are found in concentrations considerably higher than the permit levels for potable water (in Sweden).
- In the Swedish theatre there has been a lack of understanding for a process oriented perspective on leachate treatment. This may be reflected in the two examples given in this paper, where insufficient knowledge in process engineering points out dubious pathways for process design.
- An important part in leachate treatment planning would be to perform treatability tests.
- The needs for realistic criteria on effluent standards may include toxicity tests on treated water.
- The sludge quality with respect to polluting agents, both heavy metals and complex organic compounds would be investigated from leachate treatment facilities, in order to quantify the content.

Acknowledgements
Dr Sami Serti at SWECO VIAK has given the outlines for the characterisation of the biological performance in a landfill and also valuable contributions on the outlines of this paper.

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