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# The future of landfills

Leaching and degradation tests on waste from Fläskebo  
landfill

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## **Abstract**

New legislation concerning the landfilling of waste has been issued from the European Union. The consequence of the new legislation is that the composition of the waste being landfilled will change drastically and so will the chemical and physical conditions in the landfill. The question is how this will affect the emissions from landfills. Since very low amounts of biodegradable waste are allowed to be landfilled the legislation assumes that the methane emissions, which are a great problem in old landfills, will decrease to a negligible quantity. The legislation also demands that landfills shall be kept as dry as possible to minimize the formation of leachate. If a low amount of metals are leached out compared to what remains in the landfill this is a good way to reduce the effects on the environment from landfills. But concerns has been raised that the new conditions in the landfills will result in an increase in metals being leached out and thus perhaps it would be a better approach to flush them out during the monitoring phase.

Percolations tests according to the standard prCEN/TS 14405 are performed on waste from Fläskebo landfill which only has received waste consistent with the new legislation and the percentage leached are calculated. The test simulates the leaching during a time period of 1000 years. For most metals a very small percentage is leached out and thus it is a good idea to keep the landfills as dry as possible.

To investigate the possible methane formation in a landfill deposit with waste according to the new legislation the wish was to perform a mass balance of carbon. The analyses of the total organic carbon, TOC, in solid samples from before and after the percolation test showed no significant difference so a mass balance was not possible to perform.

Degradation test on the waste from before and after the percolation test was performed. They showed a significantly lower degradation on the waste after the percolation test indicating a higher TOC content or a higher microbial activity in the waste from before the percolation test.

The degradation tests also showed that degradation is possible for waste with low TOC content and thus further investigations about the methane formation is needed.

## Sammanfattning

EU har utfärdat ny lagstiftning angående deponering av avfall. Konsekvenserna av denna nya lagstiftning är att sammansättningen på avfallet som deponeras kommer att ändras drastiskt och det kommer även de kemiska och fysiska förhållandena i deponin. Fråga är hur detta kommer att påverka utsläppen från deponin. Eftersom väldigt låga halter nedbrytbart avfall tillåts deponeras antar lagstiftningen att metanutsläppen, som är ett stort problem i gamla deponier, kommer att minska till en försumbar nivå. Lagstiftningen kräver också att deponin ska hållas så torr som möjligt för att minimera mängden lakvatten. Om en liten halt metaller lakas ut i förhållande till vad som stannar i deponin så är detta ett bra sätt att minska miljöpåverkan från deponier. Men oro över att de nya förhållandena i deponin kanske kommer att leda till ökad utlakning av metaller har tagits upp och det hade kanske varit bättre att spola ut metallerna under övervakningsfasen.

Perkolationsstest enligt standarden prCEN/TS 14405 utfördes på avfall från Fläskodeponin, som bara har tagit emot avfall enligt den nya lagstiftningen, och urlakningsprocenten beräknades. Testet simulerar utlakning under en period på 1000 år. För det flesta metaller lakas bara en liten procent ut och därmed kan det konstateras att det är en bra idé att hålla deponin så torr som möjligt.

För att undersöka den möjliga metanproduktionen i deponier som följer den nya lagstiftningen planerades det att göra en massabalans på kol. Analyserna av totalhalten kol, TOC, i de fasta proverna från före och efter perkolationsstestet visade ingen signifikant skillnad så det var inte möjligt att utföra en massabalans.

Nedbrytningsförsök på avfallet från före och efter perkolationsstestet utfördes. De visade en signifikant lägre nedbrytning av avfallet från efter perkolationsstestet vilket indikerar en högre TOC-halt eller högre mikrobiell aktivitet i avfallet före perkolationsstestet.

Nedbrytningsförsöken visade också att nedbrytning är möjlig för avfall med låga TOC-halter och därför behövs ytterligare undersökningar angående metanutsläppen från nya deponier.

## **Preface**

This master thesis was done at the division of Water Resources Engineering at the Faculty of Engineering at Lund University.

My thanks go to my supervisor Hanna Modin for all her time and support and to the division of Applied Microbiology for the use of their laboratory facilities.

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# Table of contents

<i>1. Background</i>	<i>1</i>
1.1 Legislation	1
1.1.1 EU-directive on the landfill of waste	1
1.1.2 The Swedish implementation	1
1.2.3 Consequences	2
1.2 Landfills	2
1.2.1 Gas emissions	2
1.2.2 Metals in leachate	3
<i>2. Aim</i>	<i>3</i>
<i>3. Material</i>	<i>3</i>
<i>4. Method</i>	<i>4</i>
4.1 Percolation test	4
4.1.1 Percolation test of cover and filling material	5
4.1.2 Percolation test of waste	6
4.1.3 Measurements and analyses	6
4.2 Degradation test	7
<i>5. Result and discussion</i>	<i>8</i>
5.1 Percolation test of cover and filling material	8
5.2 Percolation test of waste	11
5.2.1 TOC in solid samples	12
5.2.2 Metals in solid samples	12
5.2.3 Leachate	14
5.3 Degradation test	17
<i>6. Conclusions</i>	<i>18</i>
<i>References</i>	<i>19</i>
<i>Appendix 1 - calculations</i>	<i>20</i>
Percolation test of cover and filling material	20
Percolation test of waste	22
Converting L/S fractions into a timescale for Fläskebo landfill	25
Degradation test	26
<i>Appendix 2 - concentrations in leachate</i>	<i>27</i>
Metals	27
Non-metals	29

# 1. Background

Human activity results in the creation of large amounts of waste. For example, in 2006 124 million tons of waste was generated in Sweden (Naturvårdsverket 2008). It is desirable that the impact of this large amount of wastes to the environment and to human health is minimized. To achieve this, the waste should be treated according to the EU's waste hierarchy. This hierarchy states that the first priority is to prevent the formation of waste followed by reuse, recycling and disposal of waste to landfills as a last resort. Despite this hierarchy landfilling of waste still are and will continue to be a necessary method in the disposal of waste which for some reason is not suitable for any other treatment. (Naturvårdsverket 2005)

## 1.1 Legislation

Legislation concerning waste and landfilling originate from decisions in the European Union. All member states must implement the EU-legislation in their own legislation and create detailed rules so that the aims in the EU-legislation are fulfilled.

### 1.1.1 EU-directive on the landfill of waste

In 1999 the EU-council adopted a directive on the landfill of waste (1999/31/EG) to ensure that landfilling in the future would be conducted under safe and controlled conditions throughout the union. An EU-directive is not directly binding to the member states but they have to implement the directive in their national legislation so that the goals and spirit of the directive is fulfilled. The overall objective with the directive is *"...to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from landfilling of waste, during the whole life-cycle of the landfill"* (article 1 1999/31/EG).

One main reason for the directive is to reduce the formation of methane in landfills and this is done by decreasing the amount of biodegradable waste deposited in landfills. Article 5 declares limits on how much percentage of the municipal biodegradable waste that are allowed to be landfilled five, eight and fifteen years after the directive come into force compared with amounts deposited in 1995. Also to minimize the methane emissions all landfills that receive biodegradable waste have to collect the landfill gas and the gas needs to be combusted or used.

The directive demands that landfills are designed to minimize its effects on the surrounding environment and on human health. To achieve these specific rules on how to design the landfill is stated in annex I. The aim is to decrease the amount of leachate formed, control it and if necessary treat it before releasing it to the environment. Landfills should also be classified as either landfill for hazardous waste, for non-hazardous waste or for inert waste. When designing the landfill the composition of the waste deposited and the sensitivity of the recipient need to be considered.

### 1.1.2 The Swedish implementation

In Sweden the EU-directive (1999/31/EG) was implemented in 2001 with the adopting of the Ordinance in the Landfilling of Waste (SFS 2001:512). The implementation follows the writings in the directive with regards to aims and demands on the design of landfills.

To fulfil the limits on biodegradable waste, prohibition to landfill organic and combustible waste is established (9 and 10 §§ SFS 2001:512). The Swedish Environmental Protection Agency may decide upon exceptions to these prohibitions and have done so (NFS 2004:4).

These exceptions allows for the landfilling of waste with a TOC content of less than 10 % (12 § NFS 2004:4). The county administrative board may also give exemption in specific cases if the capacity to treat the organic or combustible waste is insufficient (16 § NFS 2004:4). Since the regulations is quite strict a large number of these specific case exceptions were issued when the new legislation came into force but between 2002 and 2007 the amount of waste in these exceptions has decreased with 70 % (Naturvårdsverket 2008).

To diminish leachate formation limits are drawn for the amount of water allowed to penetrate the landfill after it is closed (22 § SFS 2001:512). These are 5 mm/year for landfills for hazardous waste and 50 mm/year for landfills for non-hazardous waste.

### **1.2.3 Consequences**

To conclude, the new legislation aims at decreasing the amount of waste being deposited at landfills and the negative effects landfills have on the environment and human health. In Sweden, the composition of waste being landfilled has changed drastically and so will the physical and chemical conditions in the landfills. Earlier the conditions in the landfills have been very much dependent on the organic matter. Landfills with large amount of organic matter undergo different phases of degradation and the leachate and gas emissions are strongly associated with the physical and chemical conditions of the phase (Kjeldsen 2002). So when these conditions changes due to the new legislation so will the emissions from the landfills. In some aspects that is exactly what the legislation wants, that is to reduce the methane emissions. But when it comes to other emissions, like the leachate, there is an uncertainty on how this new legislation will effect the composition of the leachate and therefore also the risk it may pose to the environment and human health.

## **1.2 Landfills**

The quantity of waste deposited at landfills has decreased but still in 2006 378 000 ton hazardous waste and 66 millions ton non-hazardous wastes were landfilled in Sweden (Naturvårdsverket 2008).

Landfills pose two main problems to the environment. The first one is gas emissions, mostly of methane, due to degradation of organic matter. The second problem is that pollutants are spread to the surroundings with the leachate. (Naturvårdsverket 2009).

Landfills with large amount of organic matter have low concentrations of metals in the leachate due to the sorptive capacity of the landfill (Kjeldsen 2002, Øygaard 2004, Erses 2005). Concerns has been risen that the new conditions in the landfill due to low content of organic matter will result in metals leaching out to a greater extend and therefore causing a larger environmental problem (RVF 2005).

### **1.2.1 Gas emissions**

The emissions of methane from landfills containing organic matter were one of the reasons behind the new EU-legislation (1999/31/EG). The new legislation has limits on how much organic matter waste can contain for the waste to be deposited at landfills. It is however impossible to make the waste absolutely free from organic matter and thus the question is if perhaps even this small quantities of organic matter pose a problem with methane formation. This is interesting to investigate since it has just been assumed not to pose a problem. Old landfills in Sweden with high levels of organic matter have systems to collect the methane gas and either use it or combust it. The collective systems of course have leaks and not all of the methane gas can be collected but still the question remains whether the new landfills might release a larger quantity of methane than is being leaked out from the old ones. If it does the aim with the new legislation to decrease the methane emissions from landfills is not fulfilled.



