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Utilisation of MSWI bottom ash as sub-base in road construction: First results from a large-scale test site

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Abstract

The preferred management option for municipal solid waste incinerator (MSWI) bottom ash in Denmark is utilisation rather than landfilling, but the current environmental quality criteria for bottom ash to be utilised in bulk quantities are rather strict. To evaluate the impact and risk assessments, upon which those criteria are based, a large-scale test site has been established. Three different MSWI bottom ashes have been used as sub-base in six test units ranging from 100 to 200 m^2 with top covers of asphalt, flagstones and pebbles, respectively. All units, except one, are equipped with bottom liners and leachate collection equipment. The test site provides information on the leachate quality and quantity as a function of time under different conditions and on the flow pattern in asphalt and flagstone covered roads and squares with MSWI bottom ash sub-base. In addition, the leaching behaviour of the bottom ashes has been studied in the laboratory. The test site was established in October 2002 and the project is still ongoing. Water balance results indicate that the water flow distribution is strongly influenced by lateral flow on or in the upper part of the bottom ash layer and possibly by preferential flow. Comparisons between eluates from laboratory leaching tests on the bottom ashes and observations of the leachate from the site as a function of L/S show fairly good agreement for salts but less agreement for some trace elements. Most likely, this is partly due to the fact that the pH observed in the leachate from the field sites is lower than that observed in the eluates from the laboratory leaching tests.

Keywords: MSWI bottom ash; Leaching; Utilisation; Sub-base; Large-scale test site; Site; Water balance; Road construction; Environmental impact assessment

1. Introduction

Incineration of municipal solid waste (MSW) plays an important role in Danish waste management and the annual incineration of 2–3 million tonnes of MSW in Denmark results in the production of approximately 500,000 tonnes of bottom ash (BA), which must be utilised or landfilled. In accordance with European Union (EU) and Danish waste policy, utilisation is generally preferred over landfilling, provided it can be carried out in an environmentally acceptable manner. There is a long tradition for utilisation of municipal solid waste incinerator bottom ash (MSWI BA) in Denmark, and currently 80–90% of the annual amount of MSWI bottom ash produced in Denmark is utilised for filling or construction purposes [1].

During the period 1983–2000, MSWI BA could be utilised, e.g. in road construction if it complied with a few simple quality criteria, primarily limitations on the content of Cd, Hg and Pb determined after partial digestion with nitric acid. These criteria were not very restrictive, i.e. they could be fulfilled by the bottom ash from most MSW incinerators, and they were not derived from actual environmental risk assessments.

Since January 2001, the utilisation of municipal solid waste incinerator (MSWI) bottom ash in Denmark has been regulated by Statutory Order no. 655 of 27 June 2000 on utilisation of waste products and soil for back-filling and road construction purposes [2]. The Statutory Order distinguishes between three different classes of materials according to their contents of potential contaminants (trace elements and salts) and the leachability of these contaminants. The conditions for utilisation become more restrictive with increased content and increased leachability of contaminants. The limit values for leaching of MSWI BA to be utilised were derived by the Danish EPA mainly from assessments of the potential risk of impacts on groundwater downstream from the application. The assessments are based on the results of modelling of contaminant transport in groundwater for specified utilisation scenarios using the results

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Table 1
Overview of the field test units and their main features

Unit	Origin of BA	Major objective of unit	Top	Bottom
A	MSWI 1	To study the rate of infiltration	Asphalt	LDPE liner
B	MSWI 1	To study the rate of infiltration	Flagstones	LDPE liner
C	MSWI 1	To study leachate quality as a function of L/S	Pebbles	LDPE liner
D	MWSI 2	To study leachate quality as a function of L/S	Pebbles	LDPE liner
E	MSWI 3	To study leachate quality as a function of L/S	Pebbles	LDPE liner
F	MSWI 1	To create and study a leachate plume	Pebbles	No liner

Table 2
Surface areas of the units and information on the MSWI bottom sub-base layers

Unit	Origin of BA	Surface area of unit (m^2)	Average thickness of MSWI BA layer (m)	Dry density of MSWI BA (tonnes/m^3)	Amount of MSWI BA in unit	
					tonnes	m^3
A	MSWI 1	221/260[a]	0.56	1.77	196	110.5
B	MSWI 1	98.7	0.53	1.90	94.8	50.0
C	MSWI 1	101	0.50	1.76	85.2	48.4
D	MWSI 2	104	0.54	1.76	94.3	53.6
E	MSWI 3	98.6	0.54	1.85	93.0	50.3
F	MSWI 1	200	0.72	1.89	228	120.5

[a] Surface area of asphalt/area covered by bottom liner.

(in terms of concentrations) of batch leaching tests performed at L/S = 2 l/kg as constant source terms. Only dilution effects, no natural attenuation of contaminants, are considered in the groundwater transport model used (a 3D model, Visual Modflow/MT3D'96) in the scenarios. Danish groundwater quality criteria are to be met at a point of compliance 30 m downstream of the application site. It is assumed that the infiltration into the bottom ash constitutes between 10 and 100% of the rainfall, depending of the type of application and top cover. For an asphalt-covered road an infiltration rate corresponding to 10% of the rainfall is assumed [2,3].

