Methodology for the evaluation of leachate treatment methods

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1. Abstract

The treatment of landfill leachates at local plants needs to be better evaluated. In this study a new methodology was suggested, including i) identification of compounds in the leachate prior to treatment, ii) selection of compounds which are assumed to be affected differently by treatment methods, which represent different characteristics, and for which external processes have been considered, iii) analysing the selected compounds before and after treatment, and then iv) evaluating the results. The method presented is an initiative intended to inspire further research and needs to be considered more thoroughly both in theory and in practice.

Keywords: Treatment, landfill, leachates, evaluation, methodology.

2. Background

A large number of hazardous compounds posing an environmental threat have previously been identified in landfill leachates (Öman et al. 2000, and others). The treatment of landfill leachates during the operative life of a landfill may be practised at local treatment plants or at municipal treatment plants. Ahnert and Ehrig (1992) pointed out the risk of an inadequate treatment effect of landfill leachates in municipal treatment plants, since these have not been optimised for landfill leachates. The efficiency of reducing organic pollutants at local treatment plants has often been measured and evaluated using parameters describing the total amount of organic carbon (BOD,COD,TOC, DOC). Parameters describing the total amount of organic carbon however do not always give the most relevant information about the actual environmental risks involved. The efficiency of reducing metals has often been evaluated from a small number of metals, not taking into account the specific forms of the metals such as free ionic forms, metal association with colloids, and complex formation with inorganic or less organic compounds. Evaluations have often been made without mentioning metal-organic compounds.

2.1 Purpose

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

3. Method

From literature review, field sampling and chemical analyses, five topics were considered to give valuable background for choosing a methodology for evaluation of the efficiency of landfill leachate treatment methods. The topics were;

i) identification of specific compounds present in landfill leachates,

ii) division of compounds into groups that can be assumed to be affected differently by treatment methods, and thereafter identification of compound specific characteristicss with expected impact on the treatment,

iii) consideration of external processes with expected impact on treatment processes, and

iv) consideration of previously published experience from leachate treatment methods concerning specific compounds or processes.

3.1 Identification of compounds in landfill leachates

A methodology for the characterisation of landfill leachates has previously been developed and 20 landfill leachates have been characterised (Öman et al. 2000 and Öman, in manuscript). The analytical results were divided into four groups; i) generally characteristic parameters, ii) metals and other elements, iii) metal organic compounds, and iv) organic compounds.

The generally characteristic parameters included compounds and parameters such as nitrogen, phosphorous, salts and particles. A large number of metals and other elements have also been identified such as Ca, Fe, K, Mg, Na, S, Al, As, Be, Ba, Cd, Co, Cr, Cr^{6+}, Cu, Hg, Mn, Ni, Pb, Zn, Ag, B, Bi, Br, Ga, Ge, In, La, Li, Nb, Pt, Pd, Rb, Rh, Sb, Sc, Se, Sn, Sr, Ta, Ti, Te, Tl, V, Y, Zr. Metal organic compounds previously found in leachates were organic forms of mercury, tin and lead. The results showed that a large number of organic compounds are present in leachates; these include: 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.

3.2 Grouping of compounds differently affected by treatment methods

Compounds previously identified in leachates were divided into groups that can be assumed to be differently affected by leachate treatment methods (Table 1). Possible risks of negative effects on the environment were also considered.

Table 1. Simple grouping of compounds assumed to be differently affected by leachate treatment methods, and possible risks of negative effects on the environment.

Constituent	Examples of expected impact of/on treatment methods	Example of possible impact on the environment
Nutrients	The amount of ammonia depends on pH-value. Ammonia is lost by evaporation Different nitrogen forms can be nitrificated/denitrificated to nitrogen gas.	Eutrofication Toxicity from ammonia Ammonia lost by evaporation can be transported with air and cause toxic effects elsewhere
Salts	Dilution	Toxic for fresh water organisms
Particles	Treatment by sedimentation or filtration, which generates residues.	Reduction of light in recipients Transport of pollutants
Organic matter	Can be degraded Association with pollutants	Oxygen consumption in recipient
Organic compounds	Affected by sorption, evaporation, degradation and pH/pKa	Toxic effects

Constituent	Examples of expected impact of/on treatment methods	Example of possible impact on the environment
Metals and elements	Affected by complex formation, sorption and precipitation	Toxic effects
Metal organic compounds	Affected by association to particles Little information available	Toxic effects

3.3 Characteristics of compounds with impact on treatment methods

Within each group of compounds that are affected differently by treatment, a number of processes may influence the results. For example, metals are affected by complex formation, sorption and precipitation while organic compounds are primarily affected by sorption, evaporation and degradation.

3.3.1 The characteristics of metals and other elements

The distribution of metals between solid phase and water phase is regulated by processes such as complex formation, sorption and precipitation (Jensen 1998 and Hansen 1999) (Table 2). Complex formation often increases the amounts of elements in the water phase, while sorption and precipitation often reduce the amounts in the water phase. Elements may also associate to colloids. Colloids are here defined as particles which are suspended in the water phase. Due to large surface areas, colloids have a large potential for metal association. Metals form complexes with organic and inorganic ligands. The most important inorganic ligands in leachate-polluted groundwater are carbonates (CO_3^{2-} and HCO_3^{-}) and chloride, while the most important organic ligand is dissolved organic carbon (DOC) (Hansen 1999). Conditional complex formation constants (log K_c) can be used to describe the formation of complexes between heavy metals and DOC. As the name suggests the constants depend on the conditions in which they have been determined (pH, ionic strength and the ionic composition of the solution). The solubility of the heavy metals is extremely low under conditions where sulphide precipitates are stable (Hansen, 1999). The possible re-dissolving of the sulphides therefore needs to be considered if the leachate becomes oxidised.