### **1.2.2 Metals in leachate**

The other main problem with landfills, the spreading of pollutants with the leachate has been addressed in the legislation by setting up limits on how much water is allowed to percolate into the landfill. This approach aims towards minimizing the amount of leachate that forms and thus wanting to keep the pollutants inside the landfill. The question is if the pollutants will stay in the landfill even after the monitoring phase is ended. If they do then it is a great idea to keep the landfill as dry as possible. But if the pollutants do not stay in the landfill for a very long time it might be better to flush them out during the monitoring phase even though a new problem, where to deposit the pollutants which has been flushed out, arise.

## **2. Aim**

The aim with this thesis is to investigate the possible changes in emissions from landfills due to the new legislation. It focuses on whether or not it is a correct assumption in the legislation that emissions of methane will be low enough that there are no need to collect the gas and combust or use it. The next big focus is whether or not the demand in the legislation to keep the landfill as dry as possible is the preferable way to minimize the effect of metals leaching from landfills. A third aim is to investigate the contribution of pollutants from a material currently used as filling material and material that might be used as cover material in the future.

Percolation and degradation tests will be performed to investigate the aims stated above. The percolation test gives information about the leaching of different elements and compounds over time. From this together with analyses of TOC content in the solid material a mass balance of carbon might be conducted and the gas emission estimated. The percentage of metals leached can be calculated and if most of the metals stays in the landfills even after an extensive period of time it suggest that it is a good idea to keep the landfill as dry as possible. The degradation test gives an estimation of how degradable the waste is and that indicates the potential of gas formation in the landfills.

## **3. Material**

The cover material used was sent from Lessebo paper mill and it constitutes of fibre ash and sludge. These two materials are suggested to give the cover material the capacity to withstand water penetration so that the limit on leachate formation in the legislation is fulfilled. It is not yet in use but tests are being performed to establish its strengths to see if it can be used as a cover material when closing landfills. (Modin 2009)

The filling material, constituted of weathered bottom ash, was gathered at Sysav incineration plant in Malmö. To obtain a representative sample three random samples were taken from the pile with a volume of approximate 150 m<sup>2</sup> bottom ash and mixed in a separate pile. The pile was divided into four parts and two of these were taken away and the remaining parts were mixed. This procedure was repeated once and then samples were taken from two of the fourths created in the lasting pile. All the removing and mixing were done by an excavator.

The waste used in the study comes from Fläskebo landfill which, from the start 2003, only has received waste according to the new legislation and thus the waste contains less than 10 % organic matter. The landfill is classified as a landfill for non-hazardous waste and the main part deposited constitute of construction and demolition waste. (Avfall Sverige 2009)

## 4. Method

To explore the leaching performance of the cover and filling materials and the waste from Fläskebo and their impact to the environment and to human health two tests were conducted; percolation test and degradation test.

### 4.1 Percolation test

The leachate test used was a percolation test with a continuous vertical up-flow according to the standard prCEN/TS 14405 (CEN 2003). Two different cases were simulated. The first one simulates a leak in the cover material when the landfill has been closed. To achieve this, a percolation test with cover and filling material was performed and the leachate from this test was used as inflow in the following percolation test of waste (figure 1). In the second case the wish is to investigate the effects from the waste itself and therefore deionised water was used as inflow in the percolation test of waste (figure 2). Also a control test with only deionised water in the column was performed so that the influence from the column and from tubes could be taken into consideration.

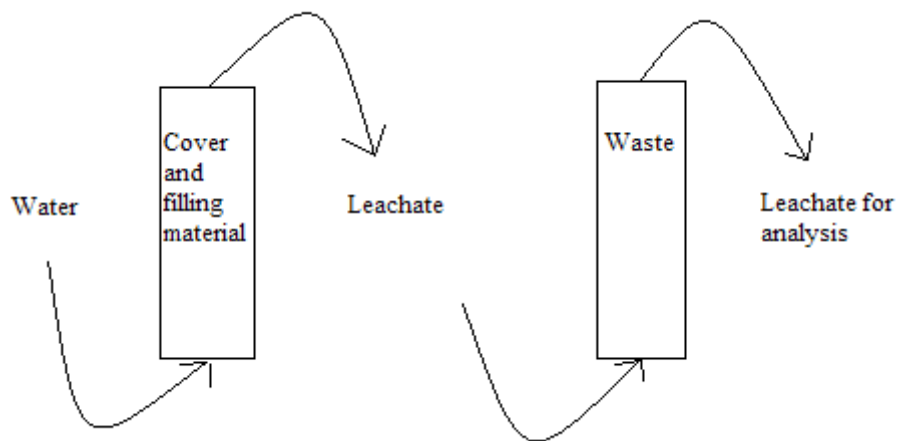


Figure 1: Simulation of a leak in the cover material when the landfill has been closed. Leachate from cover and filling material are used as inflow in the percolation test of waste.

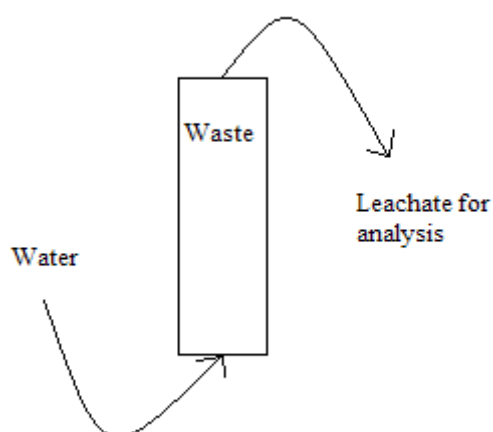


Figure 2: Investigation of the effect from the waste itself. Deionised water is used as inflow in the percolation test of waste.

The test performed deviated from the standard in the following ways: columns of height 0.5 m were used instead of recommended 0.3 m and the width was 110 mm instead of 50 or 100 mm. Also the packing weight was 600 g instead of 125 or 500 g.

The columns and tubes used were made of PVC and connections between tubes of HDPE. The columns were sealed with silicon of the brand Zwaluw Den Braven and the inside of the lids were covered with 90 µm HDPE filter to spread the inflow even and prevent larger particles from escaping at the outlet. The collection bottles for L/S 0.1, 0.2, 0.5 and 1 were conical glass flasks and for L/S 2 and 10 collection bottles were manufactured of PP-plastic. The column systems and collection bottles were blown with nitrogen gas before starting the test to create an inert atmosphere and the collection bottles were also blown with nitrogen gas after each opening. The pump used was a Masterflex L/S™ model 7519-15 from Buch & Holm A/S and the tubing used was Masterflex 2406424-14.

#### 4.1.1 Percolation test of cover and filling material

The cover material was mixed to be constituted of 2/3 sludge and 1/3 fibre ash. The column was filled with equal amounts of bottom ash and the mix of sludge and fibre ash with the latter in the bottom of the column and the former in the top. According to the standard the column should be filled in five consecutive layers and each of this is introduced in three sub-layers. Since two different materials were used in this test each material was filled in three consecutive layers with two sub-layers. All necessary calculations described in the standard were performed and are presented in the appendix 1. The results of the calculations are shown in table 1. The L/S is the ratio between the amount of liquid and solid in the test. According to the standard a flow of approximately 1 ml/min should be obtain during the test. In this percolation test the aim is to gather enough leachate to be used in the percolation test of waste. Since there are a limited time for the experiment the flow rate used is decided to be 3 ml/min.

Table 1. Calculations of volume and time for percolations test of cover and filling material

Acc L/S [l/kg]	L/S fraction [l/kg]	Volume of sample [l]	Time [days]
0.1	0.1	0.35	0.08
0.2	0.1	0.35	0.08
0.5	0.3	1.05	0.24
1	0.5	1.75	0.41
2	1	3.50	0.81
5	3	10.51	2.43
10	5	17.52	4.06

Each day pH, conductivity, redox potential and temperature were measured and for each L/S a small sample was saved in the freezer. The remaining volume of the L/S was mixed together in a large can kept free of oxygen by blowing it with nitrogen after each opening. For L/S 0.1 and 0.2 there was nothing left to be mixed in the can.

After finishing the percolation test the water was drained from the column for 24 hours. After that each material was poured into a basin, mixed well and two representative samples for each material were gathered and stored in the freezer. The representative samples were created by dividing the well mixed pile of material into four parts and removing two fourths according to figure 3. This procedure was repeated twice for each sample.



Figure 3. Representative samples.

### 4.1.2 Percolation test of waste

The waste was frozen after collection and was thawed in room temperature for approximately 16 hours before filling the columns. Three columns were filled with waste and one with deionised water. One of the columns with waste had leachate from cover and filling material as inflow and the two others had deionised water (figure 4). All necessary calculations described in the standard were performed and are presented in the appendix 1. The results of the calculations are shown in table 2. The difference in volume between the columns depends on a small difference in the amount of waste filled in each column. In this percolation test the flow used follows the standard and thus a flow of 1 ml/min is aimed for.



Figure 4. Percolation test 2 with columns numbered one, two, three and four from the left.

Table 2. Calculation of volume and time for the four columns in percolation test of waste.

Acc L/S [l/kg]	L/S fraction [l/kg]	Column 1		Column 2		Column 3		Column 4	
		Volume of sample [l]	Time [days]	Volume of sample [l]	Time [days]	Volume of sample [l]	Time [days]	Volume of sample [l]	Time [days]
0.1	0.1	0.22	0.15	0.22	0.15	0.24	0.17	0.23	0.17
0.2	0.1	0.22	0.15	0.22	0.15	0.24	0.17	0.23	0.17
0.5	0.3	0.66	0.46	0.65	0.45	0.71	0.50	0.68	0.51
1	0.5	1.10	0.76	1.09	0.76	1.19	0.83	1.13	0.85
2	1	2.20	1.52	2.18	1.51	2.38	1.65	2.25	1.70
5	3	6.59	4.57	6.53	4.54	7.14	4.96	6.75	5.10
10	5	10.98	7.62	10.88	7.56	11.90	8.26	11.25	8.49

Each day pH, conductivity, redox potential and temperature were measured and for each L/S two samples were saved, one in the freezer and one in the refrigerator.

After finishing the percolation test the water was drained from the columns for 48 hours. After that the waste was poured into a basin, mixed well and three representative samples for each column were gathered. Two of the samples were stored in the freezer and one used directly to determine the dry content and preparing solid samples for analyses.

### 4.1.3 Measurements and analyses

Temperature, ph and conductivity were measured with Buch & Holm WTW Multi 350i and redox potential was measured with Buch & Holm WTW Multi 340i. The flow and L/S

fractions were monitored by weighing the eluates in their collection bottles. Eluates with a mass less than 6 kg were weighed with a Precisa 3100D-scale with an accuracy of  $\pm 0.01$  g and heavier eluates with a FLINTAB KERN DE60K20-scale with an accuracy of  $\pm 20$  g. The statistical analyses performed constitute of a two-sample t-test with equal variance.