The inclusion in the regulations of the leaching of some organic compounds or groups of compounds, which is particularly relevant in relation to contaminated soil, is under consideration, but no definite steps have been taken so far, mainly because of the difficulties involved in the performance and interpretation of leaching tests for organic contaminants.

In order to evaluate some of the assumptions upon which the setting of the criteria in the current regulations of waste product and soil utilisation have been based, and in particular how they relate to MSWI BA, a large-scale project on utilisation of MSWI BA as sub-base in roads and parking lots has been established at Ydernæs near the town of Næstved in Denmark. The main assumptions to be investigated are those of constant source strength, the use of relatively high rates of infiltration through an asphalt-covered bottom ash layer and the decision not to include natural attenuation of contaminants in the soil/aquifer. This paper describes the ongoing project and some of the initial results.

2. Description of the test site

The project consists of six separate units. Four of the units measure approximately 10 m × 10 m, whereas the remaining two units have surface areas that are twice as big. The main characteristics of the test units are presented in Tables 1 and 2 and Figs. 1–5.

All test units contain a 50–60 cm thick sub-base layer of MSWI bottom ash, compacted in three layers as normally done in road construction using the same equipment (road roller) as used in road construction for compaction of the sub-base. All

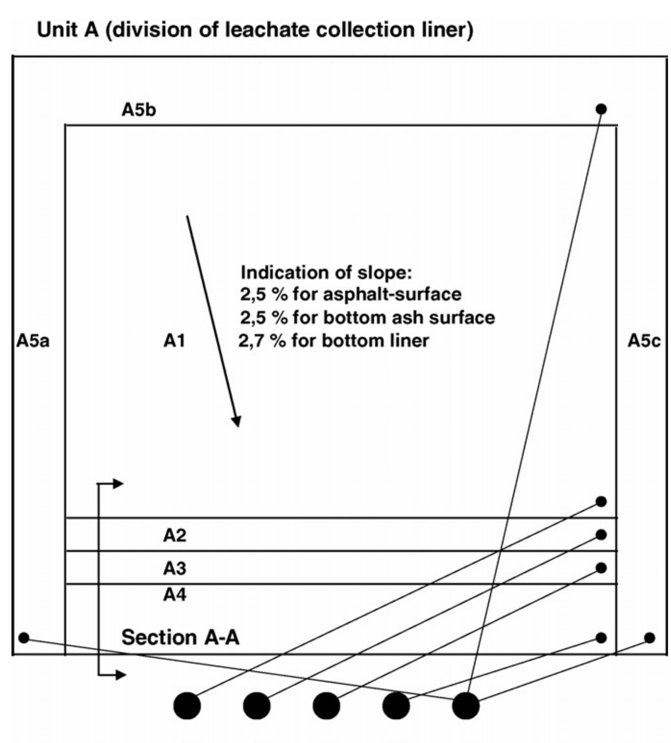

Fig. 1. Layout of test unit A showing bottom liner sections, drainage system and indicating surface slopes.

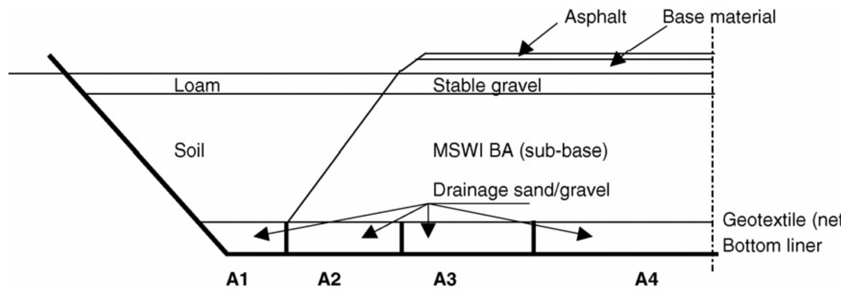

Fig. 2. Cross section of the downstream end of test unit A (vertical scale enlarged for clarity).

