Lechner P. (Hrsg.): Waste matters. Integrating views. 2nd BOKU Waste Conference 2007, 16. - 19. April 2007, Wien. Proceedings; Facultas Verlags- und Buchhandels AG, ISBN 978-3-7089-0060-5

Engineered Biocovers - Passive Mitigation Systems for Landfill Gas: Status for the Demonstration Project, BIOCOVER

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Abstract
Greenhouse gas mitigation at landfills by methane oxidation in engineered biocover systems is believed to be a cost effective technology but so far a full quantitative evaluation of the efficiency of the technology in full scale has not been carried out. A EU LIFE III funded project, BIOCOVER, has the objective of documenting the construction and efficiency of an engineered bio-cover system. The status of the ongoing project is given where the initial landfill characterization and the baseline study of the methane emission is close to being finalized.

1 Introduction
Most landfills contain organic wastes which produce biogas, containing methane (55-60 vol.%) and carbon dioxide (40-45 vol.%). Methane from landfills still accounts for between 7 and 20% of the global anthropogenic sources of methane emissions and thereby significantly contributes to global climate change. Landfill gas (LFG) is extracted at some landfills and utilized for energy purposes leading to methane emission reduction. However, it is not always feasible to extract and utilize the gas. In these cases the gas is flared with the risk of producing toxic combustion products, or simply escapes from the landfill into the atmosphere. An alternative with even lower costs could be to improve and maintain the cover of the landfill in order to optimize the biological methane oxidation in the cover. Laboratory experiments have documented that a very high methane oxidation rate can be obtained in bio-covers, high enough to significantly reduce the methane emission from the landfill. The biological methane oxidation transforms methane into carbon dioxide, and since methane has a global warming potential 20 times stronger than carbon dioxide, a significant reduction in the source to global warming is obtained. Bio-covers may also be a very cost-effective supplementary method at landfills with landfill gas utilization, since the efficiency of the gas extraction system often is in the range of 50-60 %. However, the documentation of the efficiency of bio-covers as a methane emission reduction approach is more challenging in comparison to a utilization system. The project targets methane release from landfills, an explicitly mentioned source of greenhouse gases in the

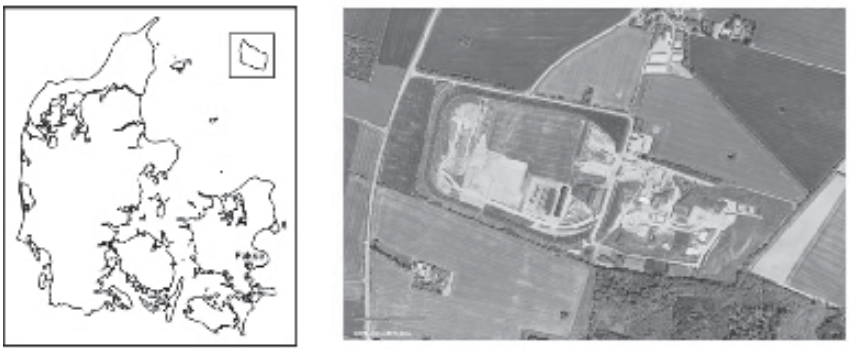


Fig. 1: a) Map of Denmark showing the location of the study landfill, Fakse Landfill. b) Arial photo of Fakse landfill showing the both section I and II

EUs Sixth Environmental Action Plan. The new suggested innovative technology is to be demonstrated at Fakse Landfill in Southern Zealand, Denmark (Figure 1). The landfill is divided in two parts; the oldest part which was in use from 1981 until 1996 will be the focus of the project activities. This part of the landfill has an area of 13 ha and received mixed waste. In total approximately 700,000 tonnes of waste have been disposed of at the older part of the landfill. The oldest part has a final cover with a relatively thick layer of soil having low gas permeability, while the rest of the landfill has a temporary cover with a thinner layer of the same soil type. The landfill is typical of Danish landfills of similar age. Preliminary evaluations of the methane emissions showed areas with significant emissions at slopes and landfill borders. The idea of the project is to construct a bio-cover system incorporating the presence of the temporary cover by establishing permeable regions – so-called windows – in the temporary cover using materials with higher permeability to enhance gas transport into the window area and high methane oxidation potential to oxidize the methane. Such materials could be mixtures of compost and coarse inert materials.

