ASH INJECTION FOR LANDFILL STABILISATION

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SUMMARY: In the wake of the EU landfill directive, many Swedish landfills are being closed. However, final closure may be difficult in many cases where fairly large and sometimes uneven settlements can be expected that can ruin the top cover. One way to solve this problem is to increase the mechanical stability of the landfill by injection (grouting) of fines into the landfill voids. The division of Waste Science and Technology at Luleå University of Technology have been testing the injection of fly ash from the incineration of RDF for this purpose in two test areas at a landfill. As a total, about 100 tonnes of fly ash were injected. The work was performed on behalf of, and in co-operation with Telge Återvinning AB – a recycling company in Södertälje, south of Stockholm, ÅF-Energi & Miljö AB, Stockholm, and Tekedo AB, Nyköping, Sweden. Initially, different ashes were tested in the laboratory with regard to rheological properties and hardening reactions. During the autumn 2002 injection tests were performed at the Tveta sanitary landfill in Södertälje. During the winter and spring 2003 the testing area was dug up in order to document the injection results.

1. INTRODUCTION

1.1 Background

A typical problem with the final cover of municipal landfills is the risk for damages caused by differential settlements of the landfill body.

The purpose of the study was to investigate the potential for stabilization of sanitary landfills by injecting fly ash. The method is supposed to prevent differential settlements in landfills and therewith to counteract damages in the final cover. Since fly ashes often contain considerable amounts of sulphur, injecting these ashes may also affect the chemical development in the landfill in a positive way and prevent metal leaching.

Big efforts are put on the sealing of landfills in order to reduce emissions that could harm the environment. To fill voids within the landfill body with a proper material could be a complement to liner constructions above and below the waste.

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The injection of grout, *i.e.* non-hardened, pumpable cement mortar, in soil and rock has been applied in large scale for more than 30 years in order to improve the geological properties and to simplify the filling of cavities (Wikman et al. 2003, Stille 1997).

Fly ash is considered to be an alternative injection material which has a number of technical, rheological, and economical benefits. Dry fly ash mixed with water in certain ratio gives a pumpable grout which often hardens within a short period of time (hours to few days) due to hydration reactions. Such slurry can be injected into a MSW landfill. Well in place the ash will react with the carbon dioxide from the landfill gas which leads to carbonation and thus further stabilisation.

1.2 The Tveta sanitary landfill

Pilot tests were performed at the Tveta sanitary landfill situated outside Södertälje, 60 kilometres south of Stockholm. The Tveta landfill site is operated by Telge Återvinning – a 100 % municipality owned company. The area has been used as a landfill since the early 1960´s. From 1975 the municipality of Södertälje took over the responsibility for all waste handling. Today, the site receives waste from 80 000 households corresponding to 40 000 tons per year.

The waste is sorted into two fractions – biowaste and a rest fraction consisting of plastics, ceramics and other non-recoverable items. Both fractions are treated biologically in an anaerobic process before composting. The compost from biowaste is used in the community.

Methane gas is recovered and used for district heating. Studies have been carried out in order to verify the water balance of the landfill. Leachate is treated locally and recycled in a nearby forest. Excess water is pumped to a local recipient.

The sanitary landfill received during 2002 almost 200 000 tons of waste of which only 10 % were deposited due to a company plan to minimise landfilling of waste and to put all efforts on sorting of waste for re-use.

2. PRE-INVESTIGATIONS

2.1 Suitable ashes

The ashes used for injection derived from the incineration of RDF (refuse derived fuel) and biofuel, respectively. Materials burned are e.g. paper, cardboard, plastic, wood, and wood chips from sorted C&D (construction and demolition) waste, chipboards, and railway sleepers. Ashes from burning biofuel are most interesting for injecting in MSW landfills because they are not classified as hazardous waste.

The applicability of both fly ash (including APC[1] residues) and bottom ash was investigated. Apart from the chemical composition of the ashes, their physical properties such as particle size, pumpability with water, solidification ability, hardening behaviour, and viscosity of the slurry were of interest.