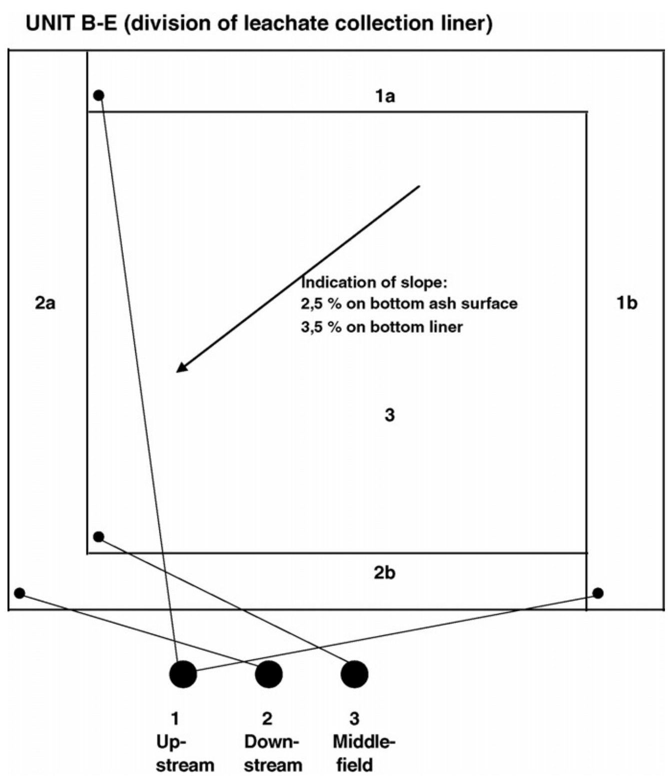

Fig. 3. Layout of test units B–E showing bottom liner sections, drainage system and indicating surface slopes.

units, except one, are equipped with low density polyethylene (LDPE) bottom liners and drainage layers as well as pumps and wells for collection of percolating leachate resulting from the infiltration of precipitation. An open geotextile (nylon) net was placed on top of the drainage sand to protect it against disruption. Bottom ashes from three different MSW incinerators (MSWI 1, MSWI 2 and MSWI 3) were placed on top of the drainage layer and the geotextile net. Prior to arrival at the site, the bottom ashes had been stored in stockpiles for 1–3 months, they had been screened through a 50 mm trommel, and ferromagnetic metal had been removed magnetically. Three of the units were covered only with pebbles, which were intended to optimise the infiltration of precipitation and the production of leachate by minimising the evaporation, which could occur from a free bottom ash surface due to limited infiltration capacity and capillary suction. The objective here is to study the contamination source as a function of time and liquid to solid ratio (L/S). Two other units have top covers of flagstones and asphalt, respectively. In these cases, the major objective is to study the infiltration reduction effectiveness of the cover as well as various edge effects. The last unit was constructed without a bottom liner and with only a pebble cover, allowing the leachate formed to leak into the secondary aquifer. Groundwater monitoring wells have been placed both upstream and downstream of this unit with the objective to evaluate and possibly improve the methods used to estimate the impact of utilised bottom ash on the groundwater. However, due to a complicated local hydrogeology, two of the groundwater monitoring wells dried up during the initial part of the project period, and it was not possible to detect the leachate plume in the remaining wells. It has therefore not been possible to study the natural attenuation of the leachate plume in the soil/aquifer as intended. The groundwater monitoring will therefore not be discussed further in this context. The major objectives of each unit are summarised in Table 1.

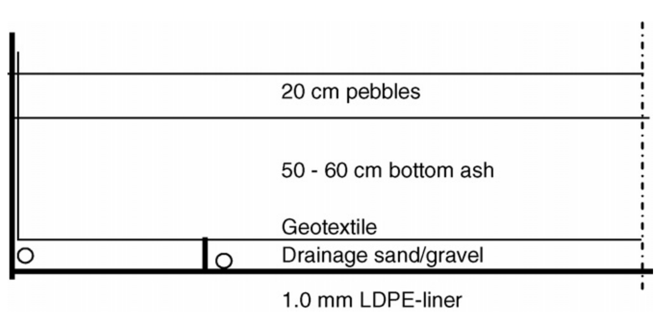

Fig. 4. Cross section of the downstream end of test units C–E. Test unit B is similar but is covered by flagstones (vertical scale enlarged for clarity).

To enable the observation of possible edge effects, the liners under units A–E have been divided into middle sections and edge sections, each with separate collection of leachate (see Figs. 1 and 3 which also show the slopes of the different surfaces and indicate the positions of the PE drainage tubes and the leachate collection wells described below). The edge sections constitute the outermost 0.5–1.0 m of the bottom liners. At the downstream end of the slightly sloped top of the asphalt-covered unit A, the liner has been further subdivided into a total of four sections, each with separate leachate collection, see Fig. 1. As seen in the cross section shown in Fig. 2, the outermost section of the liner (A1, width = 1.6 m) presumably collects leachate only from the soil adjacent to the bottom ash. The next section (A2, width = 0.76 m) collects leachate from soil and bottom ash, i.e. from the bottom ash slope outside of the asphalt cover. The third

Fig. 5. Photographs of the installation of the test units.

section (A3, width = 0.79 m) collects leachate from the bottom ash inside the asphalt cover as does the central section (A4, width = 9.75 m). The asphalt-covered unit A is used as a parking lot for personnel working at a nearby recycling plant. The surfaces of the other sites are left unused. The layout of the test units C–E are shown in Fig. 3 and the cross section in Fig. 4 (test unit B is similar to C–E, except for the fact that the pebbles on top are covered with a thin layer of sand overlaid by flagstones.

The different stages of the construction of the test units are shown in Fig. 5. Starting in the upper left corner, the figure shows the installation of the bottom liner, the geo-net in place on top of the drainage layer, the placement and subsequent compaction of a layer of MSWI bottom ash, an overview of the infiltration units with pebble covers, the placement of asphalt on top of the parking lot unit (site A), the parking lot unit after completion and one of the leachate pumping and sampling wells. The amounts of MSWI BA in each test site and the dry density of the compacted ash are shown in Table 2.