The objectives of the project are the following: a) to reduce the greenhouse gas emissions from landfills by improvement of the soil cover to better oxidize the methane produced within the landfill, b) to demonstrate a method for documentation of the obtained emission reduction, c) to analyze the economic viability of the technology, and d) to development guidelines on how to incorporate bio-covers in landfill gas management at European landfills and further disseminate the outcome of the demonstration project.

2 State-of-the-Art

Estimations of the methane production at Danish landfills without LFG utilization were carried out in 1998 (LFG Consult, 1998). Based on the original data the potential methane surface emissions have been calculated for 2004. Typical

potential methane surface emissions are in the order of 2-20 g CH_4 $m^{-2}d^{-1}$ with most emissions in the 2-10 range. For a new landfill with a thickness of 15 meters receiving municipal solid waste, a typical methane surface emission is 30 g CH_4 $m^{-2}d^{-1}$.The attenuation of methane in landfill top covers by methane oxidation has been subject to several studies (Whalen et al.,1990, De Visscher et al., 1999, Hilger et al.,2000, Scheutz et al.,2004, Gebert & Gröngröft,2006). The top covers often consist of a lower anaerobic zone where pore gas consists mainly of LFG, and an upper methanotrophic zone characterized by a pore gas mixture of LFG and atmospheric air diffusing into the top cover from the atmosphere. Studies of landfill covers through simulating column experiments have obtained methane oxidation capacities in the order of 100-250 g CH_4 $m^{-2}d^{-1}$. Thus, the oxidation capacity determined is much higher that the observed potential methane emissions for landfills as mentioned above. This indicates that biological methane oxidation in landfill soil covers indeed is a possible technology. Bio-covers may be a very cost-effective solution to reduction of green house gas emissions especially for landfills with medium to low methane production.

Attempts to enhance the attenuation process have worked with addition of organic material (compost, sludge etc.) to the soil. It proves that manipulation of landfill cover soils to maximize their methane oxidation potential might provide a complementary strategy for controlling emissions. However, at present, landfill caps are not designed with methane oxidation in mind. At many landfills the quality of the cover is in many cases not perfect, and can be of a very heterogeneous nature, and in many cases consisting of clay soils with low gas permeabilities. In such cases, regions with much higher gas permeabilities may exist. Besides, cracks may form during dry periods, or by settlement or erosion, and methane venting through such regions will not reside in the cover long enough to be oxidized. In these cases a significant attenuation benefit could be achieved with relatively simple design and/or manipulation of the top-soil cover followed up by continuous monitoring of the cover. For example, attenuation can be considerably improved thanks to better soil porosity allowing better through-flow of methane and oxygen and selection of materials with significant methane oxidation potential.

Humer and Lechner (2000) studied the stimulating effect of bio-covers on methane oxidation in the field. They have measured the methane emission from Austrian landfill test cells covered with sewage sludge compost or municipal solid waste compost during a three-year period. The results indicated a significant removal of methane. for both types of bio-covers. No methane emission could be detected at the surface during the entire measuring period. The research, however, did not include quantitative measurements of LFG fluxes through the cover before and after cover improvement, so it is difficult to estimate a methane oxidation rate from the results. This high performance was obtained when a layer of coarse gravel was installed beneath the compost layer. This layer facilitated a homogeneous gas distribution. The Austrian experiment which was performed

in a temperate climate is the only field scale documentation of methane oxidation stimulation in landfill soil covers.

Mixtures of materials (including organic waste materials, coarse sandy and gravel type soils, and landfill soil containing the methanothrophic bacteria) in the soil covers probably constitute the most efficient bio-covers for methane oxidation. Studies to optimize the methane oxidation performance by mixing different materials have only been carried out in a few cases and have never been followed up by full scale implementation at landfills.

