CLOSING OF SMALL DUMPSITES IN ESTONIA – FOCUS ON LEACHATE, GAS, AND AFTERCARE REQUIREMENTS

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Abstract. Until recent years, waste management practice in Estonia has been strongly landfill-orientated. The number of landfills exceeded 300, whereas most of them were very small. Almost all of the old landfills have been closed and covered by now as the national policy targeted. This opened a discussion about requirements for post-closure procedures and aftercare. From 2003 to 2006, about 40 previous dumpsites were inspected to evaluate their environmental status. In one landfill, a monitoring network was established to measure the emissions of landfill gas and predict its migration routes. As concluded, no significant environmental hazard was detected from small landfills, suggesting that the gapping technology was sufficient. In most landfills, however, there was a need for various immediate aftercare procedures. Based on the investigations, recommendations for corrective aftercare measures were proposed.

Keywords: landfill cover, landfill gas, methane emission and oxidation, inspection, corrective measures.

1. Introduction

During decades, most of the municipal wastes were discarded without regard to protecting the environment. Numerous villages, towns and larger industrial or agricultural enterprises used to have their own landfills for solid wastes. In 90ies, about 530 landfills were listed in Estonia [1]. Usually, landfills were constructed in abandoned quarries, pits, or other depressions in the earth, and without any bottom liner. As characteristic to Estonia, most of the dump sites were very small. Only 6% of landfills were larger than 6 ha. However, as much as 75–80% of the municipal waste was deposited of in 15 larger landfills. About 37% of landfills were with area 6 to 1.5 ha, and as much as 57% of landfills were smaller than 1.5 ha. About 70 landfills did not exceed 0.7 ha [2]. Because of the large number of small landfills (<2 ha), their total area was estimated to be 150–160 ha, which is about half of the overall area of landfills in Estonia.

The environmental impact of landfills can not be estimated on the basis of their area and volume. Environmental risk must be assessed on the basis of three main components: source of risk (leachate, gases), routes of spreading of pollutants (surface water, groundwater, air) and the object at risk (water intake, recreational areas, animal feeding, etc.). The most critical hazards are leachate and landfill gas (LFG).

The water budget of the landfill can be expressed by the equation (1):

\[ P + SI + MI = ET + SR + L + G + U + C_w \]

where \( P \) is leachate generated, \( SI \) is surface water inflow, \( MI \) is managed water input, \( ET \) is evapotranspiration, \( SR \) is surface runoff, \( L \) is leachate generation, \( G \) is water vapour contained in the LFG, \( U \) is water consumed by chemical or microbial processes, and \( C_w \) is change in moisture content of wastes.

If the cover material is added, the actual changes in water content in the cover material should also be considered.

The emissions of LFG may lead to negative effects in the surroundings; fire and explosion hazards, health risks, damage to vegetation, odour nuisances, groundwater contamination, and it contributes to global climate warming [3]. The methane budget is described in equation (2) [4,5,6]:

\[ CH_4 \text{ emission} = CH_4 \text{ production} – CH_4 \text{ extraction} – CH_4 \text{ oxidation} – CH_4 \text{ migration} – CH_4 \text{ storage} \]
Many factors and processes affect LFG generation and migration [3,7]. The processes are: diffusion, advection, dilution, dissolution of LFG in water, sorption to soil particles and methane oxidation. The factors affecting these processes are waste and landfill conditions (e.g. gas production rate, release of volatile organic compounds (VOC), internal barriers, gas ventilation wells, and lateral migration area), and soil conditions (e.g. cracks and fissures, permeability, diffusivity, porosity, water content, and content of organic matter).

Emissions are difficult to measure, since [3,5,6]:
- the spatial emissions per m² on a single capped landfill has been found to vary about three orders of magnitude;
- emissions from landfills with comparable size has been found to differ by at least one order of magnitude;
- the amount of emitted methane is a subject of hourly or daily variations, and is depending on meteorological conditions: barometric pressure, precipitation, temperature, and wind;
- the oxidation of LFG is a subject to seasonal variation. The total methane oxidation rates have been found to range from 4% to 50% of the methane flux through the cover at sites with positive emissions.