The leachate runs by gravity from the bottom of the various liner sections through polyethylene tubes and a water lock into PVC pumping wells (diameter 0.5 m, total depth 2 m, inlet placed 1 m above the bottom, which is closed) from where it is pumped to a nearby storage and treatment plant. The pumping wells are protected by locked aluminium covers. The upper part of each pumping well contains a water meter and electronic equipment for water level control of the leachate pump, registration and transfer of pumping time and water meter readings. The amount of water pumped from each bottom liner section is thus registered both by water meters and by the logging of pumping time. Peristaltic sampling pumps, which are triggered by the level-controlled leachate pumps in the pumping wells, collect flow-proportional samples of the leachate from the different liner sections from the water locks at each unit into closed 10 l polyethylene bottles. Data on pumping time as well as water meter readings are stored in a computer and transferred electronically to the DHI—Water & Environment in Hørsholm at regular intervals for further processing. As a precaution, water meter readings are also checked and registered manually on a weekly basis. Precipitation data are collected on site as well as from a nearby weather station.

The composition of the collected leachate (and the groundwater downstream of test unit F) is being monitored at regular intervals. pH and conductivity are measured on all samples, and selected samples are subjected to a fairly broad chemical analytical programme with special attention paid to constituents, which are particularly relevant to MSWI BA leachate (including sulphate, chloride, Na, K, Ca, Al, As, Cr, Cu, Mo, Ni, Pb, Zn and DOC (dissolved organic carbon)) [4] as well as to components, which are regulated (further including Ba, Cd, Hg, Sb and Sn, see Table 3).

3. Laboratory characterisation of MSWI bottom ashes

3.1. Sampling and test programme

During the construction of the test units, representative samples were collected of the MSWI bottom ash placed in each unit. From each dozer grab of BA placed in a unit, two samples were taken at random with a shovel and placed in a 180 l polyethylene drum. Approximately, 200 kg of BA were collected from each unit. The samples were screened (45 mm) and oversize material that could not be crushed was discarded. The screened material was thoroughly mixed and the sample size was reduced to 25 kg by means of a riffle sample splitter. After air-drying at room temperature, the samples were split into sub-samples using the riffle and crushed in a jaw-crusher to <4 mm for column and batch leaching testing and further ground to <0.125 mm for chemical analysis and performance of the pH-static leaching test. Column leaching tests (CEN/TS 14405) were carried out for comparison with leaching data from the test site, pH-static leaching tests (prCEN/TS 14997) in which the finely ground bottom ash is leached for 48 h at L/S = 10 l/kg with demineralised water adjusted to and maintained at predetermined pH values with HNO_3 or NaOH were carried out to describe the influence of pH on leachability/solubility and EN 12457-3, step 1 (single batch test performed at L/S = 2 l/kg using demineralised water with a contact time of 6 h) was performed because it is prescribed in the Danish regulations for waste utilisation. The eluates from

Table 3
Results of compliance batch leaching tests (EN 22457-3, part 1, L/S = 2 l/kg) on the MSWI BA from the various test units and Danish limit values for utilisation in categories 2 and 3 as well as the EU limit values for acceptance of waste at inert waste landfills [3]

Parameter	Unit	Test unit						Limit values		
		A	B	C	D	E	F	Utilisation DK		Landfilling EU
		MSWI 1	MSWI 1	MSWI 1	MSWI 2	MSWI 3	MSWI 1	Category 2	Category 3	Inert waste
pH	–	9.0	10.1	9.7	9.8	10.2	10.2		–	–
Conduct.	mS/m	280	290	290	360	470	270	–	–	–
Chloride	mg/kg	720	760	680	1180	1840	700	300 (3000)	6000	550
Sulphate	mg/kg	1760	1640	1840	1660	1580	1500	500 (4000)	8000	560
Ca	mg/kg	460	400	500	540	300	340		–	–
Mg	mg/kg	0.68	0.44	0.78	0.74	0.18	0.4		–	–
Na	mg/kg	700	780	680	880	1520	760	200 (2000)	3000	–
K	mg/kg	134	140	118	300	480	138	–	–	–
Al	mg/kg	34	32	36	60	110	38		–	–
As	mg/kg	0.0016	0.0016	<0.002	0.0028	0.0018	0.0018	0.016	0.1	0.1
Ba	mg/kg	0.094	0.072	0.096	0.112	0.060	0.088	0.6	8	7
Cd	mg/kg	0.00040	0.00038	0.00038	0.00072	0.00094	0.00036	0.004	0.08	0.03
Co	mg/kg	0.00084	0.00100	0.00082	<0.0001	0.00014	0.0007		–	–
Cr	mg/kg	0.00142	0.028	0.0138	0.0074	0.0118	0.044	0.02	1.0	0.2
Cu	mg/kg	0.60	0.64	0.54	0.104	0.64	0.7	0.09	4	0.9
Hg	mg/kg	<0.00004	0.00008	0.000094	<0.00004	<0.00004	0.00008	–	–	0.003
Mn	mg/kg	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	–		
Mo	mg/kg	0.22	0.22	0.194	0.42	0.56	0.22		–	0.3
Ni	mg/kg	0.0080	0.0102	0.0102	0.0014	0.0046	0.0078	0.02	0.14	0.2
Pb	mg/kg	0.0028	0.00182	0.00102	0.00178	0.00162	0.00080	0.02	0.2	0.2
Sb	mg/kg	0.034	0.036	0.041	0.063	0.079	0.032	–		0.02
Se	mg/kg	0.0058	0.0053	0.0058	0.0066	0.021	0.0052		–	0.06
Zn	mg/kg	0.0118	0.0106	0.0074	0.0080	0.0114	0.0074	0.2	3	2
DOC	mg/kg	36	36	34	13	94	38	–	–	240

