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FULL-SCALE PROJECT: FROM LANDFILL TO RECREATIONAL AREA

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ABSTRACT

Due to the harmful effect on the environment, landfill gas has to be collected and processed. One of the possible solutions would be to cover the landfill with a bioactive layer, where methane is oxidized. The main goals of the closure project at Kudjape landfill were to extract the fine < 40 mm fraction from the landfill in order to construct a methane degradation cover and to transform the closed landfill into a recreational area. Multi-purpose pathways were designed to cover the remediated landfill and were connected to the existing trails nearby. The trails can be used for jogging, hiking or biking and during winter time, for skiing and sledging. The surrounding area was cleaned from fly trash and new vegetation was planted into the cover layer. Car park and rest areas were created to attract people. The installation of the methane degradation layer along with the landscape restoration were finished in autumn 2013. Soon after the restoration it was noticed that some of the planted trees were not adapting to the environment and died off. The current study describes the extent of die-off over time, focuses on understanding the reasons for vegetation failure, and proposes measures to correct them. The research continues to monitor the processes within the methane degradation cover layer in order to provide recommendations for similar projects in the future.

1. INTRODUCTION

Many closed and reclaimed landfills are situated near to or within inhabited areas. This makes it attractive to use them for beneficial purposes. Concepts for remediation of large scale brownfields into multi-purpose recreational areas have been described by Gliniak and Sobczyk (2016), Nijkamp et. al (2002) and Limasset et. al (2018). Transforming previous landfills into green zones may be part of a general restoration program (Wong et al., 2013). Due to environmental and physical problems that impose restrictions, it is realistic to use them mostly as open spaces (parks, racing arenas, sporting grounds, etc.). For instance, municipal landfills are particularly difficult to reclaim to beneficial purpose because of landfill gas emission. Landfill gas is well known as greenhouse gas – a mixture of methane (CH_4), carbon dioxide (CO_2) and other trace gases, which is generated under anaerobic conditions. It can be collected and used for energy production or flared. However, the collection of gas takes decades, is not very efficient and is not feasible in low gas production phases, in low income countries where active gas collection system is beyond the budget, and in landfills where waste with low organic content is disposed of. One possible solution to avoid migration of gas would be covering the landfill with a bioactive cover layer, where methane is oxidized in-situ (Hilger and Humer, 2003; Barlaz et al., 2004; Huber-Humer, 2008; Scheutz et al., 2009). The methanotrophic bacteria uses methane as its carbon and energy source, and degrades it into CO_2 and H_2O in exothermic processes (1.1):

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 882.6\ kJ \qquad (1.1)$$

In places with limited availability of mineral cover material, soil-like fine fraction could be extracted from the same landfill cell, thus offering an alternative technology for combating climate change: instead of installing an active gas collection system, methane is degraded in-situ. Combining landfill gas treatment in natural biocover processes with park-function is rare.

2. SITE DESCRIPTION

The landfill remediation activities took place in Estonia at Kudjape municipal landfill, located on the island of Saaremaa (N 58:16:06, E 22:32:23). The landfill consisted of an approximate volume of 200,000 m^3 of disposed waste. The waste was initially disposed of on a flat unlined area; it reached a final height of approximately 12 m by the landfill closure time in 2009. Average annual temperature at the site is 5.6 °C and annual precipitation is 594 mm (Ideon, 2011).

Knowing that clay or any other material with low per-

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meability was not available locally, and that the dumpsite was considered as a low-risk site, an alternative cover design was planned with methane degradation function. As prescribed by environmental authority, about 1.5 m thick cover layer had to be used to cap the landfill. Biocover was composed of 1.2 m porous organic-rich materials, and a 0.5 m mineral gas distribution layer with the main purpose of distributing gas evenly into the top-layer, where methane is degraded (Figure 1). The cover material was extracted from the same landfill using technology known as Landfill Mining (LFM).

The upper 6 to 8 m layer of the landfill was sieved by Doppstadt SM518 drum sieve for separation of waste into two fractions: the desired < 40 mm fine fraction (biocover), and > 40 mm coarse fraction (backfill). In total, 57,777 m^3 of disposed waste was sieved during the LFM project between August 2012 and September 2013. As much as 16,430 m^3 of fine fraction (FF) was produced, giving the ratio of fine/coarse as 30/70. The properties of waste fractions are described by Kaczala et al., 2017 and Bhatnagar et al., 2017 and the properties of the tailored cover layer by Pehme et al., 2014.

