Waste Management 35 (2015) 148–158

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Development of drainage water quality from a landfill cover built with secondary construction materials

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ARTICLE INFO

Article history:
Received 21 March 2014
Accepted 17 September 2014
Available online 8 October 2014

Keywords:
Landfill cover
Ash
Sewage sludge
Drainage water
Leaching

ABSTRACT

The aim of this study was to evaluate the drainage water quality from a landfill cover built with secondary construction materials (SCM), fly ash (FA), bottom ash (BA) sewage sludge, compost and its changes over time. Column tests, physical simulation models and a full scale field test were conducted. While the laboratory tests showed a clear trend for all studied constituents towards reduced concentrations over time, the concentrations in the field fluctuated considerably. The primary contaminants in the drainage water were Cl^-, N, dissolved organic matter and Cd, Cu, Ni, Zn with initial concentrations one to three orders of magnitude above the discharge values to the local recipient. Using a sludge/FA mixture in the protection layer resulted in less contaminated drainage water compared to a sludge/BA mixture. If the leaching conditions in the landfill cover change from reduced to oxidized, the release of trace elements from ashes is expected to last about one decade longer while the release of N and organic matter from the sludge can be shortened with about two–three decades. The observed concentration levels and their expected development over time require drainage water treatment for at least three to four decades before the water can be discharged directly to the recipient.

1. Introduction

A landfill cover is a multilayer construction that serves to reduce infiltration of water to the deposited waste and to minimize emissions of landfill gas into the atmosphere. According to Swedish legislation, a top cover must be installed after landfill closure for both municipal solid waste as well as hazardous waste landfills (SFS, 2001). A landfill cover is usually built using a combination of natural materials (e.g., gravel, sand, till and clay) and synthetic materials (e.g., geomembranes). In order to preserve natural resources and to reduce costs, re-using wastes like ashes or treated sewage sludge can be an option. However, such materials may leach contaminants as trace metals, nitrogen and organic matter.

Looking at possible pollution pathways from such a cover, two types of water can be distinguished: leachate that percolates through the whole cover construction into the waste below, and drainage water that only seeps through the layers above the liner and is collected in the drainage layer. The latter is usually discharged via a ditch at the bottom of the landfill slope. At covered landfills, apart from the surface run-off, the drainage water will be the dominating water emission while leachate amounts are expected to be rather low. Previous studies have shown that the quality of the drainage water depends primarily on the materials installed above the liner (Travar et al., 2009). In cases where SCM are used, it is most likely that the drainage water cannot be discharged directly to the local recipient but needs at least some kind of treatment. Hence, it is important to determine the quality of the drainage water and its expected changes over time.

To be able to evaluate leaching trends, the conditions prevailing in a landfill cover must be known. Material properties, water infiltration and transport, redox potential, pH and temperature are relevant factors that affect the chemical conditions and thus the drainage water quality (Kylefors et al., 2003; Sabbas et al., 2003; van der Sloot, 1996). Changes of these factors result in changes of the chemical conditions by e.g., complex formation, acid-base reactions, redox processes, precipitation and dissolution reactions, adsorption and biochemical processes.

The main aim of this study was to evaluate the quality of drainage water generated in a landfill cover built with compost, ashes and sewage sludge as well as the development of the water quality over time. The evaluation was based on a full-scale field test, laboratory physical models (hereafter referred to as simulators) and column leaching tests. Differences between the field and laboratory tests and the influence of single layers on the drainage water

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http://dx.doi.org/10.1016/j.wasman.2014.09.016
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quality were discussed. Treatment needs for the drainage water were assessed based on predictions of the laboratory results in combination with the results from the field. Geochemical equilibrium calculations were used to identify mineral phases that may control the release of elements from the cover.

2. Material and methods

2.1. Full scale test

A four hectares landfill cover composed of recycled materials was established at the Tveta landfill, 30 km southwest of Stockholm, Sweden. The area was divided into six parts each using different materials. Out of these, two areas were evaluated in this paper; A1 and A4 completed in September 2003 and March 2005, respectively (Fig. 1). The areas were hydraulically separated from each other.

The foundation of the landfill cover consists of bottom ash (BA) in A1 and sand from fluid bed incinerator (FBI) in A4. This layer is connected to the gas collection system in order to avoid the accumulation of landfill gas underneath the liner. The liner consists of fly ash (FA) in A1 and a mixture of FA and BA in A4. It serves as a barrier against infiltrating precipitation water into the deposited waste and reduces landfill gas emissions. A coarse fraction of BA (>10 mm) was used in the drainage layer above the liner to collect and discharge water that percolates through the layers above. The protection layer consists of a mixture of digested and composted sewage sludge and FA in A1 and the fine fraction of BA (<10 mm) in A4. The function of this layer is to protect the liner from desiccation, freezing and root penetration. A layer of compost was placed on top of the ash-sludge mixtures in order to avoid erosion and to promote the establishment of vegetation.

The run-off from the drainage layer was sampled from wells installed in covered ditches at the bottom of the slope (Fig. 2). These wells collected drainage water from an area of about 2300 m^2 in A1 and 1900 m^2 in A4. Sampling of drainage water was performed four times per year. Totally, 20 and 9 samples of drainage water were taken from A1 and A4, respectively.