Solid samples were prepared for analyses by thawing them in room temperature for approximately 16 hours if they had been frozen, drying them at 105°C for 24 hours and stored in plastic bags. The analyses on the solid waste were done for two replicates derived from the same sample from the column. Analyses for organic matter were performed at Belab AB using the standard SS-EN 13137 and the analyses for metals were performed at the laboratory at the Section of Plant Ecology and Systematics at the Department of Ecology at Lund University. The samples were dissolved in a microwave oven and analysed according to table 3.

For the percolation test of waste and the control only three L/S fraction could be analysed for each column and L/S 0.1, 2 and 10 was chosen for this. When preparing the samples for analyses a flow representative sample was mixed for L/S 2 and 10 and all samples were filtered with 0.45  $\mu\text{m}$  filters into 60 ml test tubes. The two inflow liquids, deionised water and leachate from cover and filling material, were also prepared for analyses. The tubes were stored in the refrigerator before sending them to the laboratory. Water analyses were performed at the laboratory at the Section of Plant Ecology and Systematics at the Department of Ecology at Lund University and analysed according to table 3.

*Table 3. Analyses methods for different elements and compounds.*

<b>Analyses</b>	<b>Method</b>
Ag, Al, As, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Si, V, Zn	ICP MS, Elan 6000 (PerkinElmer)
Ag, Al, As, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Si, V, Zn	ICP AES, OPTIMA 3000 DV (PerkinElmer)
F, Cl, NO <sub>3</sub> -N, PO <sub>4</sub> -P, SO <sub>4</sub> -S	Ion Chromatography, 861 Advanced Compact IC, column Metrosep A Supp 5 (Metrohm, Herisau Switzerland)
NH <sub>4</sub> -N	FIA, FIA-star 5000 Analyzer (FOSS Tecator, Höganäs Sweden)
TOC	TOC-VCPH (Shimadzu, Tokyo Japan)
IC	TOC-VCPH (Shimadzu, Tokyo Japan)
TN	TOC-VCPH with N-module TNM-1 (Shimadzu, Tokyo Japan)

## **4.2 Degradation test**

Degradation tests based on the standard AT<sub>4</sub> presented in German legislation was performed on the waste from after the percolation test to estimate how the stability of the material has changed from before the percolation test. Degradation test on the untreated waste had previously been performed by Hanna Modin. When ending the percolation test of the waste two representative samples from each column were collected and stored in the freezer. The waste was then thawed in room temperature approximately 16 hours before starting the degradation test. To obtain useful results for the waste from column three, three tests needed to be performed and therefore the waste was thawed twice for the result for this column. Each test was performed in two replicates which mean that two bottles were used for material from each column but the material for both bottles came from the same sample from the column.

The test measures the decrease in pressure due to degradation of organic matter. When degraded it consumes oxygen and carbon dioxide is formed. The bottles are sealed and the carbon dioxide is absorbed by the soda lime in the bottle head case. The negative pressure thus formed is measured relative to an internal standard pressure. The decrease in pressure can be calculated into consumption of oxygen per mass dry weight of waste.

## 5. Result and discussion

### 5.1 Percolation test of cover and filling material

During the test the extension tube was torn by the force from the pump three times and each time air entered the tube system and the column. The flow was also affected which resulted in a variation between 0.1 and 4.0 ml/min. After the third torn tube another pump was calibrated and for some reason less pressure on the tube and also less velocity was needed to receive the required flow and after the change the flow was stabilized around 3.2 ml/min and no more tubes were torn. The duration of the test was a little less than 10 days.

The measurements performed during the percolation test of cover and filling material are presented in figure 5.

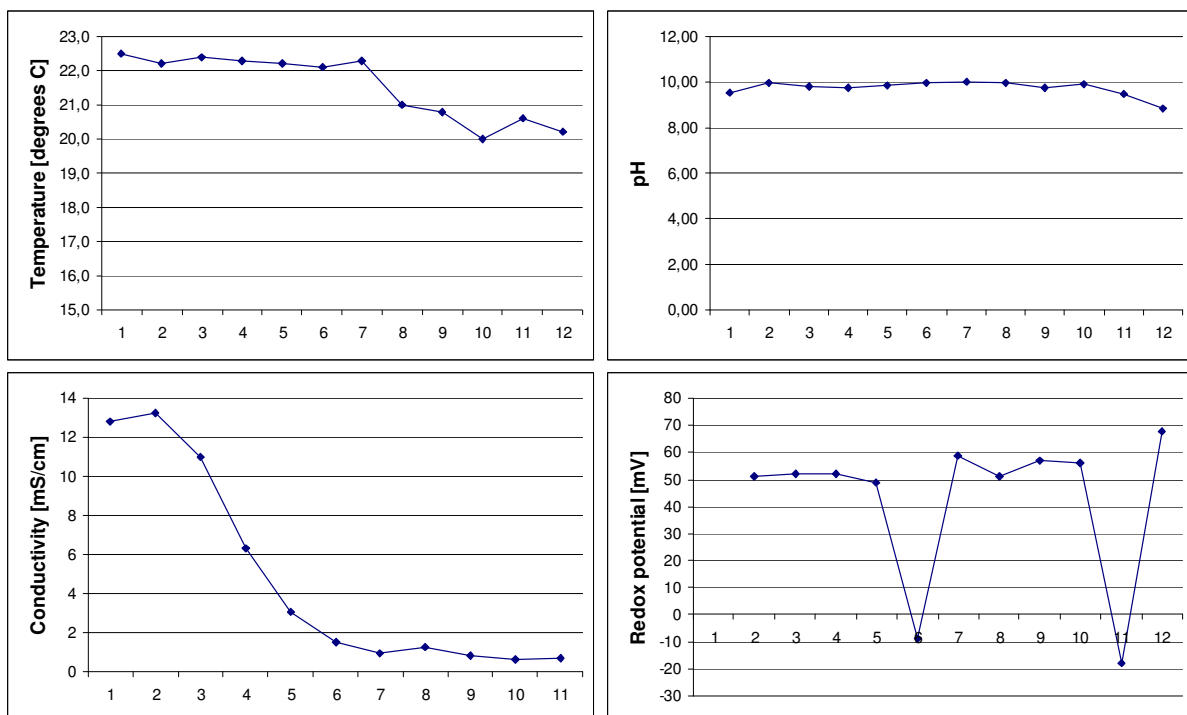


Figure 5. Measurements during the percolation test of cover and filling material. The x-axes show measurement occasions.

The temperature varies between 22.5 and 20.0°C. The pH-value of the leachate is fairly constant throughout the experiment and L/S 0.1 deviate less than 0.5 from the first small sample and thus the equilibrium condition is fulfilled. The conductivity falls quite drastically halfway through the experiment indicating that the total of dissolved ions in the leachate decreases. Redox potential measures the availability of electrons and are used to determine if a chemical or biological system is aerobic and oxidizing or anaerobic and reducing. The high values measured during the experiment suggest that oxidizing conditions are obtained and thus that an inert atmosphere was not achieved. Measurements of redox potential can be

quite unreliable due to the need for redox reaction to reach equilibrium. Most of the common redox reactions have slow kinetics and thus do not reach equilibrium (Sigg s.a).

Water analyses were performed on the mixture of all L/S fractions larger than 0.5 used as inflow in the percolation test of waste and they are presented in table 4. These results are discussed later in connection with the results from the percolation test of waste.

*Table 4. Concentrations of elements and compounds in the leachate for L/S 0.5 to L/S 10 from cover and filling material.*

<b>Species</b>	<b>Concentrations [mg/l]</b>	<b>Species</b>	<b>Concentrations [mg/l]</b>
<b>F</b>	0.108	<b>Mg</b>	2.55
<b>Cl</b>	68.9	<b>Mn</b>	0.0349
<b>NO<sub>2</sub>-N</b>	0.000	<b>Mo</b>	0.0534
<b>Br</b>	1.22	<b>Na</b>	133
<b>NO<sub>3</sub>-N</b>	0.0290	<b>Ni</b>	0.00429
<b>PO<sub>4</sub>-P</b>	0.0240	<b>P</b>	0.0132
<b>SO<sub>4</sub>-S</b>	141	<b>Pb</b>	0.000215
		<b>S</b>	131
<b>Ag</b>	0.0000420	<b>Sb</b>	0.0316
<b>Al</b>	0.387	<b>Si</b>	0.592
<b>As</b>	0.00570	<b>Ti</b>	0.000459
<b>Ca</b>	170	<b>V</b>	0.00545
<b>Cd</b>	0.000172	<b>Zn</b>	0.247
<b>Co</b>	0.000136		
<b>Cr</b>	0.00403	<b>NH<sub>4</sub>-N</b>	1.55
<b>Cu</b>	0.127		
<b>Fe</b>	0.00130	<b>TOC</b>	84.5
<b>Hg</b>	0.000358	<b>IC</b>	23.4
<b>K</b>	48.2	<b>TN</b>	4.71

Analyses of TOC and metal content in the solid material were carried out on the two materials both from before and after the percolation test and the result are presented in table 5 and 6.

*Table 5. TOC in cover and filling material before and after percolation test*

	<b>Before test</b>	<b>After test</b>
<b>Bottom ash</b>	1.1 % ts	1.1 % ts
<b>Fibre ash + sludge</b>	26.6 % ts	29.4 % ts

The cover material, fibre ash and sludge, have a high amount of TOC and perhaps it will affect the leaching of metals from the landfill. The legislation limits the TOC content in the waste to be landfilled but perhaps if large amount of TOC are allowed in the cover material it might leak into the landfill and the TOC content in the landfill will increase.

Table 6. Metals, P and S in cover and filling material before and after percolation test [mg/g].

Species	Fibre ash + sludge		Bottom ash	
	Before test	After test	Before test	After test
<b>Ag</b>	0.000222	0.000278	0.00242	0.00390
<b>Al</b>	17.5	12.1	43.8	39.7
<b>As</b>	0.000697	0.000796	0.0204	0.0198
<b>Ca</b>	117	142	106	93.7
<b>Cd</b>	0.00126	0.00139	0.00384	0.00310
<b>Co</b>	0.00254	0.00351	0.0173	0.0188
<b>Cr</b>	0.0133	0.0120	0.330	0.228
<b>Cu</b>	0.0491	0.0794	4.60	7.48
<b>Fe</b>	5.47	5.70	61.1	64.0
<b>Hg</b>	0.0000586	0.0000660	0.0000692	0.0000897
<b>K</b>	13.2	19.2	5.39	3.86
<b>Mg</b>	8.58	11.4	8.28	8.04
<b>Mn</b>	3.70	6.26	1.15	0.793
<b>Mo</b>	0.00171	0.00151	0.00869	0.00769
<b>Na</b>	1.64	2.32	9.58	5.70
<b>Ni</b>	0.00851	0.0104	0.165	0.293
<b>P</b>	3.67	6.20	3.38	3.02
<b>Pb</b>	0.0155	0.0188	0.732	1.12
<b>S</b>	6.36	4.49	6.82	4.18
<b>Sb</b>	0.000141	0.000196	0.00228	0.00507
<b>Si</b>	0.240	0.282	0.721	3.75
<b>V</b>	0.00858	0.00805	0.0417	0.0428
<b>Zn</b>	0.150	0.185	4.09	3.77

The fact that there for many metals are higher concentrations after the percolation test than before is a measure of the uncertainties in the analyses and perhaps the heterogeneity of the materials. For example there are higher concentrations of Ca, K, Mg, Mn and Na in fibre ash + sludge after the test than before and in the bottom ash there are higher concentrations of Cu and Fe after the test than before.