The concept of final use of the site was modified during the works. It was understood, that there were widely used Kudjape-Upa sporting trails nearby, which, unfortunately, were flat. The Kudjape landfill area, however, was going to be the highest peak in the surroundings, which seemed well suited for diversifying these trails. A landscape architect was contracted to draft an improvised project amendment with jogging and ski trails, a picnic corner and a sledging slope. The landfill site was designed to be as diverse as possible, taking into account both the technical construction features of the landfill closure design, the economic considerations, and sporting requirements. A total of 2,420 meters of trails were planned with different lengths and slopes: 1,360 meters are located on landfill body and 1,060 meters, around the adjacent recycling facility. The slopes are between 1:3 and 1:20. The difference in height is 12 m.

The four-meter wide trails were sited into a very soft biocover; therefore, geotextile fabric was rolled on the bottom of trails (Figure 2), which was composed of a 300-mm thick gravel layer and a 100-mm thick mixture of gravel and wood chips (Figure 3). A conflict between diminishing the prescribed thickness of the biocover (1.2 m) in view of the road surface height was minimized by lifting the trails slightly higher than the surface of the landfill.

Sufficient difference in height and a very long slope created perfect conditions for snowboarding and sledging for children. The kids' area was covered by pure soil for safety

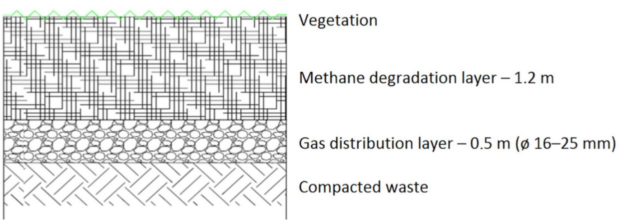

FIGURE 1: Design of the cover layer at Kudjape landfill.

FIGURE 2: Securing trails into soft biocover by supportive geotextile.

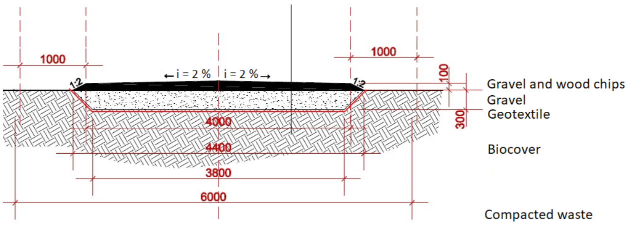

FIGURE 3: Design of the trails at Kudjape landfill.

purposes; the rest of the hill was covered by exposed fine fraction. Since winter sports trails, in particular, were not allowed to cross each other, a wooden bridge was built at the foot of the hill. Ditches two meters wide and a half-meter deep were excavated around the landfill, and a half-meter-deep pond in the northern part of the area was designed to collect stormwater during rainy periods. Rules of conduct were prominently displayed to keep the sporting crowd from falling into these ditches.

The whole area is covered by high and low vegetation, which highlights the relief along the slopes, diversifies the landscape, divides the area with different functions and stabilizes the biocover. To speed up the growth of the grass, hydroseeding was used throughout the landfill area. Lower shrubs (common honeysuckle, black elders, reeds), and trees Norway spruce (*Picea abies*), European larch (*Larix decidua*), Norway maple (*Acer platanoides*) and green ash (*Fraxinus pennsylvanica*) were planted into the cover layer. All trees were marked with numbered tags in order to create a database with tree species, initial height and GPS coordinates. In total, 338 trees and 959 shrubs were planted. All trees were at least 1 to 1.5 m in height; the diameter of root-balls was approximately 20 cm. Soon after planting it was noticed that some of the trees did not adapt to the environment and died off. Two growing seasons later, 50 species of Scots pine (*Pinus sylvestris*) and 50 species of Silver birch (*Betula pendula*) were added within the project warranty period to replace the lost species.