Numbers in parentheses are temporarily increased limit values applicable to MSWI BA.

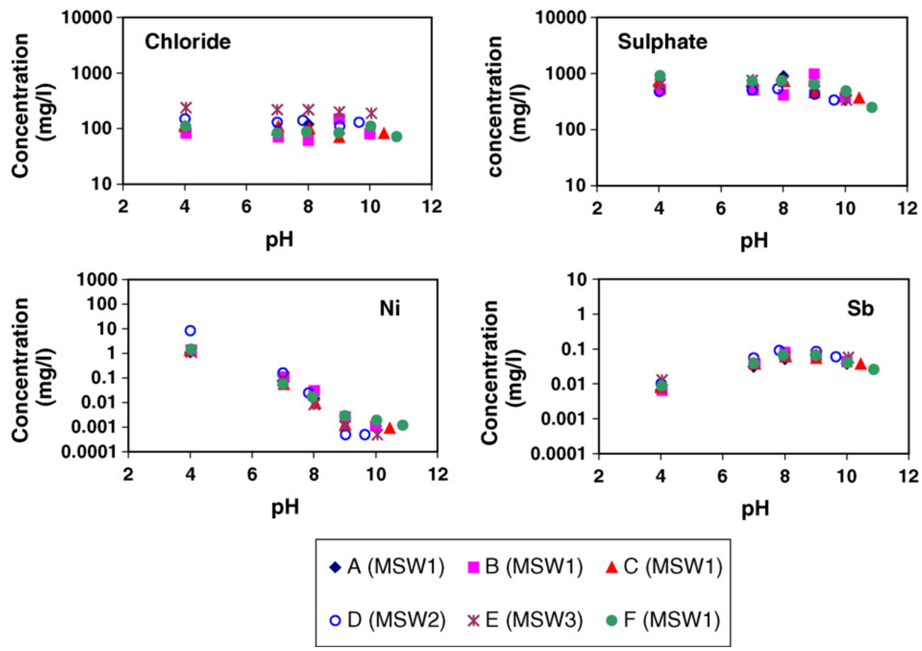

Fig. 6. Results of pH-static leaching tests (prCEN/TS 14997) performed at L/S = 10 l/kg under equilibrium-like conditions showing eluate concentrations of chloride, sulphate, Ni and Sb vs. pH.

the leaching tests were subjected to chemical analysis for the same constituents as the leachate from the field units. Particle size distributions were determined on raw samples from the units without asphalt or flagstone cover.

3.2. Laboratory characterisation results

An example of the results of the laboratory characterisation is presented in Table 3. The table shows the results of the batch test EN 12457-3, step 1 performed on the MSWI from each of the test units together with the regulatory limit values for utilisation of MSWI BA (categories 2 and 3). Category 2 materials may be used with some restrictions on the thickness of the application and some requirements concerning the infiltration-reducing properties of the top cover. For MSWI BA in category 3, these restrictions are more severe and the types of applications allowed are more limited.

All ashes comply with the temporary but not the permanent category 2 utilisation limit values for salts, and all ashes exceed the category 2 limit values for Cu, while two ashes exceed the category 2 limit values for Cr. All ashes comply with all category 3 limit values. The pH values, which are all close to or below 10, indicate that some carbonation has occurred during the period that the bottom ashes were stored prior to utilisation.

A comparison with the new European limit values for acceptance of waste at inert waste landfills [5] presented in Table 3 shows general non-compliance with the leaching criteria for chloride, sulphate and Sb for all the bottom ashes, and non-compliance with the criteria for Mo for the bottom ashes from MSWI 2 and MSWI 3. All the bottom ashes comply with the other criteria for acceptance of waste at inert waste landfills. The comparison to these criteria is relevant from an utilisation perspective because an inert waste landfill scenario in principle resembles a MSWI bottom ash application scenario [6].

Fig. 6 shows an example of the results of the pH-static leaching tests for chloride, sulphate, Ni and Sb. Whereas the leachability of chloride and sulphate from MSWI BA are relatively independent of pH at pH values below 11, the leachability of both of Ni and Sb are seen to be somewhat sensitive to changes in pH within the range shown.