2.2 Physical and chemical characterisation

When arriving at the landfill, especially fly ash has different properties compared to the conditions directly after the incinerator because the ash has been moistened in order to avoid dusting during transport. Small lumps have formed and the moisture content is about 30 % of the wet weight (w.w.). Samples of fly ash that had been deposited a few days only contained a very

[1] Air pollution control

small portion of fine particles: only 25 % were smaller than 1 mm and 40 % smaller than 2 mm whilst a fresh fly ash sampled from the same incinerator was smaller than 1 mm to 100 %.
Since a fine structure of the ashes is considered to be important for a good miscibility with water the ashes were crushed and sieved. The fine portion increased to 40-60 % after crushing. However, proper equipment with an integrated (high-pressure) crusher will be able to render a homogeneous mixture also with lumped material.

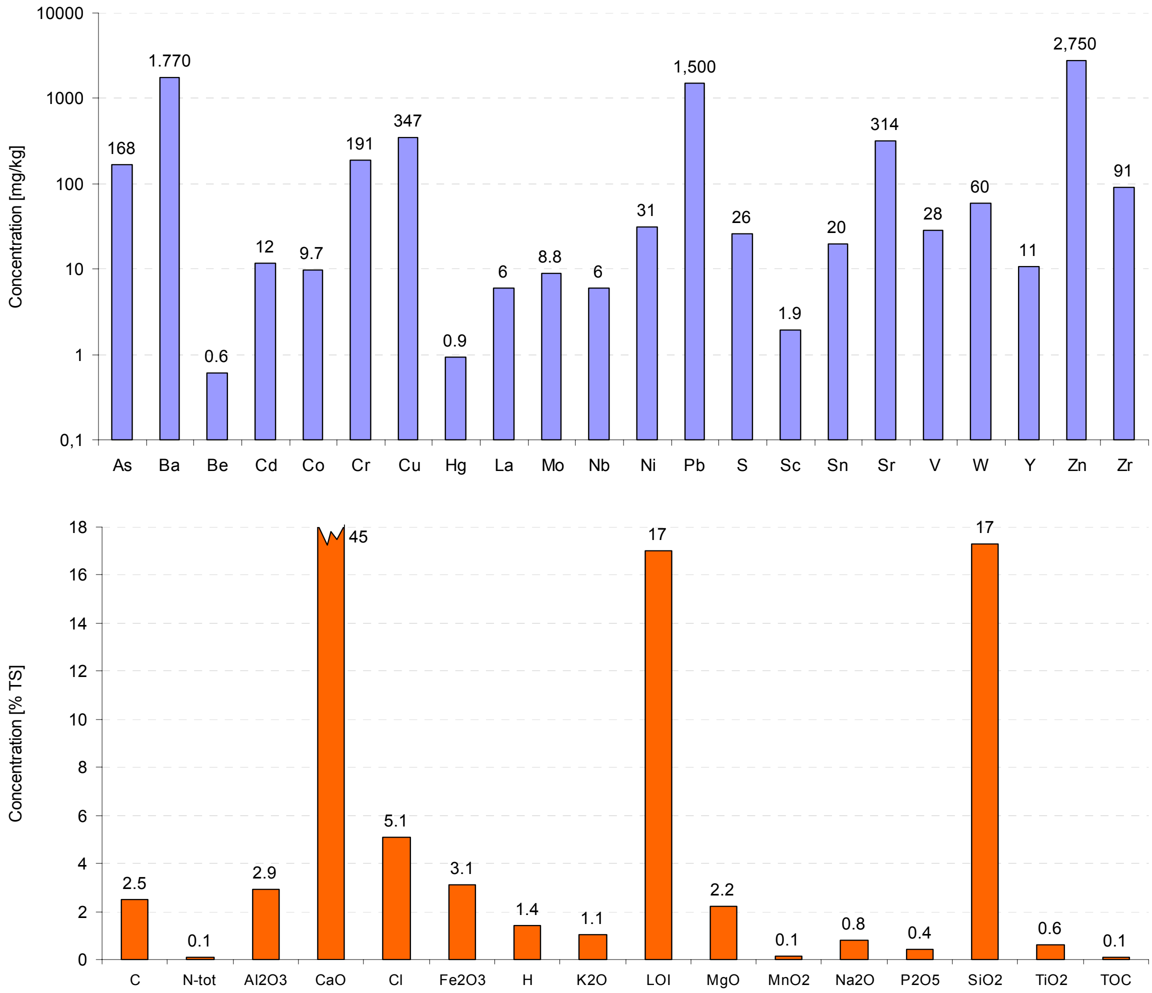

Figure 1. Chemical analysis of trace elements (mg/kg) and macro compounds (% TS) in the fresh fly ash that was grouted during the pilot experiments at the Tveta sanitary landfill.