The amount left in the solid material after the percolation test was compared to the amount that had leached out by calculating the percentage leached (table 7). The percentage was calculated by dividing the total amount leached with the total amount in the solid materials in the column before the test. For most species only a small percentage is leached out during the test with the exceptions of Na, S and Sb.



Table 7. The percentage leached out from cover and filling material.

Species	Percent	Species	Percent	Species	Percent
Ag	0.02	Fe	0.00003	P	0.004
Al	0.01	Hg	5	Pb	0.0004
As	0.3	K	7	S	20
Ca	2	Mg	0.3	Sb	20
Cd	0.05	Mn	0.02	Si	0.9
Co	0.009	Mo	7	V	0.2
Cr	0.01	Na	20	Zn	0.07
Cu	0.03	Ni	0.03		

According to this the fact that the cover and filling material contains metals does not mean that they will contribute to the leaching of metals from landfills. With exceptions of Na, S and Sb the species stays in the solid material and only a small amount is leached out. However small amounts are leaching out and this can be a problem if the substance is very toxic. Since the question of the effects from the cover and filling material was not the main objective with this thesis it will not be discussed any further.

## 5.2 Percolation test of waste

A flow of 1 ml/min was not possible to maintain during the course of the experiment. Table 8 show the mean flow, the variation in flow and the experiments duration time for each column. The mean flow was calculated by dividing the total volume of eluat from the column with the duration time.

Table 8. The flow during the experiment and the duration of the test.

Column	Mean flow [ml/min]	Flow variation [ml/min]	Duration of test [days]
1	1.53	0.8-1.8	10
2	1.51	0.4-2.6	10
3	1.52	0.8-2.3	11
4	1.57	0.4-2.1	10

The measurements performed during the percolation test of waste and control are presented in figure 6. The temperature was kept equally constant in all columns, varying between 20.5 and 23.0°C. The deviation in pH between first sample and L/S 0.1 is less than 0.5 for all columns which indicates that the equilibrium condition is fulfilled. The conductivity measurements indicate that the amount of total dissolved ions is highest in the leachate from column one which has leachate from cover and filling material as inflow and should be expected to receive an addition of ions from that. The difference is consistent with the higher conductivity in inflow from cover and filling material compared to the conductivity in deionised water that constituted the inflow to column two and three. The conductivity in column two and three are basically the same throughout the experiment which is reasonable since they contain the same material and the leachate should hopefully give similar results. The conductivity decreases in all three columns during the course of the experiment but not as much as in the percolation test of cover and filling material. The negative redox potential indicates that an inert atmosphere is achieved for columns one, two and three at least in the beginning if the experiment but it should be reminded that measurements of redox potential are quite unreliable.

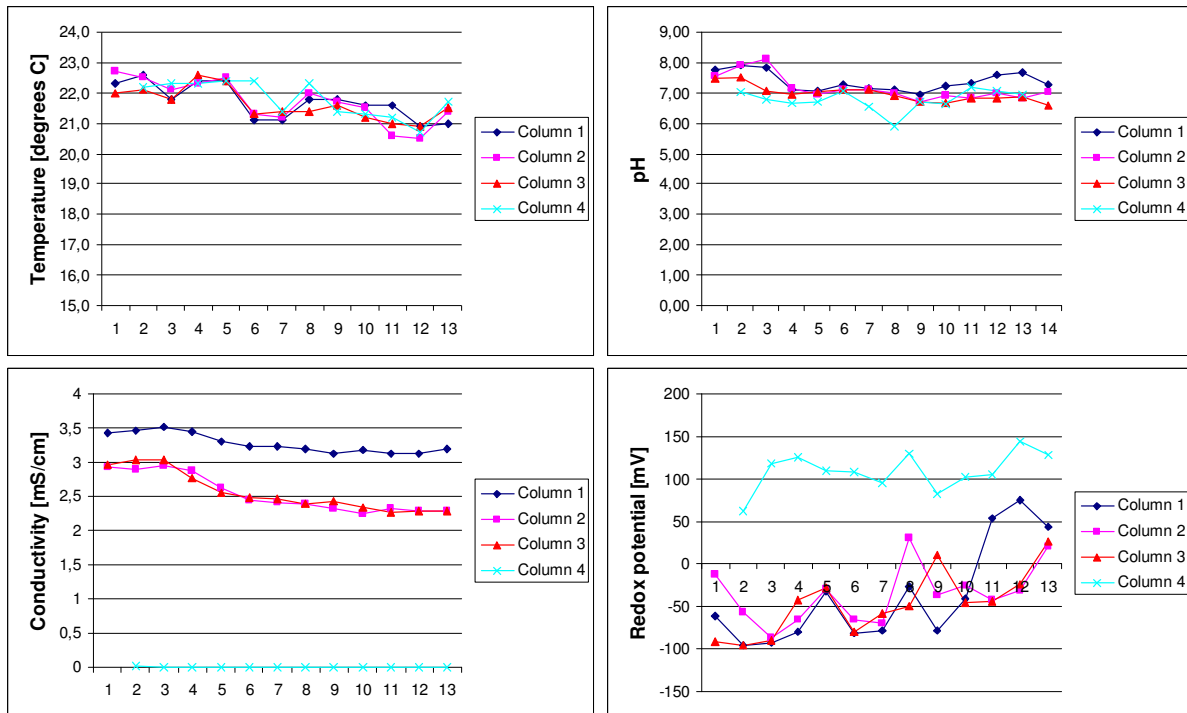


Figure 6. Measurements during percolation test of waste. The x-axes show measurement occasions.

### 5.2.1 TOC in solid samples

There is a small tendency for less TOC in the waste from column two and three compared to column one and compared to before percolation test but it is far from significant (table 9). Therefore a mass balance to estimate the methane gas formation is not possible to carry out but the fact that there are very small differences and that they are not significant indicates that the methane formation probably is of no significant amount. The assumption in the legislation that the methane gas formation is very low can therefore not be refuted.

Despite the large amount of TOC in the cover material it does not seem to contribute to the TOC content in the waste and thus it might not be necessary to decide on limits for the amount of TOC allowed in the cover material.

Table 9. TOC content in solid waste samples from before and after percolation test.

Sample	Mean [% ts]	Standard deviation
Before test	3.55	0.35
After Test		
Column 1	3.55	0.49
Column 2	3.40	0.28
Column 3	3.10	0.42

### 5.2.2 Metals in solid samples

The mean value and standard deviation from the result of metal analyses in solid waste are shown in table 10. The standard deviation is often small compared to the mean which suggests a reliable result. Mean and standard deviation was also calculated from the four replicates from column 2 and 3 together (table 11). Between these replicates the deviation is larger than within the same column but the standard deviation is still small compared to the mean.

Table 10. Metals, P and S in solid waste samples before and after percolation test.

Species	Before test [mg/g]		After test [mg/g]					
			Column 1		Column 2		Column 3	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Ag	0.00050	0.000025	0.0011	0.00063	0.0012	0.00037	0.00079	0.00044
Al	14	0.45	12	0.66	12	1.8	12	0.20
As	0.0070	0.0032	0.0044	0.00090	0.0042	0.00041	0.012	0.011
Ca	160	17	110	3.6	110	5.3	120	2.9
Cd	0.0010	0.00022	0.00090	0.00041	0.0059	0.0055	0.00062	0.000016
Co	0.0092	0.0034	0.0085	0.0011	0.010	0.0043	0.0084	0.0022
Cr	0.091	0.0038	0.11	0.062	0.068	0.011	0.073	0.013
Cu	0.083	0.012	0.095	0.038	0.095	0.014	0.11	0.075
Fe	23	5.5	28	2.9	22	8.1	25	0.24
Hg	0.00023	0.000014	0.00019	0.0000047	0.00028	0.000067	0.00014	0.0000028
K	2.2	0.18	3.0	1.1	1.8	0.30	1.7	0.22
Mg	9.3	0.49	8.5	0.38	9.3	2.7	7.6	0.64
Mn	0.45	0.0093	0.45	0.014	0.37	0.055	0.38	0.030
Mo	0.0017	0.0015	0.012	0.014	0.0011	0.000039	0.0024	0.0016
Na	3.3	0.060	2.6	0.34	2.7	0.59	2.3	0.17
Ni	0.039	0.0076	0.038	0.0032	0.035	0.0031	0.063	0.042
P	0.86	0.70	0.41	0.18	0.29	0.026	0.30	0.034
Pb	0.075	0.019	0.072	0.046	0.11	0.00042	0.51	0.53
S	86	9.2	55	0.021	58	1.6	61	4.0
Sb	0.0019	0.0023	0.00014	0.000025	0.000081	0.0000066	0.00021	0.00016
Si	0.99	0.24	0.33	0.097	0.45	0.077	0.45	0.15
V	0.041	0.0014	0.038	0.0024	0.037	0.0044	0.045	0.017
Zn	1.3	0.65	1.6	0.80	1.0	0.12	0.99	0.21

Table 11. Metals, P and S in solid samples from column 2 and 3.

Species	After test [mg/g]		Species	After test [mg/g]	
	Column 2 and 3			Column 2 and 3	
	Mean	Standard deviation		Mean	Standard deviation
Ag	0.0010	0.00042	Mn	0.38	0.036
Al	12	1.1	Mo	0.0017	0.0012
As	0.0080	0.0077	Na	2.5	0.41
Ca	120	6.1	Ni	0.049	0.029
Cd	0.0032	0.0044	P	0.29	0.025
Co	0.0092	0.0029	Pb	0.31	0.38
Cr	0.070	0.010	S	59	3.2
Cu	0.10	0.046	Sb	0.00015	0.00012
Fe	24	4.9	Si	0.45	0.096
Hg	0.00021	0.000088	V	0.041	0.011
K	1.8	0.22	Zn	0.99	0.14
Mg	8.4	1.9			

### 5.2.3 Leachate

The accumulated L/S ratio can be converted into a timescale for a specific landfill and thus indications can be drawn about how the composition of the leachate changes over time. It is assumed that Fläskebo landfill is going to be filled according to the permission and thus that 1.5 million m<sup>3</sup> waste is deposited on an area of 135 000 m<sup>2</sup>. Further more it is assumed that the infiltration corresponds to the maximal infiltration allowed in the legislation that is 0.05 m/year. The amount of water inside the landfill has not been considered in the calculations. The calculations, estimations and assumptions behind the coarse conversion of L/S fractions into the timescale shown in table 12 are presented in appendix 1.