Documentation of the efficiency of improved covers at landfills for mitigation of greenhouse gas emission is not a fully developed methodology. A documentation procedure includes measurements of methane emissions from the entire landfill before and after the cover has been improved for improved mitigation of methane emissions. Several methods exist for measurement of emissions from the entire landfill , including mass balance modelling, flux chamber techniques, micrometeorological techniques, and tracer techniques (Galle et al.,2001). The tracer technique as developed by the Chalmer group (Galle et al.,2001) seems to be the most reliable method for landfills.

Policy development is needed to secure a sustainable and cost effective management of landfill gas at landfills also incorporating low technology solutions based on natural methane emission reduction by bio-covers. A guideline needs to be developed to obtain a reliable technology for the reduction in methane emission from the landfill by installing a bio-cover system. The guideline should describe the full procedure of establishing a bio-cover system on landfills and methods for documenting the efficiency of the installed bio-cover system for mitigating the methane emission from the landfill.

3 BIOCOVER – a full scale demonstration project

The full title of the BIOCOVER project is *Reduction of Greenhouse Gas Emissions from Landfills by use of Engineered Bio-covers*. The project is funded by the LIFE III ENVIRONMENT programme, the Danish Environmental Protection Agency, and RENOSAM and runs from August 2005 to November 2008. The project is divided into a logical order of activities. The project activities are as follows:

Initial characterization of landfill. The landfill is characterized according to area, volume, waste characterization, soil thicknesses and types, and vegetation. Expected landfill gas production is estimated based upon the collected data using available landfill gas generation models.

Baseline study of methane emissions. An initial evaluation of the spatial variability in methane emission is carried out on each of the landfills, and the total methane emission is measured by use of the tracer technique.

Testing improvement strategies in the laboratory. Mixtures of locally available soils and organic waste residuals are tested in the laboratory to determine the best suited material mixture to be used for cover improvement.

Improvement of cover layer. On the basis of the baseline study which showed the

spatial variability of the gas emission, and the tests on the improvement strategies, a cover improvement plan is developed. The plan will include details on material additions to selected areas of the landfill and maintenance plans of the total landfill cover. The covers are improved following the proposed plans.

Establishing full scale demonstration bio-cover system. After the cover has been improved a monitoring plan is setup including the activities as described under "Baseline study of methane emissions". The spatial variability and the whole landfill emissions will be evaluated, and the emissions after the cover improvement will be compared to the emissions obtained during the baseline study. Evaluation of the oxidation efficiency at selected localities within the landfills will be made using the probe/flux chamber approach.

Analysis of the economic viability of the bio-cover technology. The standard cost for this reduction technology (in DKK/tons CO_2 GWP removed) will be calculated and compared to other reduction technologies, especially the gas flaring technology. Scenarios for other landfills will be calculated based on the experiences obtained from the two studied landfills.

4 Initial characterization of Fakse Landfill

Data regarding waste amounts, waste composition and waste chronology have been used for providing a theoretical estimate of the production of landfill gas (LFG) at the site. The production of LFG was evaluated using four available gas production models; *LandGEM* (US EPA, 2005), *GasSim* (UK EA and Golder Associates, 2004), *Multi Phase Model* (Afvalzorg, 1998) and *IPCC First Order Decay method* (IPCC, 2000). All models describe the gas generation using first order kinetics, but vary in the required detail of the waste input data and the methodologies for determining the biodegradable content of the waste. Whereas the IPCC model is a so-called single phase model that assumes a uniform decay rate of all degradable matter, the GasSim and Multi Phase Models are both multi phase models that differentiate between 3 grades of degradability.

Gas production simulations have been performed for both Section I, which is the main focus of the BIOCOVER project, and for Section II, which is the new part of Fakse Landfill. Furthermore the production of LFG in the covered and temporarily covered part of Section I has been evaluated separately as has each of the 7 disposal subunits in Section I.