The water holding capacity (field capacity) of the ashes was determined to about 35 % w.w. for fly ash and 26-28 % w.w. for bottom ash.

The chemical composition of the fly ash that primarily was used for the field tests is shown in Figure 1. The high content of CaO promotes the hardening of the ashes. The sulphur concentration was between 22 and 42 g/kg TS in different ashes and is beneficial for the immobilisation of heavy metals. The variations can be connected to different fuels at different times of sampling.

Tests with regard to the hardening behaviour showed that the ash-water-mixtures (at about field capacity, both fly and bottom ashes) did not harden as long as they were covered with a plastic film. After removing the film after 40 hours the fly ashes (FA1, 2, 3, see notes to Table 2) hardened within half a day. Looking at the bottom ashes, hardening could only be observed for

BA3 but not for BA1. The plastic film over the beakers with the sample mixtures prevented on the one hand water from evaporating and the access of CO_2 on the other hand.

2.3 Rheological properties

Values for viscosity and shear stress that are appropriate for injection were found in Kipko et al. (1993) and Kutzner (1996) and are compiled in Table 1.

Table 1. Suitable values for dynamic viscosity and shear stress according to literature.

Variable	Unit	Range	Reference
Dynamic shear stress τ	Pa	50 – 200	Kipko et al. (1993)
Dynamic viscosity η	Pa·s	0.02 – 0.07	Kipko et al. (1993)
- " -	- " -	0.8 – 1 (pumpable)	Kutzner (1996)

The rheological measurements were made with a ConTec rotation viscometer. Dynamic viscosity and shear stress were tested for fresh (recently landfilled) and aged fly ash, aged bottom ash and a number of mixtures of bottom and fly ash. The samples (about 6 litres each) were mixed with water by hand until field capacity was approximately reached. Then, depending on the result of the measurement, more water or ash was added in order to reach the requested values. The results are given in Table 2, together with the water content at which the best combination of dynamic viscosity and shear stress values was received.

Table 2. Water content, dynamic viscosity and shear stress in different ash-water-mixtures.

Mixture	Water content [%]	Shear stress τ [Pa]	Dynamic viscosity η [Pa s]
40 % FA1 / 60 % BA1 < 1,12 mm	29 %	13 - 30	0.3 - (0)
50 % FA1 / 50 % BA1 < 1,12 mm	35 %	20 - 28	(0)
55 % FA1 / 45 % BA1 < 1,12 mm	32 %	35 - 77	2.4 - 0.3
BA3, aged < 1,12 mm	37 %	23 - 48	6.3 - 0.2
FA3, aged < 1,12 mm	42 %	57	0.25
FA2 < 1,12 mm	34 %	60	0.22
FA2 < ca 5 mm (crushed, not sieved)	35 %	56 - 58	0.7 - 0.9

FA1 fly ash, sampled directly from a hopper at the incinerator and stored for 1.5 years (dry).
FA2 fly ash, deposited at the landfill for a few days.
FA3 aged fly ash, deposited at the landfill for more than one year.
BA1 aged bottom ash, deposited at the landfill for about 11 month, stored for 1.5 y, sandy consistency.
BA3 aged bottom ash, deposited at the landfill for more than one year.

Viscosity values in the desired order of magnitude could be achieved for all sample mixtures. However, shear stress values of above 50 Pa were only reached for the mixtures with fly ash and a high portion of fly ash, respectively.

The wide range of the results is mainly caused by the fact that the values changed over time until a certain balance was appointed. The mixtures with a high portion of the bottom ash BA1 settled during the measurement even though each measurement took only 3-4 minutes and the mixture had been homogenized directly before. The equipment gave error values for the viscosity which is marked with "(0)" in Table 2.

Especially the slurry of the fresh fly ash was rather sensitive to changes of the water content with regard to the measured viscosity and shear stress values. For example, small additions of water led to a noticeable drop of viscosity.

Hardening was not observed for any of the mixtures. The testing times were between two and six hours, for the first test (BA3) even over night (covered with film). All samples were homogenized right before each new measurement.

As a result of these tests, fly ash was chosen as preferable material to inject and the recommended water content in order to get pumpable slurries of the ash-water-mixtures was estimated to 35-45 % w.w.