A timescale of more than 100 years for L/S 10 at a covered field scenario has been suggested (van der Sloot s.a) but others have suggested that it correspond to 400 to 4000 years (RVF 2005). So the time scale calculated in this experiment is within the range of what others has arrived at.

*Table 12. Coarse conversion of L/S fractions into a timescale.*

<b>L/S [l/kg dry matter]</b>	<b>Time [years]</b>
0.1	10
2	200
10	1000

The most interesting part about the leachate is to determine how much of the metals have leached out from the waste compared to how much that remains. Since column one has leachate from cover and filling material as inflow and therefore a contribution of metals from the inflow it is not relevant to calculate the percent leached from column one. The percentage in table 13 is the percentage leached out at the end of each L/S in the percolation test that is after approximately 10, 200 and 1000 years of leaching. For most metals a very small amount has been leached out even after 1000 years and this suggests that it is a very good idea to keep the landfills as dry as possible which the new legislation demands. The other approach, to flush the metals out during the monitory phase of the landfill will be very hard to achieve since the metals seems to be strongly bound to the interior of the landfill. Even if this would be possible the metals can not be destroyed, just gathered together and then they need to be stored somewhere else. Since the metals mostly stay within the landfill it is easier to just let them stay there. The metals that has been leached out to any extend at L/S 10 is Ca, K, Mn, Mo, Na, S and Si. At least Ca, K and Na are easy soluble metals so this result makes sense.

Table 13. Percentages of metals, P and S leached out after 10, 200 and 1000 years.

Species	Column	Percent L/S 0.1	Percent L/S 2	Percent L/S 10
<b>Ag</b>	<b>2</b>	0.00014	0.0012	0.0028
	<b>3</b>	0.00010	0.00080	0.00080
<b>Al</b>	<b>2</b>	0.000040	0.000018	0.000061
	<b>3</b>	0.0000021	0.00000087	0.000036
<b>As</b>	<b>2</b>	0.0000021	0.067	0.15
	<b>3</b>	0.00000087	0.0046	0.13
<b>Ca</b>	<b>2</b>	0.0073	0.78	<b>3.7</b>
	<b>3</b>	0.0051	0.041	<b>3.8</b>
<b>Cd</b>	<b>2</b>	0.0046	0.012	0.037
	<b>3</b>	0.041	0.87	0.020
<b>Co</b>	<b>2</b>	0.040	0.44	0.70
	<b>3</b>	0.040	0.0022	0.10
<b>Cr</b>	<b>2</b>	0.00066	0.011	0.030
	<b>3</b>	0.00072	0.00074	0.027
<b>Cu</b>	<b>2</b>	0.00040	0.0040	0.0049
	<b>3</b>	0.031	0.00010	0.00010
<b>Fe</b>	<b>2</b>	0.034	0.0019	0.038
	<b>3</b>	0.0022	0.000050	0.083
<b>Hg</b>	<b>2</b>	0.000894	0.020	0.069
	<b>3</b>	0.00073	0.0023	0.080
<b>K</b>	<b>2</b>	0.00070	3.6	<b>7.5</b>
	<b>3</b>	0.00057	0.21	<b>7.4</b>
<b>Mg</b>	<b>2</b>	0.00089	0.70	0.96
	<b>3</b>	0.00010	5.1	1.0
<b>Mn</b>	<b>2</b>	0.00014	1.6	<b>4.0</b>
	<b>3</b>	0.00017	7.6	<b>3.3</b>
<b>Mo</b>	<b>2</b>	0.000049	3.0	<b>9.0</b>
	<b>3</b>	0.0023	1.3	<b>4.4</b>
<b>Na</b>	<b>2</b>	0.0024	2.8	<b>4.0</b>
	<b>3</b>	0.0016	0.23	<b>4.2</b>
<b>Ni</b>	<b>2</b>	0.33	0.45	0.72
	<b>3</b>	0.22	1.1	0.24
<b>P</b>	<b>2</b>	0.21	0.0054	0.0091
	<b>3</b>	0.071	0.00041	0.0060
<b>Pb</b>	<b>2</b>	0.045	0.00051	0.00051
	<b>3</b>	0.046	0.0000074	0.000092
<b>S</b>	<b>2</b>	0.093	1.2	<b>5.7</b>
	<b>3</b>	0.085	0.064	<b>5.9</b>
<b>Sb</b>	<b>2</b>	0.054	0.099	0.23
	<b>3</b>	0.19	7.0	0.16
<b>Si</b>	<b>2</b>	0.14	2.2	<b>7.2</b>
	<b>3</b>	0.094	0.14	<b>7.1</b>
<b>V</b>	<b>2</b>	0.42	0.0030	0.010
	<b>3</b>	0.19	0.0060	0.0085
<b>Zn</b>	<b>2</b>	0.21	0.031	0.038
	<b>3</b>	0.040	0.00018	0.014

The calculation of the percentage of metals leaching out from the landfill gave a strong indication that the demand in the EU-legislation to minimize the leachate is a good way to reduce the spreading of metals from landfills under a long period of time. The uncertainties in this result must however be taken into consideration. The analyses of metals in solid samples have already been discussed and are considered reliable since the standard deviation for the replicates is small compared to the mean. Unfortunately the same can not be concluded for the analyses of the water samples. The concentrations of the different elements and compounds in the leachate from the columns can be found in appendix 2.

The trend for the concentrations of metals in the leachate is that column one has higher concentrations than the leachate from column two and three. Another trend is that the concentrations decrease with larger L/S ratios. These trends are illustrated with figure 7 showing the concentrations for As. There are however exceptions to these trends. For Al, Cd, Hg, Mb and Na the concentration in column one does not decrease with larger L/S ratio and this can be explained by the continuous contribution of the elements from the inflow. For Ca the concentrations are approximately the same in all L/S ratios and for all columns except for the control. Fe and Zn show a very irregular and unexplainable pattern. The control, column four, seems to have been contaminated with Cu and Pb.

Not only metals have been analysed for in the leachate. The TOC content will be discussed in connection with the degradation test. P and S for which percentage leached has been calculated show similar trends as the metals but with P having too high concentration in column four and S having the same concentrations in all columns except for the control. The remaining constituents analysed will not be discussed the focus of this thesis has been on the metals and TOC content.

The concentrations of metals and other species in the leachate in this study do not exceed the concentrations in leachate from landfills with organic matter found in literature (Kjeldsen 2002). On the other hand a study comparing the leachate from Fläskebo with leachate from old landfills containing large amounts of organic matter concluded that leachate from Fläskebo had lower concentrations of TOC and nitrogen compounds and higher concentrations of metals (Avfall Sverige 2009).

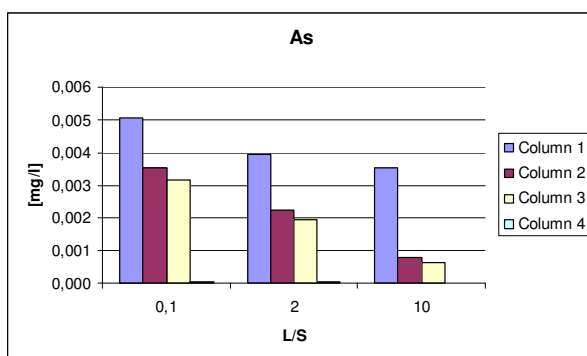


Figure 7. Concentrations for As in eluats from percolation test.

As mentioned before the trend is that more metals are leached out from the waste when it has leachate from cover and filling material as inflow which is expected since the leachate from cover and filling material contribute with more metals into the waste.

### 5.3 Degradation test

Column one had leachate from cover and filling material as inflow. The cover material had a TOC content of 26.6 % and the waste from this column could be expected to have a higher TOC content than the waste from column two and three since it receives TOC from the inflow. The analyses of the solid sample showed a small tendency for this but it was far from significant. When looking at the TOC content in the leachate (figure 8) a contribution of TOC from the leachate of cover and filling material to column one could be assumed. But the fact that the leachate from the control has almost the same TOC content as column two and three suggests that the errors in the analyses are quite large and thus it can not be concluded.

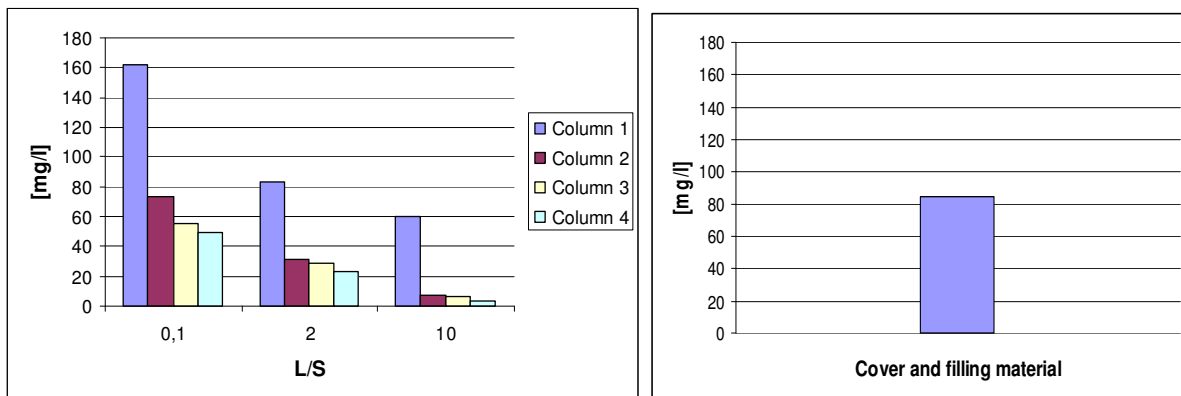


Figure 8. TOC content in leachate from waste and cover and filling material.

The result from the degradation test is shown in figure 9. When comparing the degradation test at hour 60 the waste from column one had significantly higher oxygen consumption than the waste from column two and three which indicates a higher TOC content or higher microbial activity in the waste from column one. Hour 60 was chosen for the comparison instead of hour 96 as the standard states because after 60 hours the two replicates from column one deviate from each other.

The degradation of waste from both column one and from column two and three were significant lower than the degradation of waste from before percolation test. This indicates that leaching of organic matter has occurred during the percolation test.

The degradation test also shows that gas formation is possible even with this small amount of TOC. The TOC measurement did not indicate a difference in the amount of TOC present before and after the percolation test but the biological test show a significant difference in oxygen consumption. This suggests that the biological test is more sensitive to the changes in TOC content than the measurements of the actual TOC content.