According to the Estonian Waste Management Plan [8], adopted by the EU Landfill Directive [9], all landfills which did not meet the environmental standards had to be closed at the latest by 2009. In 1999, as much as 221 and 47 landfills were in operation for municipal and industrial waste, accordingly. Between November 1999 to December 2000, 180 municipal landfills were closed for dumping. This resulted in massive capping works between 1999 and 2004–05, as part of the national policy.

The Estonian Landfill Regulations [8] established the requirements for closure procedures. Environmental departments were allowed to simplify these requirements on the basis of environmental impact assessment and environmental risk assessment. Therefore, most of the small landfills in Estonia have been covered in a simplified manner. As a typical solution, the landfill bodies were profiled to egg-shape, and covered by a layer of soil (Fig. 1). A couple of passive gas-ventilation wells were installed in each of the landfills.

The ways in which landfill covers were technically implemented in Estonia were somewhat different since it affected the cost of the closure. Generally, the landfill covers are intended to remain in place and provide protection to the environment for a number of years. In small municipal landfills, waste eventually fully stabilises. In larger landfills, stabilisation takes longer, perhaps centuries. However, the knowledge and technologies in properly closing the landfills have only been in existence for about 20–30 years. It is not known exactly how the landfill cover performance will change over time, and how much maintenance they require.

The cover of the landfill has to:
- isolate wastes to prevent direct contact with wastes, and control littering by wind or water;
- provide erosion control and slope stability, allow surface water management and form the basis for vegetation;
- minimize infiltration to prevent water from percolating through the waste where it forms leachate;
- control LFG to prevent the release of explosive and toxic greenhouse gases.

Standard procedures for maintaining capped landfills do not exist in Estonia, and must be established. The objectives of this research were:
- to identify environmental hazards in closed and capped landfills;
- to create a methodology for inspection of environmental status of small landfills;
- to inspect generation, release, and migration of LFG.

2. Methods

2.1. Inspection of landfill sites

From 2003 to 2006, 39 inactive landfills were inspected to evaluate their environmental status [16]. The following aspects were described and assessed:
- Location and access to the site and general appearance of the site;
- Shape of the landfill body: slope gradients and erosion, cracks and settlements;
- Cover material: type and depth of cover material, vegetation layer and its maintenance;
- Ditches: depths, slope, outlets, and sediments;
Leachate and surface run-off: where possible, electrical conductivity of the run-off water was measured;
Landfill gas: conditions of the gas wells.

2.2. The gas study

The site
The Laguja municipal landfill is an unlined landfill situated in a groundwater recharge area in Tartu County, South Estonia (N 58:09:51, E 26:26:54). The dumping area occupies 1.4 ha and it contains about 40 000 tons of waste. The landfill was closed in 2004, and covered by 2005 as described elsewhere [10–15]. A monitoring network was established in 2006, and, during seven weeks, the emissions of LFG were measured and its migration routes evaluated [17].

Gas sampling methodology
A combination of measurement methods was selected from a large number of gas sampling methods [5]:
MI: A static closed chamber-method was used for rapid screening of spatial gas emissions through the cover layer. A 45-litre sampling box was placed on the landfill cover and sealed by soil. Increase in concentration of methane in time (0.5 h) was measured. Methane fluxes through the surface were obtained from the rate in increase of concentrations.
Closed chambers are simple, easy to understand and applied world-wide, although correlation problems between neighbouring sampling points occur [18]. In order to get good correlation, at least 20–30 measurements are recommended [18]. In Laguja landfill, LFG was measured in 20 points inside the landfill borders, and in 5 points outside it (Fig. 2). Vegetation was removed from sampling points, as for CO₂ emissions may be influenced by assimilation-dissimilation patterns of the vegetation. In sampling points A2 and A6 (Fig. 2), cover material was removed and the measurements were repeated directly from waste. Occasionally, gas was attempted to detect from cracks and cavities by using the same method.
MII: Dynamic closed chamber-method was used as a modification of static chambers. A continuous gas-flow was maintained through the box by using a battery-operated ventilator as recommended [5].
MIII: There are two passive gas outlets, installed as part of the closure design (h = 1 m, d = 1 m, and filled with macadam). Both of them, K1 and K2 (Fig. 2) were covered by a plastic tent for one week, and gas concentrations measured directly from the air-space under the tent.
MIV: Four sets of gas wells (Fig. 3) were hammered into the cover material and waste in locations A1–A3, and A6 (Fig. 2) to determine gas concentrations in different depths. Each set consisted of four 15 mm metal tubes with perforated ends as described on Fig. 3. The outlet of the tubes was sealed with rubber valve to prevent oxygen intrusion between sampling events.