Table 2. Example of processes assumed to affect metals and other elements during leachate treatment.

Processes
Formation of free ions
Complex formation
Association to colloids
Sorption
Precipitation

3.3.2 Organic compounds

Emissions of organic compounds from landfills depend on the characteristics of the specific compounds (Öman, in press). It can be assumed that the fate of organic compounds in leachate treatment systems also depend on the compounds' characteristics. 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 constants, pK_a, the Henry's law constants, H, and the potential of the compounds to be biologically transformed.

Kreuger (1999) studied the environmental fate of pesticides and found that pesticides with a log K_{ow} value above 3.5 were detected more frequently in the sediment samples compared to those with a lower log K_{ow} value.

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 suggested that the ranking score system previously used inside a landfill (Table 3) could also be used for leachate treatment methods. Obviously, the scoring values may need to be adjusted in the perspective of the different treatment methods.

Table 3. Ranking of the characteristics of specific organic compounds related to their fates inside landfills (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.

3.4 External processes

It is also necessary to consider external processes which can be assumed to have an expected impact on the leachate characteristics, and which therefore may affect the treatment of landfill leachates. Obviously the change of leachate characteristics due to the degradation of waste inside the landfill may alter the treatment results. Kylefors (1997) suggests that leachates should be collected separately; due to the waste characteristics and to degradation stages. Also precipitation and chance in the flow paths through the landfill may alter the leachate characteristics (Rosqvist et al.1997 and Öman and Rosqvist 1999).

3.4.1 Transformation stages

In landfills containing organic waste, biological, chemical and physical processes take place which affect the state of the solid waste, the leachate and the gas produced (Öman 1991 and Öman 1998). Based on earlier literature results an idealised classification of these processes was made in five sequential transition stages, covering the lifetime of the landfills. The transformation of waste, leachate and landfill gas with time has 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. In the long perspective starting with the humic stage it may be assumed that oxygen intrudes into landfills (Öman 1991 and Bozkurt 2000). The levels of oxygen in the waste will change the way in which the metals are bound (Bozkurt 2000). With regard to the evolution of pH conditions, calculations made by Bozkurt indicated that higher mobilisation of metals due to lowering of pH should not be expected for many thousands of years.

3.5 Treatment methods

Kylefors (1997) assumed that leachate treatment will be necessary for hundreds of years, and therefore suggested that active treatment methods during the operative life of a landfill is then replaced by passive leachate treatment procedures. Much experience has been earned from landfill treatment methods, of which only a few results concerning specific compounds are given here. The treatment methods include biological methods, physical-chemical methods, methods requiring minor technical support, and combinations of these.

3.5.1 Biological methods

Examples of biological methods are aerated lagoons, anaerobic degradation, and sequential batch reactors (SBR). For biological methods it is necessary to ensure sources for carbon and nutrients and to avoid inhibition. Ahnert and Ehrig (1992) pointed out the risk that microbial processes might be disturbed by persistent pollutants present in the leachates. Anaerobic degradation may be performed as acidogenoic or methanogenic, and previous results have shown that methanogenic degradation has higher efficiency in reducing the amounts of BOD, COD, TOC, nitrogen, phosphorous, iron, manganese, arsenic, cobalt, and zinc (Kylefors and Lagerkvist 1997). Ecke (1997) suggested a methanogenic fermantative step following an acid fermentative step for the treatment of metal-containing leachates.

3.5.2 Physical-chemical methods

Examples of physical-chemical methods are ozonisation, precipitation, filtration, reverse osmosis, and evaporation. Robinson et al. (1997) suggest that ozonisation may be justified in some circumstances, to assist in the degradation of resistant organic compounds such as some pesticides.

3.5.3 Methods requiring minor technical support

Examples of methods requiring minor technical support are irrigation of constructed or natural vegetation areas and filtration through natural filters. For practical evaluation of these systems a collection system is needed for the treated water.

4. Results

The following four-step methodology was suggested for the evaluation of leachate treatment methods:

1. Identification of specific compounds in the leachate prior to treatment. The sampling, treatment and analysis may be performed according to the method previously developed (Öman et al. 2000).
2. From the compounds present in the leachate, a suitable number of compounds are selected. The selections are made from three defined criteria:

- Include groups of compounds which are assumed to be affected differently by treatment methods, as shown in Table 1.
- Include organic compounds, metals and elements representing different characteristics, as shown in Tables 2 and 3.
- Consider external processes with an expected impact on the treatment processes, as described above.

3. The chosen compounds are analysed before and after each treatment step.

4. The results are then evaluated according to the above criteria.

5. Further research

The method presented here is an initiative intended to inspire further research and it obviously needs to be considered more thoroughly both in theory and in practice.

Further research is also needed concerning metal-organic compounds on aspects such as sampling and analytical methods and concerning the environmental impacts.

6. Conclusions

It was concluded from this study that a new methodology for evaluation of the efficiency of landfill leachate treatment methods could be suggested. It was also concluded that the methodology needs to be evaluated in actual practice.

7. References

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