Samples of the pore water from the bottom of the vegetation layer were taken at one occasion during autumn 2008. Rhizon pore water samplers (polymeric, 10 cm long, Ø4.5 mm, medium pore size 0.1 μm, MacroRhizon, Eijkelkamp, Netherlands) were used to take four samples in A1 and A4 each. All samples were stored frozen at −20 °C prior to analysis.

The temperature in the protection layer was measured with three vertical probes installed in each area. Each probe had sensors at three depths: at the bottom, in the middle and at the top of the protection layer.

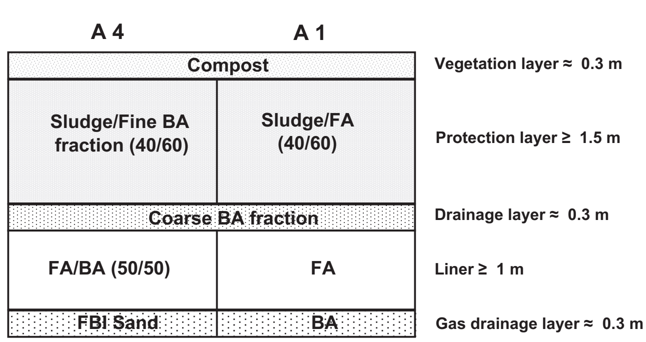

Fig. 1. Design of the sub-areas A1 and A4 of the landfill cover test area at the Tveta landfill. BA = Bottom ash; FA = Fly ash; FBI = Fluid bed incineration.

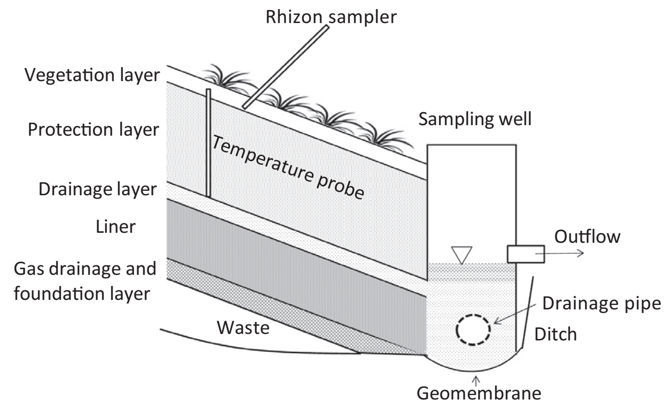

Fig. 2. Cross section of the landfill cover test area with measurement equipment.

The liquid to solid (*L/S*) ratio was used for comparison of the results from the full scale test with those of the laboratory tests. The following equation was used to calculate the *L/S* ratio in l kg^{-1}

$$L/S = (L/S)_0 + (I/(\rho \cdot h)) \quad (1)$$

where $(L/S)_0$ is the initial *L/S* ratio, *I* is the net water infiltration through the material in l m^{-2}, ρ is the compacted dry density of the material in kg m^{-3} and h is the total height of the protection and vegetation layer in m. The initial *L/S* ratio was calculated as the ratio between the total amount of water and the total amount of solid material in the layers above the liner. The initial *L/S* ratio in both areas was 0.9 l kg^{-1}. The *L/S* in the full scale test was calculated based on the actual precipitation and for a Swedish conditions typical hydrological regime assuming that about one third of the precipitation infiltrates into the ground while the rest evaporates and runs off as surface water (Raab and Vedin, 1995). A *L/S* of about 0.17 l $(kg\,yr)^{-1}$ was estimated which gives a cumulative *L/S* 1.9 l kg^{-1} after 6 years for A1 and 1.8 l kg^{-1} after 5 years for A4.

2.2. Materials

The ashes used in the liner originate from an incineration plant with three furnaces; grate type, fluid bed and pulverized fuel incinerators. The grate type incinerator is supplied mainly with paper, plastic, wood and wood chips. The fluid bed and the pulverized fuel incinerators are fed mainly with wood and peat.

The FA is a mixture of electrostatic precipitator ash and bag house filter ash, containing among other, reacted and unreacted lime from the semi-dry flue gas cleaning process and ammonia. It was moistened prior to transport and used immediately after arrival at the landfill. When this was not possible, FA was stored covered by tarpaulins. At the time A1 was built, the FA and BA were not yet separated at the incinerator. The mixed ash was sieved at the construction site (<10 mm) which means that the used "FA" actually was the fine fraction of a FA–BA mixture containing FA predominantly. At the time A4 was built, FA and BA were separated at the incinerator and mixed in 50:50 ratio by weight at the landfill prior to construction. Most of the BA came from the grate type incinerator.

For the drainage and protection layer, BA from a municipal solid waste incineration (MSWI) plant was used. It was quenched and then stored for a couple of months for drying and aging. Afterwards, magnetic components were removed, and it was sieved through 8 mm mesh sieve. The coarse fraction was used in the drainage layer while the fine fraction was mixed with sewage sludge to build the protection layer.

The sewage sludge derived from a municipal wastewater treatment plant where it was an aerobically digested and dewatered. It