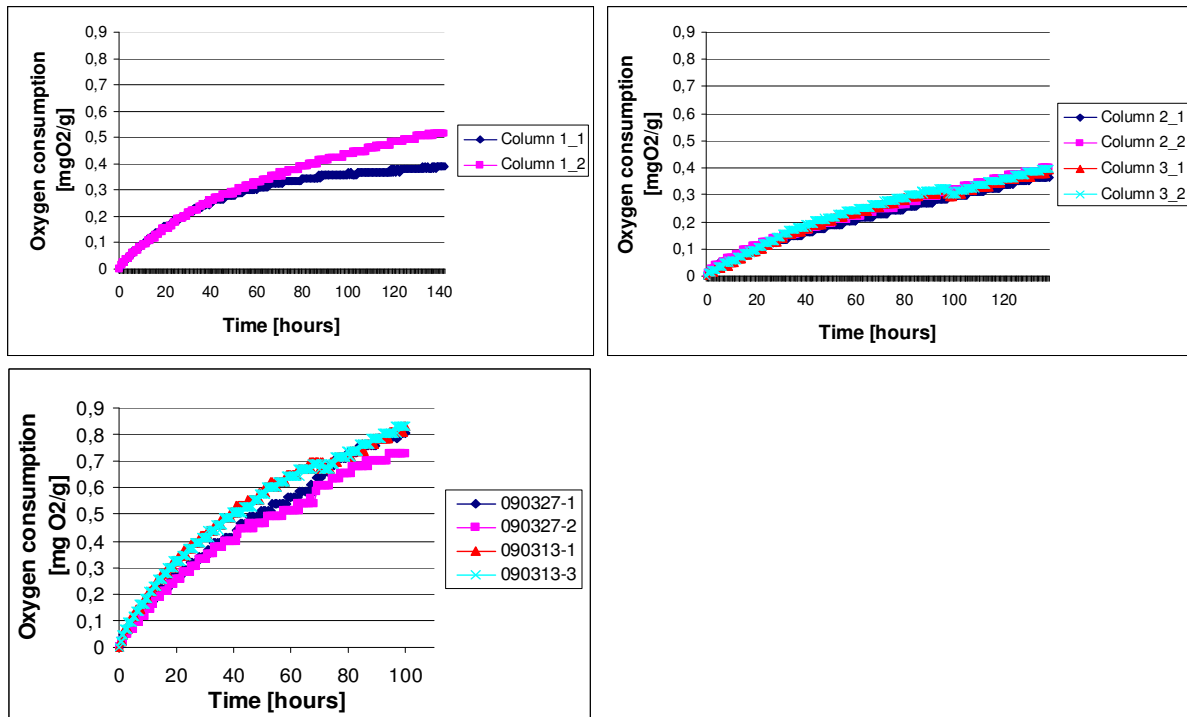


Figure 9. Oxygen consumption during degradation test of waste before and after percolation test. To the upper left the two replicates from column one, to the right the two replicates from column two and three and the lower figure shows the degradation of the untreated waste.

## 6. Conclusions

This study strengthens the assumption in the EU-legislation that the methane emissions from landfills with low content of biodegradable waste probably are negligible. That some degradation is possible for the waste can be concluded from the degradation test but no mass balance could be performed. Measurements at actual landfills should be conducted to be sure of this since the conditions in the laboratory differ from the conditions in real life.

Elements and compounds were leached out but the concentrations were not higher than concentrations found in leachate from old landfills containing large amounts of organic matter. Concerns have been raised that metals will be of greater concerns in leachate from landfills receiving waste according to the new legislation than in old landfills. This study does not support these concerns. Most metals are leached out at a very low percentage even after L/S 10 and it is the conclusion of this study that the demand in the legislation to keep the landfills as dry as possible is a good way to minimize the negative environmental effects from landfills.

Landfills will always affect its surroundings in some ways and further investigations are needed to fully understand how and how to best minimize these effects. But the new legislation does not just aim for reducing the effects from landfills but takes all parts of waste disposal into consideration. A sustainable community can not keep dispose of waste, which can be reused in some way, by digging it down without proper containment.



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## Appendix 1 - calculations

### *Percolation test of cover and filling material*

#### **Bottom ash**

##### *Calculation of bulk density*

Mass bottom ash: 1701.24 g measured  
Volume bottom ash: 1200 cm<sup>3</sup> measured

Mass bottom ash: 2279.45 g measured  
Volume bottom ash: 1600 cm<sup>3</sup> measured

$$\text{Bulk density: } \frac{\frac{1701.24}{1200} + \frac{2279.45}{1600}}{2} = 1.421178 \text{ g/cm}^3 = 1421.178 \text{ kg/m}^3$$

##### *Calculation of dry residue*

$$m_v = (424.63 - 9.91) \text{ g} = 414.72 \text{ g}$$

$$m_t = (400.13 - 9.91) \text{ g} = 390.22 \text{ g}$$

$$m_v = (500.04 - 9.98) \text{ g} = 490.06 \text{ g}$$

$$m_t = (469.14 - 9.98) \text{ g} = 459.16 \text{ g}$$

$$m_v = (428.68 - 8.97) \text{ g} = 419.71 \text{ g}$$

$$m_t = (402.83 - 8.97) \text{ g} = 393.86 \text{ g}$$

$$w_r = \frac{\frac{390.22}{414.72} + \frac{459.16}{490.06} + \frac{393.86}{419.71}}{3} = 0.9388$$

##### *Calculation of column volume*

Column diameter: 0.105 m measured

Column height: 0.5 m approximately measured

$$\text{Column volume: } \pi \cdot \left(\frac{0.105}{2}\right)^2 \cdot 0.5 = 0.0043295 \text{ m}^3$$

##### *Calculation of dry mass*

$$\text{Volume bottom ash: } \frac{\pi \cdot \left(\frac{0.105}{2}\right)^2 \cdot 0.5}{2} = 0.0021648 \text{ m}^3$$

$$\text{Mass bottom ash: } 1421.178 \cdot \frac{\pi \cdot \left(\frac{0.105}{2}\right)^2 \cdot 0.5}{2} = 3.0765 \text{ kg}$$

$$\text{Dry mass bottom ash: } 0.9388 \cdot 1421.178 \cdot \frac{\pi \cdot \left(\frac{0.105}{2}\right)^2 \cdot 0.5}{2} = 2.8879 \text{ kg}$$

### **Fibre ash + sludge**

*Calculation of dry residue*

$$m_v = (81.65 - 5.73) \text{ g} = 75.92 \text{ g}$$

$$m_t = (35.82 - 5.73) \text{ g} = 30.09 \text{ g}$$

$$m_v = (86.39 - 8.37) \text{ g} = 78.02 \text{ g}$$

$$m_t = (38.47 - 8.37) \text{ g} = 30.10 \text{ g}$$

$$m_v = (82.74 - 5.38) \text{ g} = 77.09 \text{ g}$$

$$m_t = (36.24 - 5.38) \text{ g} = 30.86 \text{ g}$$

$$w_r = \frac{\frac{30.09}{75.92} + \frac{30.10}{78.02} + \frac{30.86}{77.09}}{3} = 0.3941$$

*Calculation of dry mass*

Total mass in the column: 4.64 kg measured

Mass fibre ash + sludge:  $4.64 - 3.0765 = 1.5635 \text{ kg}$

Dry mass fibre ash + sludge:  $0.3941 \cdot 1.5635 = 0.6162 \text{ kg}$

### **Bottom ash and fibre ash + sludge**

*Calculation of dry mass of test portion*

Dry mass:  $2.8879 + 0.6162 = 3.5041 \text{ kg}$

*Flow rate*

The flow rate should be 15 cm/day in empty column according to standard page 11 and the equation below from page 11 in the standard are used to calculate the flow rate in ml/h.

$$\phi = v_L \cdot \pi \cdot d^2 \cdot 0.0104$$

where

$\phi$  leachant flow rate [ml/h]

$v_L$  linear velocity of the leachant through the empty column [cm/day]

$d$  diameter of the column

$$\phi = 15 \cdot \pi \cdot 10.5^2 \cdot 0.0104 = 54 \text{ ml/h} = 0.90 \text{ ml/min}$$

In this percolation test the aim is to gather enough leachate to be used in the percolation test with the waste. Since there are a limited time for the experiment the flow rate used is decided to be 3 ml/min.

*Volume and time*

To calculate the volume and time for each L/S ratio a table is formed and for each fraction the same calculations are performed (table 1).

The volume of sample is calculated by multiply the L/S fraction with the dry mass. The execution time for respective volume is calculated with the equation below from page 13 in the standard.

$$t = \frac{L/S \cdot m_0 \cdot 1000}{24 \cdot \phi}$$

where

- t execution time of the test [days]  
 L/S final liquid to solid ration [l/kg dry matter]  
 m<sub>0</sub> dry mass of the test portion [kg]  
 φ leachant flow rate [ml/h]

Table 1. Calculations of volume and time for percolations test for cover and filling material

Acc L/S [kg/l]	L/S fraction [kg/l]	Volume of sample [l]	Time [days]	Acc volume [l]	Acc time [days]	Acc time [h]
0.1	0.1	0.35	0.08	0.35	0.0811	1.95
0.2	0.1	0.35	0.08	0.70	0.1622	3.89
0.5	0.3	1.05	0.24	1.75	0.4056	9.73
1	0.5	1.75	0.41	3.50	0.8111	19.47
2	1	3.50	0.81	7.01	1.6223	38.93
5	3	10.51	2.43	17.52	4.0557	97.34
10	5	17.52	4.06	35.04	8.1113	194.67

## Percolation test of waste

### Waste

Calculation of dry residue

$$m_v = (167.09 - 9.95) \text{ g} = 157.14 \text{ g}$$

$$m_t = (108.11 - 9.95) \text{ g} = 98.16 \text{ g}$$

$$m_v = (161.91 - 10.04) \text{ g} = 151.87 \text{ g}$$

$$m_t = (103.04 - 10.04) \text{ g} = 93.00 \text{ g}$$

$$m_v = (145.73 - 9.05) \text{ g} = 136.68 \text{ g}$$

$$m_t = (91.40 - 9.05) \text{ g} = 82.35 \text{ g}$$

$$w_r = \frac{\frac{98.16}{157.14} + \frac{93.00}{151.87} + \frac{82.35}{136.68}}{3} = 0.6132$$

### Flow rate

The flow rate should be 15 cm/day in empty column according to standard page 11 and the equation below from page 11 in the standard are used to calculate the flow rate in ml/h.

$$\phi = v_L \cdot \pi \cdot d^2 \cdot 0.0104$$

where

$\phi$  leachant flow rate [ml/h]  
 $v_L$  linear velocity of the leachant through the empty column [cm/day]  
 $d$  diameter of the column

$$\phi = 15 \cdot \pi \cdot 10.5^2 \cdot 0.0104 = 54 \text{ ml/h} = 0.90 \text{ ml/min}$$

Since the pumps aren't very accurate a flow rate of 1 ml/min could be aimed for.