Four additional shallow (0.5 m) gas wells were installed to monitor horizontal migration of the gases (A7–A10, Fig. 2 and 4).

2.3. Equipment

Portative instruments: penetrometer MTP-1 (Russia), slope compasses (Silva Eclipse Pro, Sweden and GK-2 N5982, Russia), electrical conductivity meter (Eutech Instruments CyberScan CON 11, Singapore), and a portable gas analyser GA2000 (Geotechnical Instruments, UK) were used. The accuracy of the infra-red absorption gas-analysers was: CH₄ ± 0.5%; CO₂ ± 0.5%, and O₂ ± 1%, and the accuracy of the electrical conductivity meter was ± 1%.

![Fig 2. Gas sampling points at Laguja dump site: 1–25 is a screening network; K1 and K2 are passive gas vents; A1–A3 and A6 are sets of gas wells, and A7–A10 are wells for determining migration of gases](image)

![Fig 3. Set of gas wells](image)
3. Results

Inspection of landfill sites

The inspected landfills were 1–3 ha large, the age was approximately 30 years, and they were capped approximately 1–4 years ago. The landfill body was damaged by uneven settlements in 11 landfills (28%). In 28 landfills (72%), the waste had been compacted sufficiently, and no settlements occurred. The slope was much too steep (>1:3) in 2 landfills, acceptable (1:3–1:10) in 26 and too gentle (<1:10) in 11 landfills. Very steep slope is a subject for erosion, and too gentle slope poorly compensates uneven settling.

In 13 landfills (33%) the cover layer was thicker than 0.5m, but in 26 landfills (67%) it was less than 0.5m. This can be considered inadequate. Sometimes, the waste items were penetrating through the cover, posing a threat to humans and animals.

There were serious problems with ditches and run-off management in 27 landfills (69%). The ditches were too shallow, with negative slope, eroded, filled with sediments, or not connected to the recipient. Run-off water was possible to collect in 17 landfills (44%). The conductivity exceeded 1000 µS cm⁻¹ (maximum 7200 µS cm⁻¹) in 10 landfills. Leachate was not possible to collect in any of the landfills. The passive gas outlets were generally not damaged.

In all sites but one, no kind of aftercare activities (e.g. mowing) were detected. Some landfills were reopened by local people, which must be considered unacceptable. Sometimes the thin cover layer was seriously damaged by off-road heavy machinery.

The gas emission monitoring

LFG is not actively extracted in small landfills. Following the methane budget as described in equation (2), storage and migration issues are relevant for considering emissions, therefore must be determined.

The cover layer of Laguja landfill was 0.39 m thick as an average, being thicker (max 0.56 m) on top of the landfill and thinner (min 0.2 m) in the edges. This is less than in typical landfills, where thickness up to 1.0 m is targeted.

The rate of gas emissions through the cover as measured by MI method was 0.0075–0.022 m³m⁻²h⁻¹. No significant differences in results between methods MI and MII was found. The rate of gas emissions from passive gas vents (M III) was 0.1 m³ m⁻²h⁻¹. This demonstrates that the gas vents were fully operational. The net daily methane emission was 27 m³ CH₄ ha⁻¹d⁻¹ per each ventilation well. The hourly rate, 1.125 m³ CH₄ ha⁻¹h⁻¹ is much less than the limit value for establishing active gas collection system, used in Finland [17]. In A2 and A6, methane was found in high concentrations (max 70% in A2, 1.5 m deep). This demonstrates that the landfill contains easily degradable organic matter, and the decomposition process is very active. Methane, however is not freely escaping as no methane was detected outside the landfill borders, in A7–A9. Vertical profiles of LFG components demonstrate that an intensive methane oxidation takes place in the upper part of the landfill. In gas mixture from upper layers, mainly carbon dioxide was found. Methane flux in different depths refers on a balance between generation and oxidation of methane in the landfill body (Fig. 5, 6 and 7).