The resulting landfill gas production for 2005 in Section I of Fakse Landfill was estimated in the range from 0.6 – 1.3 million m^3/yr. Seventy-five percent of this gas production was estimated to take place in the uncapped part of Section I comprised by Units 4-7.The reported range includes model estimates obtained using the models IPCC, GasSim and Multi Phase Model. LandGEM results were assessed to overestimate the gas production at Fakse Landfill, since the model was intended for U.S. landfills with a high amount of municipal solid waste.

The gas production in 2005 for Section II was estimated in the interval 0.04 – 0.4 million m^3/yr. According to GasSim and IPCC results, the gas production in



Fig. 2: a) Hot spot on soil cover. In many cases a change in vegetation, or lack of vegetation has been observed a these zones of high landfill gas emission,
b) The picture on the right shows the flux chamber coupled with the FID.

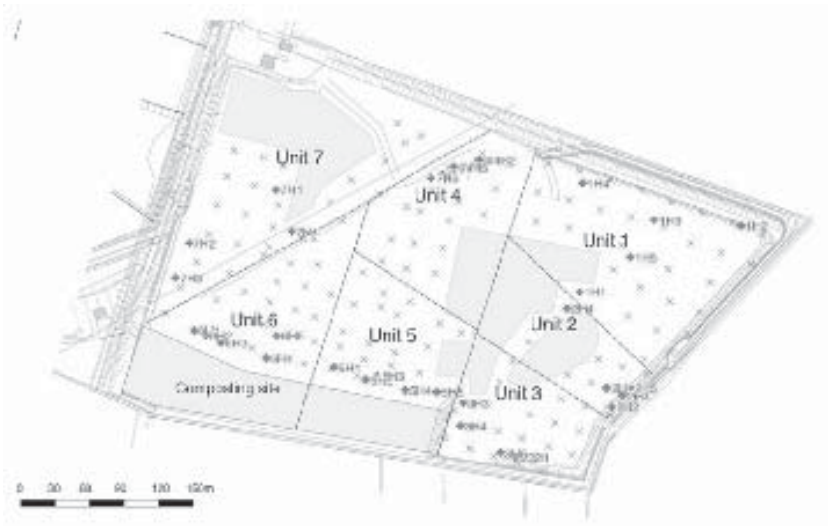


Fig. 3: Map of section I of Fakse Landfill showing the seven disposal units and the measured locations of grid points and hot spots marked at the site. Grid points are shown as grey crosses, and hot spots are shown as solid plusses. Areas on the site shown in grey are areas used for storage and handling of compost, combustible waste, and cover soil among other uses. Grid points have not been marked on these areas

Section II contributes with only 6-7% of the total gas production in 2005; however, the Multi Phase Model results indicate that the production from this area could be more significant.

The estimated gas production for Section I in 2005 corresponds to a methane

surface emission rate of 3 - 8 g $CH_4/m^2/d$ in the covered part and 8 - 16 g $CH_4/m^2/d$ in the temporarily covered part. These values represent maximum emissions assuming that no methane is oxidized in the top soil and that the produced gas is released evenly distributed over the surface area.
Soil cover sampling and analyses have been performed in order to characterize the existing soil cover at Fakse Landfill. The likely transportation routes of landfill gas to the atmosphere have been evaluated considering the landfill design and the cover soil characteristics. The evaluation suggests that the leachate system is a probable transportation route of landfill gas to the atmosphere especially in the well-covered areas.

5 Baseline study of methane emissions

Several activities have been performed for evaluating the spatial variability in the landfill gas emission patterns. Initially, nine gas probes to measure landfill gas composition with regards to main components (CH_4, CO_2, O_2, and N_2) and excess pressure in the waste mass were installed in section I with the gas sample screen in a depth of 2.5 meters. The compositions were typical for LFG with methane concentrations in the range of 40-65 % vol. Oxygen was below 1%vol. and nitrogen was only observed in a few probes.