The results of the particle size distribution analyses are presented in Fig. 7. The figure shows that the particle distributions of the MSWI bottom ashes in units C, E and F are very similar to each other, while the bottom ash in unit D has a slightly higher content of small particles than the others.

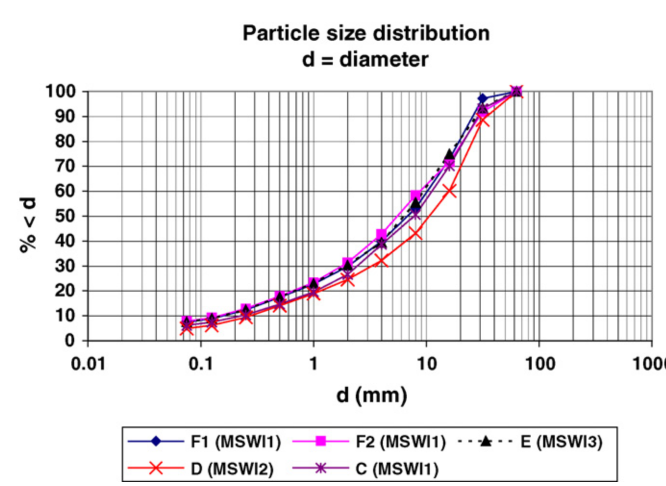

Fig. 7. Particle size distribution curves for the MSWI bottom ashes in test units C–F.

Table 4
Water balance results for test unit A for the period October 2002 to January 2005

Section of bottom liner under unit A	Percentage of surface area	Percentage of leachate collected	Percentage of precipitation collected as leachate
A4, middle section (BA)	51.8	3.9	3.1
A3, edge section under asphalt (BA)	4.2	0.6	0.4
A2, edge section outside asphalt (BA and soil)	4.0	2.1	1.7
A1, edge section outside asphalt (soil)	8.6	58.6	46.5
A5, other three edge sections	31.4	34.8	27.6
A, all sections	100	100	79.3

4. Preliminary test unit results and discussion

4.1. Water balance results

Some of the water balance results for the first 2 years and a few examples of the leachate quality results are presented and discussed below.

The water balance results for the asphalt-covered site (unit A) for the period October 2002 to January 2005 are summarised in Table 4, which shows the percentage of leachate collected in each of the various sections of the liner below the site (see Fig. 1). The total accumulated precipitation during the period was 1650 mm.

As can be seen, 79% of the precipitation during the period was collected as leachate. Comparison of the percentages of leachate collected to the percentages of the total area of each section of the liner indicates – not surprisingly – that only 4.5% of the leachate is collected in those sections which are covered by asphalt, although they constitute 56% of the surface area.

The major proportion of the leachate is collected in the downstream liner sections, which receive the surface run-off from the asphalt top. It appears that the run-off water from the asphalt runs-off on top of the bottom ash slope at the interface between ash and soil in section A3 and into section A4, from where most of the water (59% of the total) is collected (the corresponding surface area is 8.6%).

Table 5 shows that approximately the same percentage of the precipitation (75%) has been recovered as leachate from the flagstone-covered unit B (from which surface run-off is not collected) as from unit C (74%), which contains the same bottom ash but is covered by pebbles. The table further shows that most of the leachate is collected from the liner sections at the downstream edges.

The results seem to indicate that a substantial part of the leachate flows laterally on top of the upper part of the MSWI BA layer in all the test units. The reason why most of the leachate is collected in the downstream edge sections of the units is that once the leachate is there it cannot flow any further, because the bottom liners continue up the sides to a height of 10 cm above ground level. The leachate that flows on top of or in the upper part of the bottom ash layers has to pass through the ash in the lower part of the downstream edges (or flow along the outer walls at that place) to reach the drainage system. It was observed that the surface of the ash layers in units B–D and F were very hard, possibly due to carbonation. From the differences in the amounts of leachate collected in the downstream edge sections it appears that the lateral transport of leachate is highest for bottom ash from MSWI 1 and least important for bottom ash from MSWI 2. It also appears that for a new asphalt-covered road under conditions similar to those at the test site, a flow of leachate of less than 4% of the precipitation may be expected below the MSWI BA sub-base covered with asphalt.

4.2. Leachate quality: comparison of field and laboratory results

If the liquid to solid ratio (L/S) is defined as the amount of water (percolating rainwater), which at any given time has been in contact with a given amount of granular solid material (in this case the bottom ash) under conditions that approach equilibrium, leaching results (in terms of concentrations in the leachate or accumulated leached amounts of components) described as a function of L/S may be used to compare results of different leaching tests carried out on the same material. It may also be used to compare the results of laboratory leaching tests (e.g. column tests) to the results of field studies or large-scale lysimeters. For a given physical scenario under known conditions, the L/S-scale may be converted to a time-scale. In an up-flow column leaching test, it is fairly easy to ensure that that the flow is evenly

Table 5
Water balance result for test units B–E for the period October 2002 to January 2005