Elements of outdoor furniture and supporting infra-

FIGURE 4: View of remediated landfill in 2013 (Tammjärv et al, 2016).

structure, e.g. a staircase on top of the hill, an information board, picnic tables and litter bins were made by Elegrotech OÜ from recycled mixed plastics (Kriipsalu and Käsnar 2016), which actually contained plastic material, which had been excavated from the same landfill. The Kudjape Waste Recycling Facility is situated next to the landfill; therefore, the aim was to expose it to potential visitors, for educational purposes. Landscaping (Figure 4) was done within the existing closure permit, although the initially proposed (Figure 5) and final look (Figure 6) of the project were much different.

Landfill cover is monitored and maintained according to waste permit, which was issued by local environmental authority. Landfill owner has to monitor and report the following: groundwater level in four monitoring wells; quality of groundwater and surface water; landfill gas composition in one 10-m deep gas well; settling of waste masses, erosion of slopes. He has to maintain ditches, remove littering, and apply corrective measures against erosion. Grass is cut up to 15 times per season, which greatly exceeds the planned frequency (2 to 3 times). The reason for very good grass growth is nutrient-rich cover material and favorable moisture conditions in upper soil layer, as precipitation exceeds evapotranspiration by 200 mm in Estonia.

Objectives of the current full-scale project, where the landfill was remediated into recreational area, were: to monitor long-term functional performance of the cover layer (landfill gas safety); to monitor vegetation die-off; and to evaluate the social acceptance of the recreational area.

3. MATERIALS AND METHODS

Efficiency of the methane degradation layer was determined two years after the cover layer was installed. Methane and carbon dioxide emissions through the cover layer were monitored in twenty-nine measuring points which crossed the landfill (Figure 7). All measurements were taken by closed loop static chamber (40 L) method (Heinsoo et al., 2016), using portable GA2000 gas analyser (Geotechnical Instruments, UK) (Geotech, 2009).

The moisture content and temperature values were measured in situ with portable device Field Scout TDR 300 (Spectrum Technologies, USA). The soil samples taken from 29 measuring points were analysed in laboratory to measure pH and duplicate moisture content values. The pH was determined by the device pH/Cond340i (WTW, Germany) from the water extracts obtained from 5 g of the soil sample and 50 ml of distilled water. The water content of the soil samples was calculated from the dry matter content which was determined by gravimetric analysis.

ArcGIS for Desktop drawings were used to compose lo-

FIGURE 5: Layout of a remediated landfill as initially proposed (Kriipsalu et al., 2016).

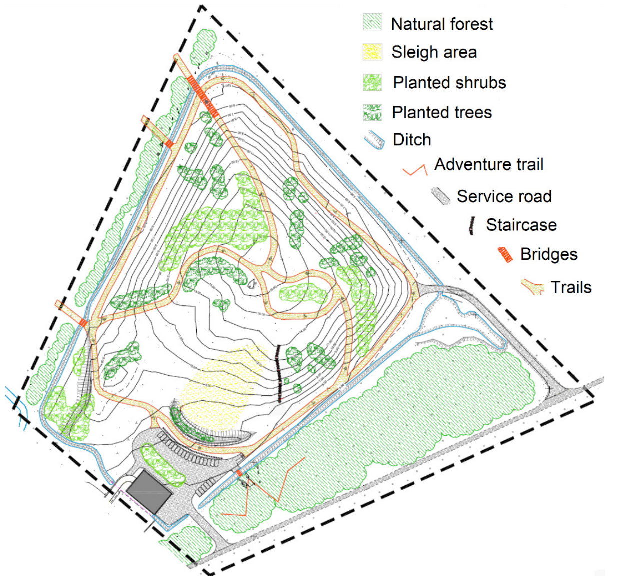

FIGURE 6: Layout of a remediated landfill as actually constructed (Kriipsalu et al., 2016).