3. FIELD TESTS

3.1 The test area at the Tveta sanitary landfill

The injection of ash slurry was tested in two different parts of the Tveta landfill:

- A part amidst the landfill with a surface area of about 200 m^2. Perforated injection pipes were plunged to a depth of 9 m. The waste in this area was a mixture of unsorted household waste and industrial waste (1:2) and was landfilled within the last two years before this study. Gas drainage pipes are placed in 12 m depth. The temperatures in the injection holes were between 30 and 53°C at 3 m depth and between 51 and 57°C at 9 m.
- A test cell of about 290 m^3 (6•6•8 m) bordered with railway sleepers and sealed with plastic film. It was filled with food waste (about 250 t) which was about seven years old. The temperatures at 3 and 6 m depth were between 20 and 30°C.

The upper 3 m of the injection pipes were not perforated. Assuming that the ash slurry spreads about 2.5 m around the injection holes and 0.5 m above and below the perforated section of the pipe, the landfill volume available for injection was estimated to about 1750 m^3 (7 m • 250 m^2). Including the test cell the total volume was about 2000 m^3.

The porosity of the landfill was estimated to 30-40 % whereof about half of the pores would be big enough to be filled with slurry. The pore volume within the injection area disposable for injection can then be calculated to 300-400 m^3. For the sealed test cell the whole volume is taken into account and thus the disposable pore volume can be calculated to 43-58 m^3.

3.2 Equipment for the injection

The pipes used for injection were ordinary gas drainage pipes made of steel with a diameter of 32 mm. The diameter of the perforation holes was 20 mm.

For pumping a platform ("Willisch") with a 150 litres mixing tank and a pumping capacity of 20-80 litres per minute was used, see Figure 2. A high pressure jet mill provided the mixing and smashed bigger ash lumps. A piston pump fed the slurry through the injection hose (commonly used for cement injection, diameter 25 mm) and a pressure sleeve into the injection pipes with a pressure up to 20 bar. The pressure sleeve was inflated and emptied with the help of a hydraulic pump.

Other types of equipment are available if one aims at higher throughput as would be the case for a full-scale application, e.g. injection of a whole landfill. For example, injection can be done simultaneously with the drilling, providing that the rig is equipped for injection.

Figure 2. Equipment for the injection tests: pumping platform with a 150 litres mixing tank (a), high pressure jet mill (b), equalization tank (c) and piston pump (d).

3.3 Injection of fly ashes in pilot scale

The field tests took place in November 2002. The ashes coming from the incineration plant were not older than about one week. Before mixing with water they were sieved to a particle size of smaller than 9 mm. The water content of the ash that came to the landfill was about 28 % w.w. The ash was injected with a water content of 45 to 65 % w.w., on average 48 % which corresponds to a volume ratio of ash to water of about 2.6 to 1.

Fifteen pipes were injected in the test area at the landfill and one in the test cell. Originally, more holes had been plunged but in the end only fifteen were used for injection. The amount of slurry injected per hole differed due to the inhomogeneity of the landfill body and because of plugging in the pipes. The latter one was also reason for the fact that the injection could not be performed from the deepest level at 9 m depth in all of the pipes.

Starting at the bottom level, ash slurry was injected in each level until a backpressure from the landfill would occur or until the slurry came up on the outside of the pipe, see Figure 3. Since backpressure occurred only due to clogging in the injection hose and pipe, respectively, and all holes should be used for injection within a certain period of time an amount of 1 m^3 of slurry per meter of pipe was defined to be injected before the sleeve was moved up to the next higher level. Without this limit, amounts of up to 10 tonnes of slurry (about 12 m^3) were injected into a single level in one hole without meeting resistance.

After removing the sleeve and the hose from a pipe the slurry rose in the pipe and came up to the surface. The slurry that rose within a pipe at the end of a working day usually was hardened the next morning so that injection could not be continued in this pipe. Figure 3 shows slurry of fly ash and water that had risen in and around hole 12.

All holes but two were injected with fresh fly ash. A test with aged bottom ash (as BA3) was truncated after a short time because of problems with stone-like hard lumps that led to repeated clogging in the injection hose or sleeve.

As a total, 75 tonnes of ash slurry (about 87 m^3) were injected into the test area at the landfill and 24 tonnes (about 27 m^3) in the test cell. This corresponds to a filling degree of the disposable pore volume of 22 to 29 % for the landfill area and 46-52 % for the test cell.