Unit	Origin of BA	Top cover	Percentage of precipitation collected as leachate			
			Upstream edges	Downstream edges	Middle section	Total
B	MSWI 1	Flagstones	16.2	51.6	7.2	75.0
C	MSWI 1	Pebbles	11.1	57.2	5.7	74.0
D	MWSI 2	Pebbles	17.0	30.9	17.2	65.2
E	MSWI 3	Pebbles	16.6	41.0	9.4	66.9
Approximate percentage of area			17–24	21–23	55–62	100

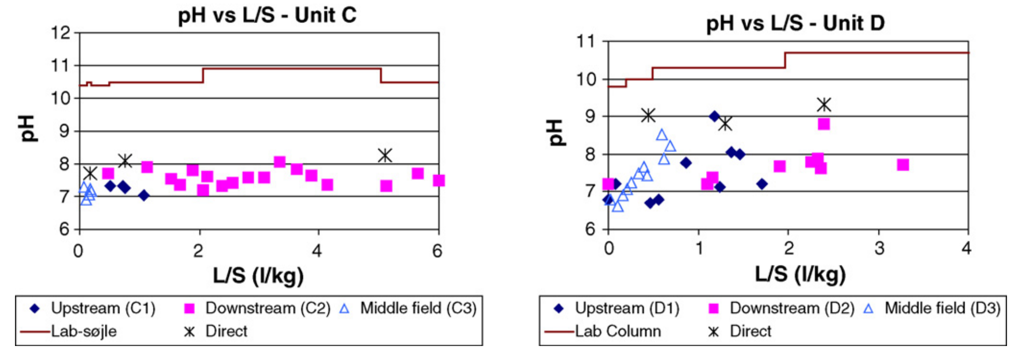

Fig. 8. pH as a function of L/S for the leachate collected from units C and D, for direct measurements in the collection wells and for laboratory column tests performed on the bottom ash in these units.

distributed across the column. In application sites like the test sites in this study, the bottom ash may be unevenly compacted and cracks may occur both in the bottom ash and the top cover, causing channelling and preferential flow through the material. If the progression of the leaching as a function of L/S, particularly at lower L/S values, appears to be faster in the field than in a very controlled laboratory leaching test, it may often be an indication of the occurrence of preferential flow.

Fig. 8 shows pH measured in the leachate from two of the sites, C and D, as a function of L/S (calculated separately for each section of the liner using the total dry weight of the bottom ash in each section as the basis for the calculation). The figure also shows pH of the eluates from the laboratory column tests performed on the bottom ashes in the two sites as a function of L/S, as well as measurements of pH in the leachate performed as the leachate was produced ("Direct")—as opposed to the other measurements which were carried out on leachate collected over some time. As can be seen, there is a substantial difference between pH observed in the column tests and that observed in the leachate. For site D, post-collection carbonation due to uptake of carbon dioxide from the atmosphere can explain most of the variation, but for site C (and for the other sites using MSWI 1), namely sites A and B there is little or no difference between the pH measured on-site and that measured in the collected leachates. For these sites carbonation in the collection system and a more pronounced preferential flow could be the explanation for the disagreement in measured pH. This would be in agreement with the more pronounced lateral flow for MSWI 1.

Fig. 9 shows a few examples of comparisons between the release of contaminants under laboratory and field conditions. In the figure, the concentrations of chloride, sulphate, nickel and antimony found in the leachate from site D are compared to those found in the eluates from the laboratory column test (CEN/TS 14405) performed on the same MSWI bottom ash. The concentrations are shown as a function of L/S, and there

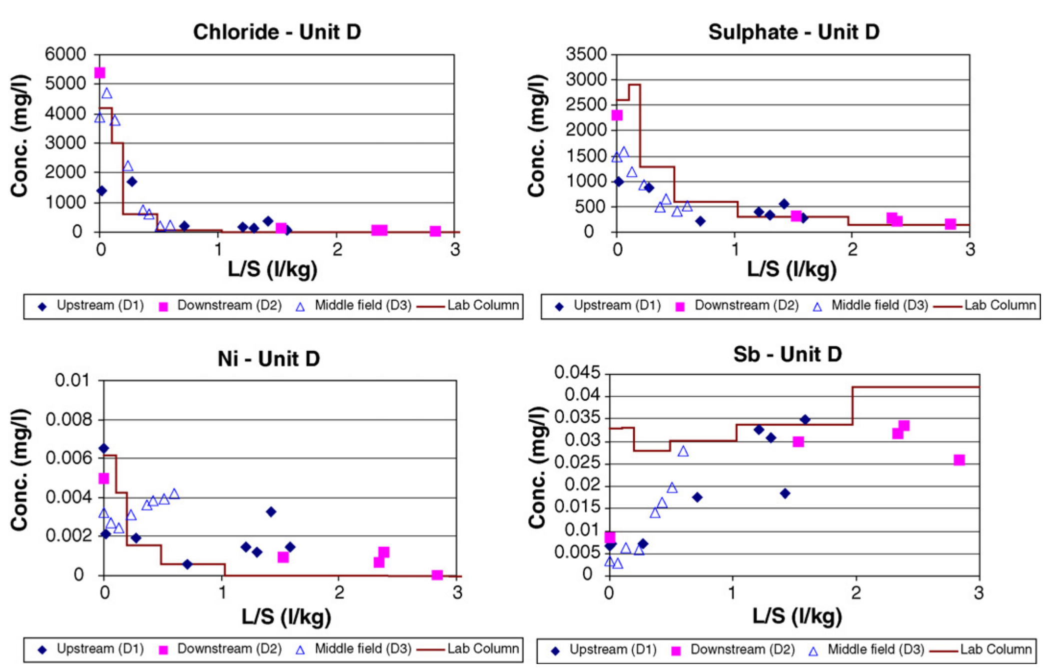

Fig. 9. Concentrations of chloride, sulphate, Ni and Sb in leachate from site D as a function of L/S.