### Column 1

#### Calculation of dry mass of test portion

Mass wet waste: 3.58 kg measured

Dry mass waste:  $0.6132 \cdot 3.58 = 2.20 \text{ kg}$

#### Volume and time

To calculate the volume and time for each L/S ratio a table is formed and for each fraction the same calculations are performed (table 2).

The volume of sample is calculated by multiply the L/S fraction with the dry mass. The execution time for respective volume is calculated with the equation below from page 13 in the standard.

$$t = \frac{L/S \cdot m_0 \cdot 1000}{24 \cdot \phi}$$

where

$t$  execution time of the test [days]  
 $L/S$  final liquid to solid ration [l/kg dry matter]  
 $m_0$  dry mass of the test portion [kg]  
 $\phi$  leachant flow rate [ml/h]

Table 2. Calculation of volume and time for percolation test for waste in column 1.

Acc L/S [kg/l]	L/S fraction [kg/l]	Volume of sample [l]	Time [days]	Acc volume [l]	Acc time [days]	Acc time [h]
0.1	0.1	0.22	0.15	0.22	0.15	3.66
0.2	0.1	0.22	0.15	0.44	0.30	7.32
0.5	0.3	0.66	0.46	1.10	0.76	18.29
1	0.5	1.10	0.76	2.20	1.52	36.59
2	1	2.20	1.52	4.39	3.05	73.18
5	3	6.59	4.57	10.98	7.62	182.94
10	5	10.98	7.62	21.95	15.24	365.88

## Column 2

Calculation of dry mass of test portion

Mass wet waste: 3.55 kg measured

Dry mass waste:  $0.6132 \cdot 3.55 = 2.18$  kg

Volume and time

To calculate the volume and time for each L/S ratio a table is formed and for each fraction the same calculations as for column one are performed (table 3).

Table 3. Calculation of volume and time for percolation test for waste in column 2.

Acc L/S [kg/l]	L/S fraction [kg/l]	Volume of sample [l]	Time [days]	Acc volume [l]	Acc time [days]	Acc time [h]
0.1	0.1	0.22	0.15	0.22	0.15	3.63
0.2	0.1	0.22	0.15	0.44	0.30	7.26
0.5	0.3	0.65	0.45	1.09	0.76	18.14
1	0.5	1.09	0.76	2.18	1.51	36.28
2	1	2.18	1.51	4.35	3.02	72.56
5	3	6.53	4.54	10.88	7.56	181.41
10	5	10.88	7.56	21.77	15.12	362.81

## Column 3

Calculation of dry mass of test portion

Mass wet waste: 3.88 kg measured

Dry mass waste:  $0.6132 \cdot 3.88 = 2.38$  kg

Volume and time

To calculate the volume and time for each L/S ratio a table is formed and for each fraction the same calculations as for column one are performed (table 4).

Table 4. Calculation of volume and time for percolation test for waste in column 3.

Acc L/S [kg/l]	L/S fraction [kg/l]	Volume of sample [l]	Time [days]	Acc volume [l]	Acc time [days]	Acc time [h]
0.1	0.1	0.24	0.17	0.24	0.17	3.97
0.2	0.1	0.24	0.17	0.48	0.33	7.93
0.5	0.3	0.71	0.50	1.19	0.83	19.83
1	0.5	1.19	0.83	2.38	1.65	39.65
2	1	2.38	1.65	4.76	3.30	79.31
5	3	7.14	4.96	11.90	8.26	198.27
10	5	11.90	8.26	23.79	16.52	396.54

## Column 4

Calculation of dry mass of test portion

There is no waste in this column but to calculate the volume and time for sampling an imaginary mass is calculated which is the mean of the mass in the tree other columns.

Mass wet waste:  $\frac{3.58 + 3.55 + 3.88}{3} = 3.67$  kg

Dry mass waste:  $0.6132 \cdot 3.67 = 2.25$  kg

### Volume and time

To calculate the volume and time for each L/S ratio a table is formed and for each fraction the same calculations as for column one are performed (table 5).

Table 5. Calculation of volume and time for percolation test in column 4.

Acc L/S [kg/l]	L/S fraction [kg/l]	Volume of sample [l]	Time [days]	Acc volume [l]	Acc time [days]	Acc time [h]
0.1	0.1	0.23	0.17	0.23	0.17	4.08
0.2	0.1	0.23	0.17	0.45	0.34	8.15
0.5	0.3	0.68	0.51	1.13	0.85	20.38
1	0.5	1.13	0.85	2.25	1.70	40.77
2	1	2.25	1.70	4.50	3.40	81.54
5	3	6.75	5.10	11.25	8.49	203.84
10	5	11.25	8.49	22.50	16.99	407.69

### Converting L/S fractions into a timescale for Fläskebo landfill

By analysing the units the following equation for converting L/S fractions to timescale has been constructed

$$t = \frac{L/S \cdot h \cdot \rho}{I}$$

where

L/S	liquid to solid ratio [l/kg dry matter]
h	height of the landfill [m]
$\rho$	dry bulk density [kg/l]
I	infiltration [m/year]

The height is estimated from the planned landfill area of 135 000 m<sup>2</sup> and planned waste volume of 1.5 million m<sup>3</sup> to 10 m. The dry bulk density is assumed to be the same at the landfill as in the experiment and is therefore calculated to be approximately 0.5 kg/l. The infiltration is assumed to follow the legislation and to be maximal 0.05 m/year. The amount of water inside the landfill has not been considered in the calculations. The results from these coarse estimates are presented in table 6.

Table 6. Coarse conversion of L/S fraction into a timescale.

L/S [l/kg dry matter]	Time [years]
0.1	10
2	200
10	1000

## **Degradation test**

The measured decrease in pressure is calculated into the mass of consumed oxygen by using the ideal gas law.

$$p \cdot V = n \cdot R \cdot T$$
$$n = \frac{m}{M} \quad \Rightarrow \quad m = \frac{M \cdot p \cdot V}{R \cdot T}$$

where

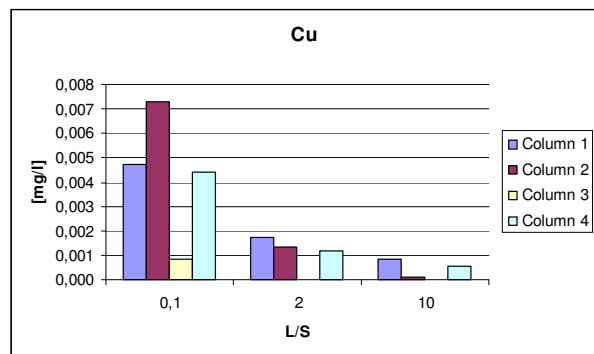
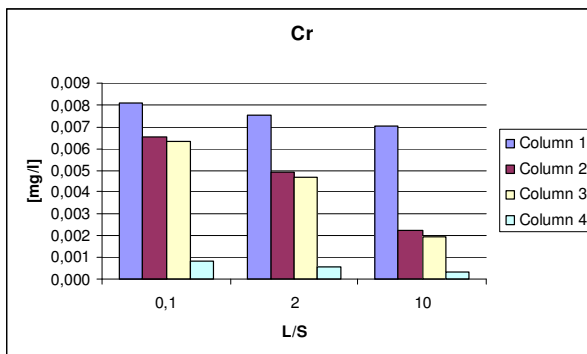
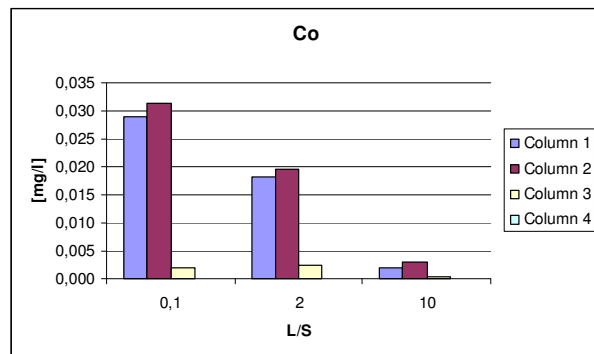
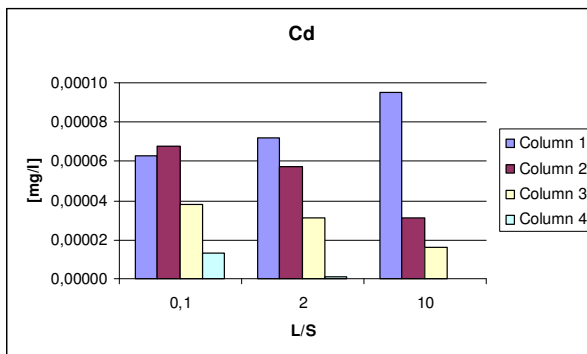
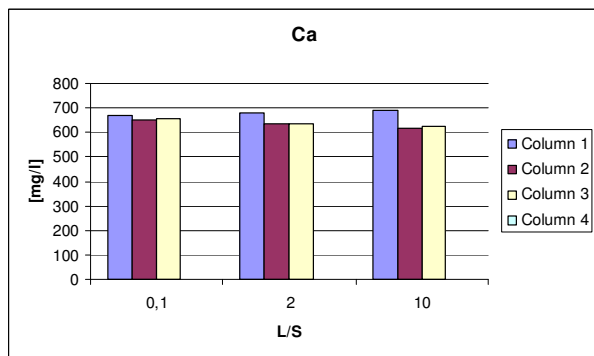
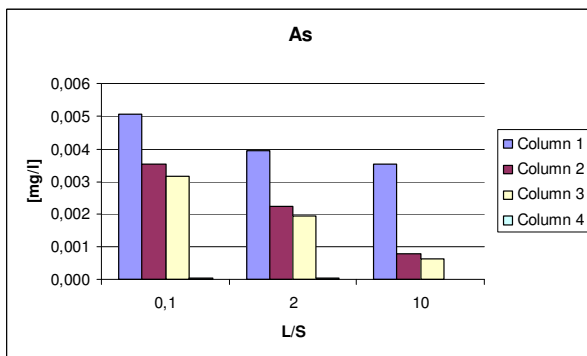
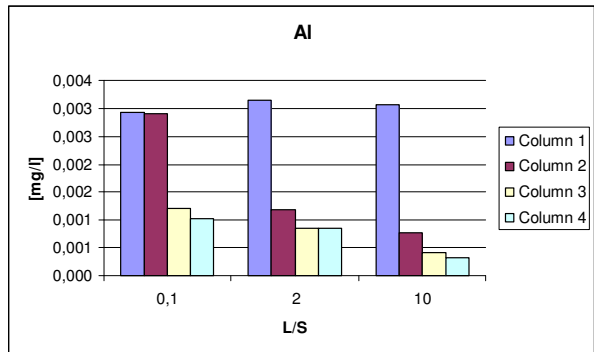
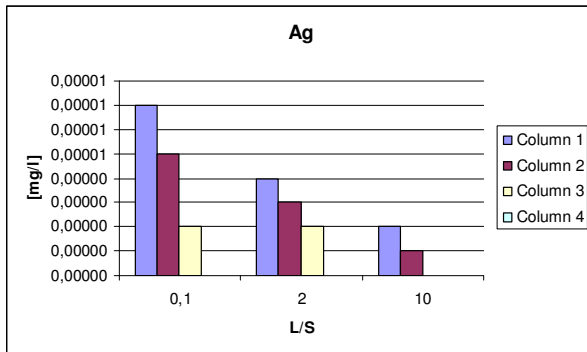
p	pressure [Pa]
V	free volume in the bottle [m <sup>3</sup> ]
n	quantity of substance [mol]
R	8.314 Pa/(mol*K)
T	293 K