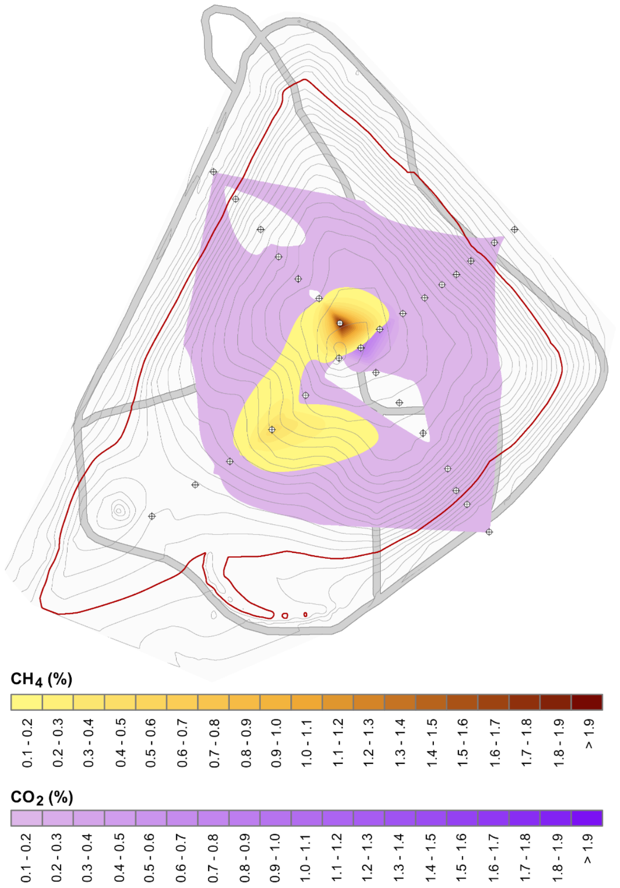

FIGURE 7: Distribution of landfill gas through the surface of the landfill in July 2015 (Heinsoo et al., 2016).

cation maps of measurement points. The Land Use Office orthophotograph was used as the base map. The interpolation of the measurement results was done using the natural neighbour method. All trees were inspected in 2014 and 2015 according to Tammjärv et al. (2016). Readings were inserted into the database and linked with numbered tags and GPS coordinates of trees.

Social acceptance was studied according to local media monitoring and assessment was made by interviewing personnel of the recycling center.

4. RESULTS AND DISCUSSION

4.1 Functional performance of the cover layer

It appeared that CH_4 and CO_2 emissions through the surface of the landfill were missing or very low (Figure 7). Methane was detected only from two measuring points out of twenty-nine and the values were low (maximum recorded value 2.1% vol) (Heinsoo et al., 2016). Spatially presented results demonstrate slight emissions of CO_2 (Figure 7), which is a result of degradation of methane (1.1). Emissions were missing during winter when the surface is frozen. From this perspective, the site is safe to visit. According to these results, the methane degradation layer which is made from excavated fine fraction serves as biocover very well.

4.2 Vegetation die-off

Two years after planting, 60% of the larches and 40% of the spruces had died off. The large number of dead trees suggests several possible reasons: a) wrong species; b) wrong planting time, planting methods or size of planted trees; c) unsuitable soil; d) unsuitable soil moisture, pH or gas content in soil; e) vandalism or other.

As seen from Figure 8, the pH was 7.5 to 8.0 in most places where trees were planted. It is higher than typical for Norway spruce (pH 5.2 to 5.5) or European larch (pH 6 to 6,5). The survived larches had a mean annual growth increment of 6 cm and spruces, 3.5 cm, which is at least 3 to 5 times less than expected. Scots pine and silver birch have adapted better in soils with higher pH and moisture fluctuations; this was confirmed visually.

Lack of moisture may also be a reason for die-off. Figure 9 shows lower moisture values than typical, but there was no obvious signs of withering or water stress yet.

Size of the planted trees and their root balls appears to be critically important. Root balls of pine and birch had the same size as spruce and larch, but their shoot-root ratio was less than 3:1, which ensures better adaptation to unusual growing media. The average height of pine and birch was 50 cm, compared to 1.0 to 1.5 m for spruce and larch. Spruce and larch had unfavourable shoot-root ratio (7:1), which might have promoted die-off.