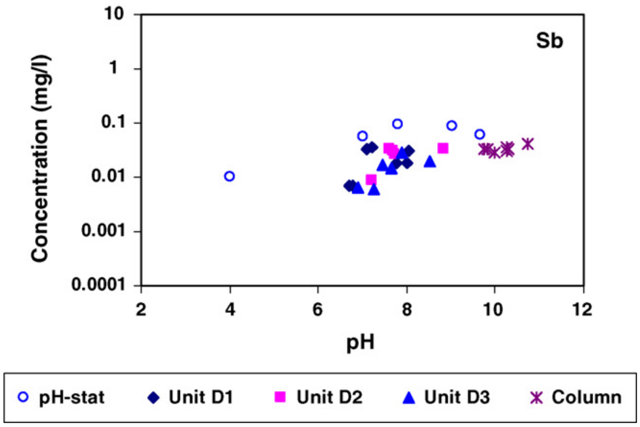

Fig. 10. Measured concentration of Sb in leachate from unit D and the elutes from the column test performed on the ash in unit D plotted with the results of the pH-static leaching test on that ash (see also Fig. 9).

is a reasonable agreement between laboratory and field results, particularly for the salt anions, chloride and sulphate. The initially low concentration of Sb in the field leachate is, however, not seen in the laboratory leaching test. Based on consideration of the influence of pH alone, one would have expected almost similar release behaviour of Sb under laboratory and field conditions (this is indeed observed at some of the other sites). Fig. 10 which shows the results of the pH-static leaching test and the column leaching tests on MSWI bottom ash 2 as well as the concentrations of Sb in the leachates collected from all three sections of unit D as a function of pH indicates that the leachate may be undersaturated with respect to Sb, possibly due to preferential flow in the test unit.

For some other parameters that are very pH sensitive, such as, e.g. Al, the observed differences between laboratory and field results are more pronounced.

The comparison between the results of laboratory leaching tests and field observations as well as the causes of the lowered values of pH under field conditions are subject to further investigation in the study.

With few exceptions, the release of the components investigated exhibit decreasing concentrations levels as L/S increases, although some, like Sb in MSWI 2, initially show an increase to a maximum.

5. Conclusions and perspectives

To evaluate some of the assumptions upon which the impact assessment modelling used in the setting of leaching criteria in the Danish regulation of utilisation of MSWI BA, a large-scale test site has been established. MSWI BA from three different MSW incinerators has been placed as sub-base in six test units with various types of cover and exposed to ambient conditions for more than 2 years. Preliminary water balance data and examples of leachate composition and laboratory characterisation data are presented and discussed. The surface of the MSWI BA sub-base layers are sloped (2.5%) and the results indicate that lateral flow on top of the surface of the sub-base plays an important role in the water balance. This effect varies with the ash type. There are also indications that edge effects and preferential flow may be important. A leachate production rate of approximately 4% of the rainfall was observed from the middle section of a sub-base layer, which was covered by asphalt.

Comparison of laboratory leaching test results and field observations show a substantial difference in pH for some of the test units (a lower pH probably induced by increased carbonation and preferential flow under field conditions). For most components, decreasing concentrations with increasing L/S and time are observed in the leachate. There is good agreement between the leaching of several components, particularly the soluble salts, under laboratory and field conditions when they are presented and compared as a function of L/S. For a number of pH-sensitive trace elements, the leaching is less comparable at some of the units. The exact causes of the lower pH under field conditions are being further investigated in the ongoing project.

The results of the regulatory leaching tests performed on the bottom ashes used at the site show non-compliance with Danish category 2 criteria, which allows utilisation under less restrictive conditions than category 3 criteria, with which all the ashes comply. Non-compliance for all the MSWI bottom ashes tested is also shown with the new European leaching limit values for acceptance of waste at landfills for inert waste.

The preliminary results indicate that there may be probable cause to review the assumptions made when the Danish MSWI bottom ash utilisation criteria was set, including the assumed constant source and the assumed rate of infiltration through asphalt-covered roads in the impact scenario modelling. The project has not produced results describing the attenuation of contaminants in the soil/aquifer, but the use of a decreasing source instead of a constant source in the calculations would mean that the inclusion of contaminant/soil interaction, e.g. in the form of sorption would lead to less conservative estimates of the impact for many components and hence possibly to less restrictive utilisation criteria without compromising the protection of the environment.

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