Measurement of methane concentrations just above ground level was carried using a flame ionization detector (FID) for methane measurement on random locations marked at the site and at location in a grid spread out over the entire landfill (see Figure 2a), and measured for precise locations using GPS. At the grid points (about 120 in total) –see Figure 3 - most observed concentrations were close to background level (below 2 ppmv), and nearly all are below 10 ppmv indicating low emissions of LFG through the low permeability soil cover of the landfill disposal units. Based on the random/systematic screening several emission hot spots were found - about 35 in total (se Figure 3). The location was marked using GPS and the areas of the hot spots were estimated.

Methane fluxes were measured four times at five random locations on the soil cover using stationary flux chambers where samples were withdrawn from the headspace and stored in evacuated glass vials for analysis of methane using a gas chromatograph. Methane emission above detection limit was only observed at the location on unit 7, which is temporarily covered. The methane flux is very low compared to the flux measured at the hot spots on unit 7. The low emissions in general are probably a result of the low gas permeability of the soil used for covering.

Measurement of methane flux through each hot spot using a flux chamber coupled with a flame ionization detector for methane measurement (se Figure 2b). Based on the average measurement for four rounds and the areas of the hot spots the overall methane emissions through the hot spots was estimated as shown in Table 1.

Due to the low permeable soil cover and the lack of a LFG abstraction system,

the leachate collection system (including several leachate inspection wells) is believed to be a potential route for emitting LFG. To measure methane emission rates from the leachate collection system, a continuous tracer release method was used in desired locations. The principle of this method is to continuously release a gaseous tracer (carbon monoxide) at a constant known rate near the source of the methane emission (bottom of leachate wells), and subsequently compare measurements of concentrations of tracer and methane in the plume downwind after background concentrations of tracer and methane have been measured (se Figure 4).

Tab. 1: Average fluxes measured, total areas, and methane emissions of groups of hot spots.

Group	Location	Id.	Average methane flux (4 campaigns) ($g\ m^{-2}\ d^{-1}$)	Area (m^2)	Methane emission ($kg\ d^{-1}$)
1	Various locations on unit 1 and 2	1H1, 1H2, 1H3, 1H4, 1H5, 2H4	4.8	6.0	0.03
2	Near leachate pumping station on unit 2	2H1, 2H2, 2H3, 2H5	14	100	0.1
3	Slope on unit 3	3H1, 3H2, 3H5	13	34	0.5
4	Small slope on unit 3	3H4	322	4.0	1.3
5	Slope on unit 5 and 3	3H3, 5H1, 5H2, 5H3, 5H4, 5H5	71	56	4.0
6	Slope on unit 6	6H1, 6H2, 6H3, 6H4, 6H5	70	53	3.7
7	Slope on unit 7	7H2, 7H3	560	90	50
8	Slope on unit 4	7H5 4H1, 4H2, 4H3, 4H4, 4H5	180	98.5	18
9	Slope on unit 7	7H1	3900	25.0	98
10	Near electrical pole on unit 7	7H4	1300	5.0	6.6
		Total	**650**	**380**	**180**

The measurement was carried out for all leachate wells at periods with stable weather to obtain representative results not affected by changes in barometric pressure. Estimated overall methane emission rate from the leachate collection system was 350 kg/d. The total methane emitting through "hot spots" in the soil cover, which have a combined area of 0.4% of the total area of the site, was estimated as already described to be 180 kg/d. Comparing these rates to the results of methane production modelling, the measurements suggest that more than half of the gas produced at the site emits through the leachate collection system, and the bulk

of gas emitting through the soil cover discharges through a few relatively small areas of the landfill.