The planting time of spruce and larch (end of August) was unusual due to the end dates of the project. Soil char-

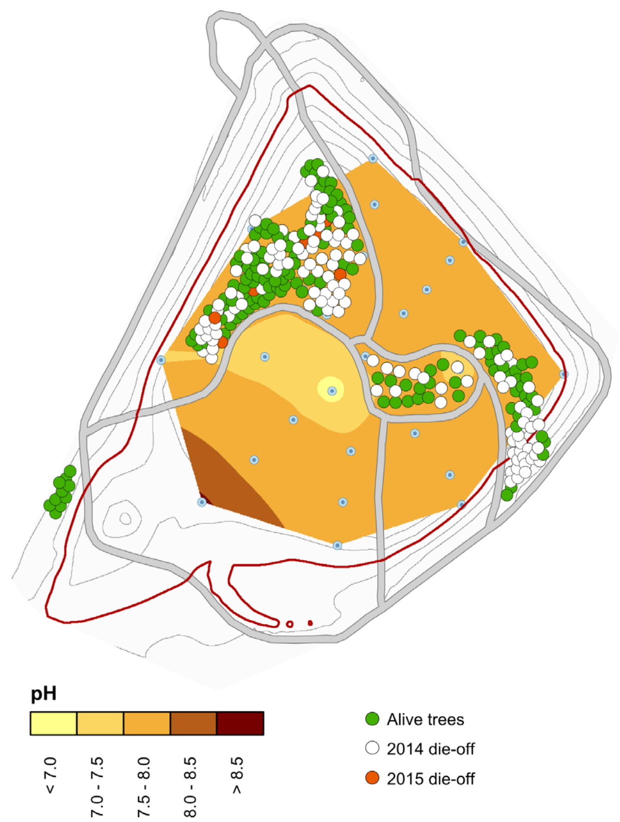

FIGURE 8: Tree mortality one and two years after planting, considering pH of cover layer (Tammjärv et al., 2016).

FIGURE 9: Tree mortality one and two years after planting, considering pH and moisture of cover layer (Tammjärv et al., 2016).

acteristics are expected to be highly dynamic in time, because of mineralization of organic material in biocover. Therefore, the growing conditions will continue to change in time. Tree species should be selected on different bases as compared to regular forestation or landscaping. It is useful to test various tree species in actual conditions before large-scale planting works.

4.3 Social acceptance

After the recreational area was opened it was immediately accepted among local people. Initially, people visited it out of curiosity, however more and more came for sport or just spending time actively. The number of visitors is increasing. The area is being used for walking, jogging, Nordic walking, Nordic skiing, biking, snowboarding, sledging and most frequently just for walking dogs. Recently, disc golf was installed, and is in active use. Visitors are coming from the nearby town Kuressaare. The travel distance is 4 km from the center, and 1.5 from town border. There is a public recycling center at the site, which provides a double reason to visit the park. The multi-purpose pathways existed near the landfill site long before the opening of the recreational area, therefore people were used to using the surrounding area for sports and recreation.

In early days, there was also some criticism among the visitors. They didn't like the little pieces of glass and plastic that could be noticed on the ground, even if the material for trails was free of any waste. These complaints stopped after the grass grew. The landfill area is continuously maintained and that guarantees its pleasant look. Some visitors were disturbed by the sight of dead trees. The response was to plant replacement trees.

Additionally, there were some complaints about the sporting trails. Some kids who rode bicycles in the opposite direction of the planned route got into a bicycle accident. After placing additional signs describing the proper use of sporting trails there were no more complaints.

5. CONCLUSIONS

The biocover concept may be considered as a useful and sustainable tool for remediation of small to medium landfills with low-level CH_4 emissions. It is possible to extract cover material from the existing landfill body. The results of the study show that the spatial emissions of CH_4 and CO_2 through the surface of the landfill were very low or missing. This demonstrates that the design of the methane oxidation layer was appropriate.

The planting of trees requires good planning and some trial and error. The die-off of larches and spruces was unacceptably high – 60 and 40% respectively. The die-off of pine and birch, however, was very small. It is recommended, that in addition to selecting species which tolerate soil gases, unusual pH and unfavourable moisture conditions, the plants should be rather small. Shoot-root ratio should not exceed 3:1, and planting time should be in early vegetation period.

It was possible to create a fully functioning recreational area from old landfill. It was accepted among local people from the first day. As it is still an anthropogenic landscape, the information about proper use of the area should be provided for visitors in order to make its use safe and enjoyable. It accomplished its goal of restoring the previous landfill area for the benefit of the community.

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