Figure 3. Slurry of fly ash and water around an injection hole with injection hose and hydraulic hose. The slurry rose outside the injection pipe and also inside the pipe after the pressure had been removed from the sleeve.

Documentation and quality control was done during the whole injection period. Samples were taken for the control of viscosity, water content, density, and hardening time of the grout.

The water content in the field tests was somewhat higher than was suggested from the lab experiments. Yet, the viscosity of the mixtures was with values between 0.07 and 0.5 Pa s within the range that is recommended in the literature for pumping and grouting. Longer mixing times (the normal mixing time was about 3-4 minutes) led to a more viscous slurry which did not cause problems for the equipment. Apart from freezing due to *unbeneficial* weather conditions on some days, hard ash lumps or stones and metal pieces in the ashes were actually the *only* factors that caused problems during the injection.

3.4 Evaluation and follow-up

In order to evaluate the impact of the injection, *i.e.* if and how far the ash slurry spread around the injection holes, how well it filled available voids, if the material hardened etc., the following measures were carried through:

- Measurement of gas emissions at the surface of the areas intended for injection;
- Measurement of H_2S in the injection holes;
- Measurement of settlements while loading the injected area and a reference area with a weight according to a landfill cover construction (about 4.5 t/m^2);
- Excavation of a part of the landfill test area as well as the test cell.

No methane emissions could be observed based on the surface emission measurements that were performed in 21 spots on both the landfill area and the test cell at three different days for each spot before the injection. The hypothesis was that the methane emissions would decrease due to the injection but since no methane had been detected before the injection the analyses were not repeated afterwards. Instead, the concentrations of methane and hydrogen sulphide were measured inside some of the injection holes (some of them were totally filled with grout). The results indicate that the concentration of both gases is slightly lower in those holes that had been injected compared to some empty holes. However, the variety of the results is big and no clear conclusions can be drawn.

The measurements of settlements took place about two month after the injection had been finished. They did not show any significant differences between the injected area and the reference area. The weights had settled on average 72 mm within a period of 32 days for both areas.

About three month after the injection a part of the landfill test area as well as the test cell were excavated. Only little ash could be found during the excavation: less than 10 % of the injected volume of ash slurry. It was not possible to clearly determine from which hole the ash had spread and how it had moved through the voids. The ash was found in the form of lumps of the size of some millimetres up to some centimetres. The consistency of the ash lumps was hard and often brittle.

4. CONCLUSIONS

About 100 tonnes of ash slurry were injected during the pilot experiments. This corresponds to a filling degree of 22-29 % and 46-52 % of the available pores in the landfill body and the test cell, respectively. As a result of both the lab and the pilot tests, the following conclusions can be drawn:

- Ash is miscible with water to a pumpable slurry that can be injected without hardening inside the equipment.
- Fly ash worked better than bottom ash mostly because of its finer consistency. From the pre-investigations only minor differences could be observed for fresh and aged fly ash.
- Neither the waste nor the grouting material caused a backpressure during the injection and nothing indicated that the injected ash deforms the landfilled waste. The ash-water-slurry flows through the voids in the waste easily and may thus dispread quite far from the injection holes. Using a more powerful equipment backpressure and movements in the waste might occur. It was not possible to estimate the flow required for backpressure in this study. Large variations are possible but for safety reasons the maximal pressure should be limited with regard to the expected stability in the actual area.
- The grouted ash will harden within the landfill body within a couple of days. It accumulates in hard but brittle lumps, which may result in an increased stability of the landfill. Further studies are necessary in order to evaluate how the stability is affected and what amounts of ash are required. Grouting of about a thousand tons of ash in a landfill is probably needed to achieve noticeable affects.
- The economic evaluation in this study shows that it is beneficial to use relatively large equipment for grouting in landfills. The cost will be about 800 SEK/tons of dry ash (85-88 Euro) if the equipment has a capacity of 10 tons per hour (including drilling and operating crew). However, this cost could probably be reduced to the same level as today's landfill tax in Sweden (370 SEK/ton, about 40 Euro) if the drilling and grouting is performed in one step and the work is done in two shifts.
- Another advantage with large equipment is that the grouting could be performed continuously in a process where drilling of the grouting holes and grouting is done at the same time. Equipment with a capacity of 100-200 liters per minute and a mixing tank for at least 500 kg material is recommended for grouting in landfill areas. The pump should have a maximal pressure of 20-30 bar to open up fractures in the waste during the start of the grouting work.

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