The evaluation of the baseline study confirmed the conceptual model of the LFG emission at Fakse Landfill developed through the initial characterization of the landfill. Important activities in the cover improvement plan to be developed are to block the uncontrolled gas emission through hot spots (by adding clay covers to reduce the gas permeability of the

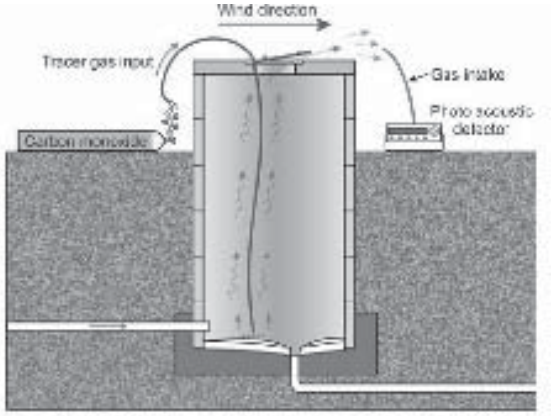


Fig. 4: Tracer release measurement of methane emission at a leachate collection well. Only one detector is shown on the illustration.

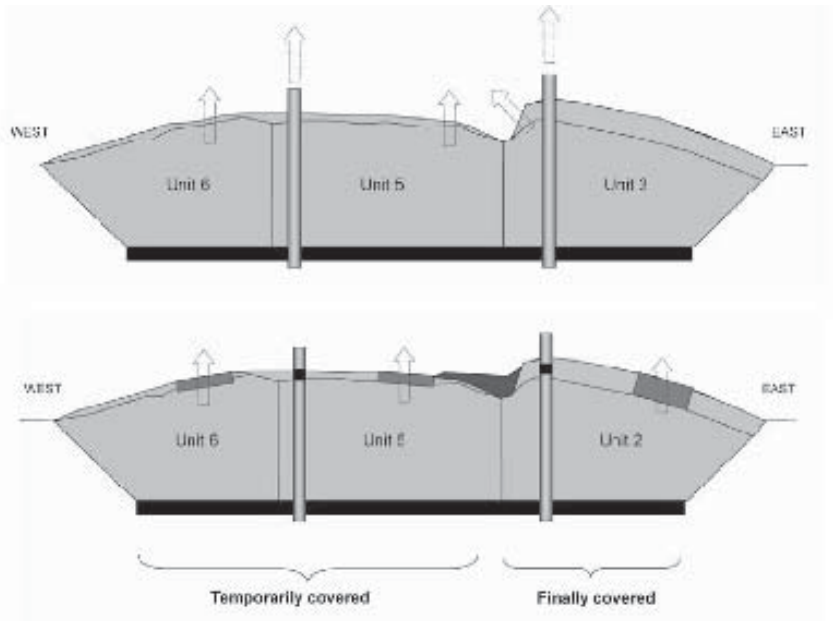


Fig. 5: Conceptual models of the gas flow patterns before improving the landfill cover (top figure) and after improvement, where uncontrolled emission through hot spots and leachate wells has been blocked and high permeable methane oxidizing compost windows have been constructed.

local soil cover) and leachate wells (by gas tightening the top part of the wells) and at the same time constructing high permeable compost windows through which gas will emit with a simultaneous oxidation of methane to benign carbon dioxide (see Figure 5 showing the conceptual gas flow patterns before and after the cover improvement).

6 Project activities and results in the near future

At the moment several activities are ongoing. Measurements of methane emissions for the entire landfill are carried out in Collaboration with Chalmers University of Technology in Sweden and Afvalzorg and ECN in the Netherlands using tracer release approaches. One field campaign was carried out in October and another is planned for February.

Testing of improvement strategies for the bio-cover system is ongoing in the laboratory. Initially the types and amounts of compost-based materials stored at the landfill have been evaluated together with the production of compost at the landfill's composting facility. Quick testing of the different available materials using a simple batch incubation method has been finalized and the most promising materials (or combinations of materials) are at the moment tested in column experiments simulating the LFG transport in bio-cover windows. On the basis of the column test results the best material for methane oxidation is selected and will be used in the bio-cover windows. The cover improvement plan is under its way including a detailed monitoring plan (including well tops for blocking the gas escape route through the leachate collection system, soil gas probes, flux chambers, sampling plans, etc).

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