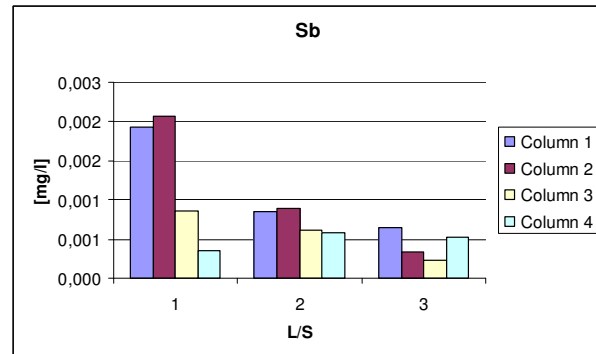
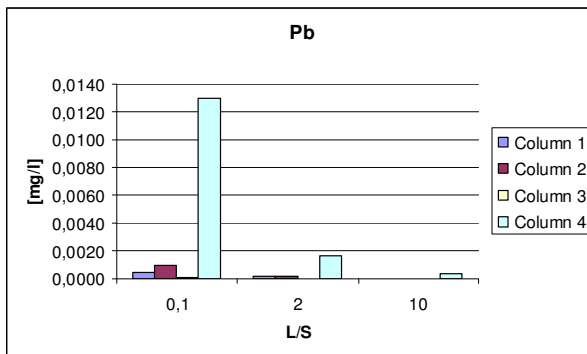
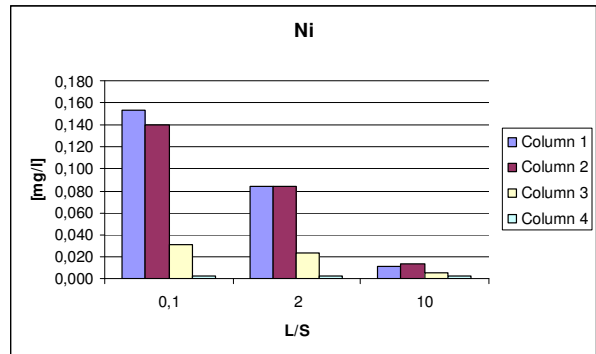
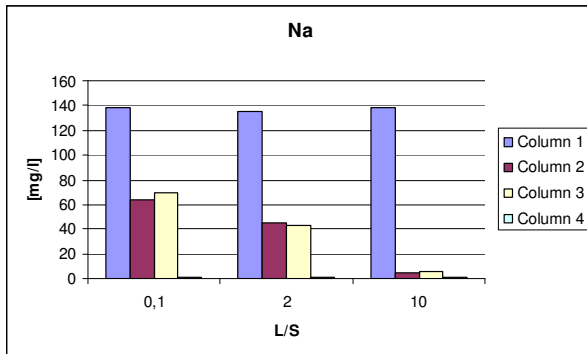
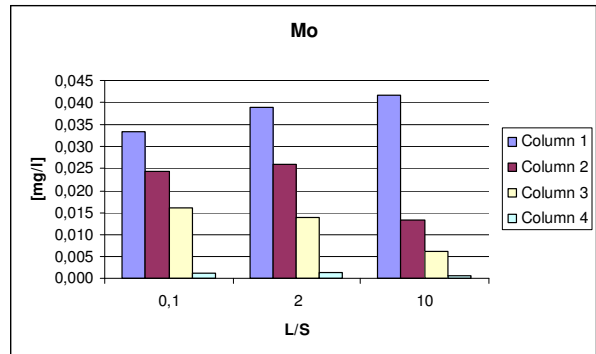
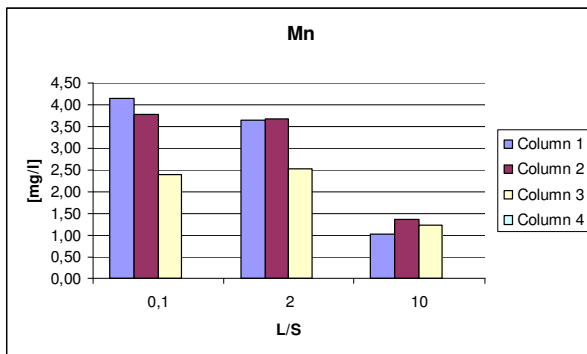
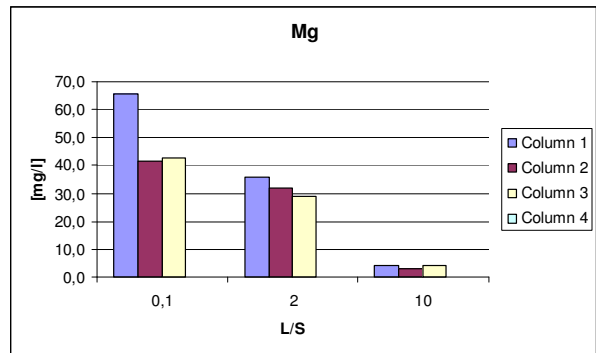
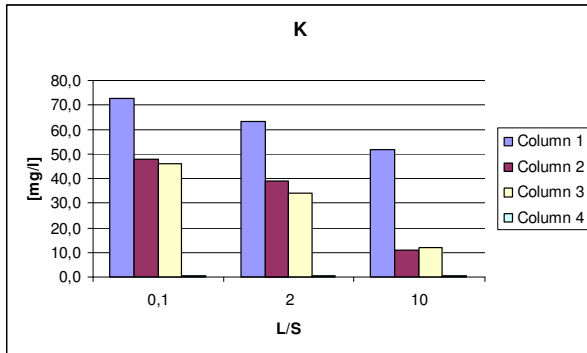
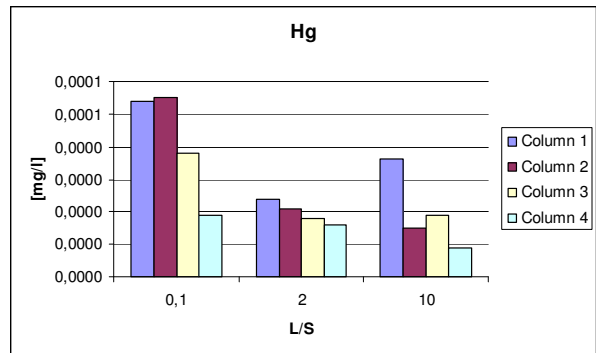
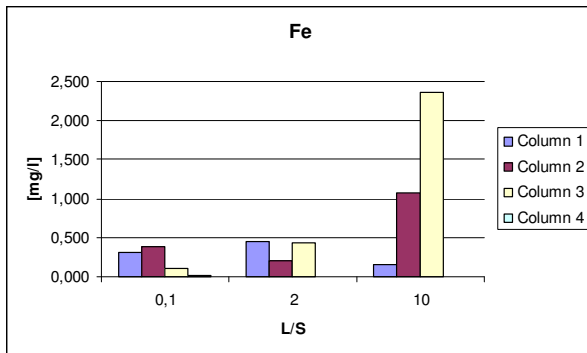
To derive the consumption of oxygen per gram dry mass waste in the sample the mass oxygen are divided with the disturbing material factor and with the dry mass of the sample. Before doing this, all bad measurements in the beginning of the experiment are deleted and a new starting point calculated.

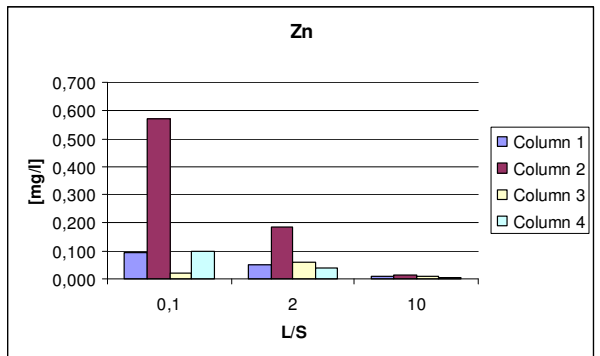
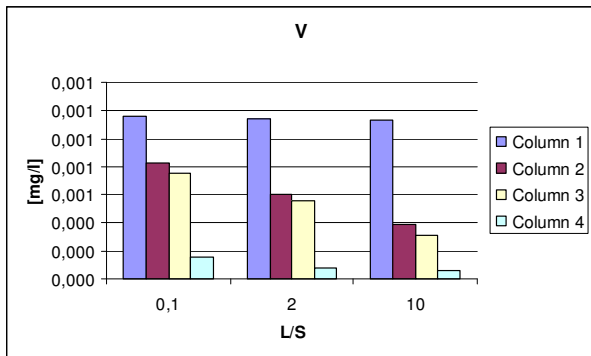
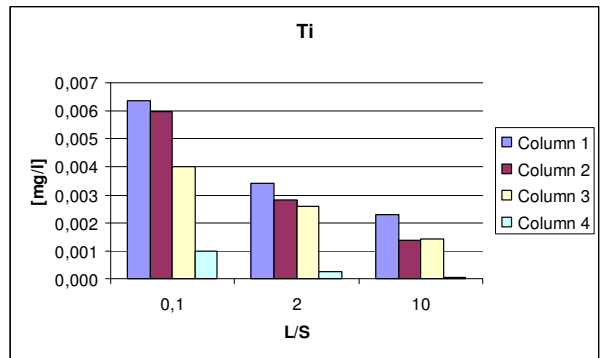
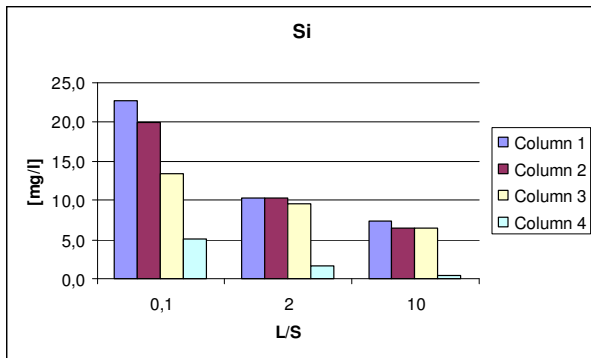


# Appendix 2 - concentrations in leachate

## Metals







**Non-metals**