In A6 at 0.75 m (Fig 7), the larger fluctuations of methane concentration possibly refer on active oxidation of methane because of deep intrusion of oxygen. Despite of the very warm season, the waste underneath the cover material was found relatively moist. This demonstrates relocation of moisture by migration of gases, which must also be considered in water budget (equation 1), if
necessary. Humid environment is known to contribute to biological oxidation of methane [4,19,20].

![Graph showing methane concentration in vertical profile A6 as a function of time.](image)

**Fig 7.** Methane concentration in vertical profile A6 as a function of time

### 4. Conclusions and recommendations

Small inactive landfills can be considered as a source for point-pollution. Major environmental problems are due to leachate and gas. An appropriate cover design significantly reduces environmental risks. Generally, most of the visual aspects of the landfill inspection (e.g. shape of the landfill body, erosion, cracks etc) were directly dependant on the capping technology. If the slopes were correctly done (1:3 to 1:10), sufficient cover layer applied, and dense grass layer developed, then the landfill requires minimal corrective actions. A common mismanagement aspect was insufficient mowing of vegetation. In early capping stage, a dense grass cover is required, but bushes and trees are not.

Usually leachate can not be managed in small landfills, but the run-off water should be collected by open ditches and removed. Treatment of the run-off depends on its quality. Therefore, sampling wells may have to be installed. Direct discharge of the run-off water is unfavourable. Instead, some part of the ditch should be modified to serve as the oxidation ditch or constructed wetland.

Ventilation outlets must be inspected at regular intervals to ensure that they are not plugged and are operating properly. Damaged ventilation pipes must be repaired promptly. It is not recommended to carry out extended gas measurements as a standard procedure on former landfills. As found in the study, methane is generated in the landfill body, but it is not escaping easily. Evidence from natural oxidation of methane was found, which is favourable. No horizontal migration of gas was detected. Only in cases where these conclusions can not be drawn, a further assessment of the gas emission is recommended.

In most landfills, there was a need for various immediate aftercare procedures. To decide upon remedy, landfills must be regularly inspected. It is necessary to monitor the landfills on yearly base during three years after their closure. Later on, monitoring may take place once per three years. The inspection of the surface of a landfill cover is straightforward. The overall inspection check-list for small landfills is summarized as follows:

**Site**
- Is the access to the site restricted?
- Is the site aesthetical?
- Is there any scattering of waste by wind or water?

**Cover**
- Is there any direct contact with landfill contents?
- Is the landfill body re-opened by residents?
- Is the landfill cover eroded (by wind and water)?
- Is the surface covered by vegetation?
- Is there any bush or tree root intrusion into the waste?
- Is there any animal intrusion into the waste?

**LDFG and odours**
- Do passive gas wells exist?
- Are the gas wells operational?
- Does the gas disposal equipment exist?

**Water**
- Does surface water drainage exist?
- Is the surface drainage operational?
- Is the surface run-off collected and removed?
- Is the surface run-off water treated?
- Is infiltration into the waste minimized?
- Is leachate collected and removed?
- Is leachate treated?
- Does groundwater contact with the waste exist?

**Other**
- Are there any other site-specific requirements?
- Based on the check-list, the following action plan can be recommended:
  - Minor corrective works include mowing grass and removing bushes, maintaining ditches (removing sediments and erosion faults), removing waste items, correcting minor erosion damages, monitoring gas wells, and removing litter.
  - Major corrective works include correcting large erosion damages and filling of settling cavities, digging new ditches and supporting their slopes, constructing wetland systems for treating run-off waters, adding gas wells, and adding cover material or correcting slopes. These activities may require approval by the authority in each particular case.

It is critical to store the landfill coordinates in databases of the local authority. As observed, the landfill sites were very difficult to find as they are becoming a part of the nature.

In general, no significant environmental hazard was detected from small landfills, suggesting that the capping technology was favourable to the nature. However, they must not be forgotten. Aftercare activities and corrective measures should be a part of a National Waste Strategy. All inactive landfill sites should be evaluated to estimate risks to human health and the environment. The Decision Tool for Landfill Aftercare has to be developed on a National base to provide the municipalities with guidance in determining whether the presumptive remedy is appropriate for a specific landfill and in selecting the necessary components to adequately contain the waste.
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References