Bio-Reactive Cover Systems: Inexpensive Approaches for Mitigating Methane Emissions from Landfills

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Progress Report 1

Year 2

by

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PROJECT STATUS

The first biocover study (S1 biocover) described in the Annual Report (August 2003 to August 2004) is continuing to be sampled on a monthly basis and evaluated for long term trends. A second biocover study (S4 biocover) was initiated to determine the effect of a coarser biocover material in an area with greater methane flux. The S4 site was sampled for about 6 months before application of biocover in July 2004 and continues to be sampled on a monthly basis. For both biocovers the methane flux is determined with static flux chambers, oxidation is determined using carbon isotope ratios, and the profiles of methane concentration is determined from pipes inserted to various depths in the cover. Research on biofilters that can be installed on vent pipes and other point sources of landfill gas emissions is also being conducted.

In this report we will first give a brief description of the site and methods used. Then we will discuss the first biocover study, the second biocover study, and the biofilter study. Finally we will summarize the results and discuss future plans.

Materials and Methods

The studies are being conducted on municipal solid waste that has been placed using conventional sanitary landfill techniques at the Leon County Landfill. The S1 biocover is located on 8+ year old waste covered with 47 to 100 cm of compacted sandy
clay (Fig. 1). The biocover-treated area was made by placing a 10-cm thick gas-dispersion layer consisting of gravel-sized recycled glass on the three 7.6 m by 7.6 m squares (labeled 2D, 4D, and 6D), and then covering the area, including space between the squares, with 46 to 51 cm of compost. The compost extended 3.8 m beyond the edges of the experimental squares. This compost was derived from chipped yard waste that had been windrowed and turned for three years. A comparison set of untreated squares (2B, 4B, and 8B) were located next to the biocover.

The S4 Biocover study was placed on 2+ year old waste that had a temporary cover of about 15 cm of compacted sandy clay (Fig. 2). Crushed fluorescent tube glass was placed 10 to 15 cm deep on the two 18 m by 32 m areas to be used for the mulch treatment. Freshly chipped yard waste was placed 60 cm deep over the glass in the deep mulch area and 30 cm of mulch was placed over the shallow mulch. An untreated (No mulch) area for comparison was established next to the biocovers.
To achieve good methane oxidation the media must have a balance of water-filled and gas-filled pores. Too little gas porosity and oxygen cannot diffuse through enough depth. Too little water and the bacteria stop metabolizing. Figure 3 shows the result of bulk density and particle density determinations for S1 on April 28, 2004. The compost is clearly wetter with volumetric water ranging from 0.33 to 0.44, whereas it was only 0.08 to 0.09 for the sandy clay. These values change rapidly in response to infiltration of rainfall, and on some days it appeared that the compost was saturated, resulting in insufficient oxygen diffusion.
Methane flux was determined by the static chamber technique and isotopes by mass spectrometry (see the “Annual Report for August 2003 to August 2004” for details). The fraction of methane oxidized ($f_{ox}$) is determined from the proportion of $^{13}$C and $^{12}$C in the anoxic CH$_4$ ($\delta_A$) and emitted CH$_4$ ($\delta_E$) and the fraction factor ($\alpha$) which is a measure of the temperature-dependent microbial preference for $^{12}$CH$_4$ (Chanton and Liptay, 2000):

$$f_{ox} = 1 - \left( \frac{\delta_E + 1000}{\delta_A + 1000} \right)^{\alpha}$$  \hspace{1cm} (1)

Methane lost by oxidation (L, g/m$^2$/d) is calculated from $f_{ox}$ and the methane flux from the surface (F, g/m$^2$/d):

$$L = F \left[ \frac{1}{1 - f_{ox}} - 1 \right]$$  \hspace{1cm} (2)

First Biocover Study

Flux samples were taken for about 2 months before applying compost on March 17, 2004 (“pre” samples), and flux and isotope samples were taken afterwards (“post” samples, Table 1). Both mean and median values are reported because the distributions were often skewed so that the mean is overly influenced by a few high
values. In this case the median is a better indicator of central tendency. The median flux for both compost and no compost areas declined after March 17, but Compost treatment declined more (60%) as compared to No-compost (29%). No-compost did better in methane oxidized after March 17, however, with the median value 68% greater than compost. This was probably due to greater flux of methane through the No-compost area.

Table 1. Site 1 methane flux and oxidation for two treatments (compost and no compost) before application of compost (“pre,” Jan. 12 ’04 to Mar. 16 ’04) and after (“post,” Mar. 17 ’04 to Jan. 26 ’05†).

<table>
<thead>
<tr>
<th></th>
<th>Compost</th>
<th>No Compost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pre</td>
<td>post</td>
</tr>
<tr>
<td>Methane Flux (g/m²/d)</td>
<td>117.55</td>
<td>23.04</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>0.47</td>
</tr>
<tr>
<td>Oxidation (%)</td>
<td>mean</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>na</td>
</tr>
<tr>
<td>Methane Oxidized (g/m²/d)</td>
<td>mean</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>na</td>
</tr>
</tbody>
</table>

† The pre Compost sampling locations are in the same area but not usually directly under the post Compost locations.

After application of compost methane flux increased from the biocover until July (Fig. 4). This may have been due to the wet and compacted compost not allowing enough oxygen in to effectively oxidize the methane. After July the flux decreased dramatically and this corresponded with lower precipitation and the growth of vegetation on the biocover which removed water from the compost. Flux from the no-cover area also increased in the early summer, declined in August and has increased since then. Since September the biocover treatment has had a lower median flux than the no-cover area (Fig. 6).
Figure 4. Methane flux from the S1 biocover treatment. For this semi-log graph, 9 flux values <0.01 g/m²/d were plotted as 0.01.

Figure 5. Methane flux from the S1 no-cover area. For this semi-log graph, 10 flux values <0.01 g/m²/d were plotted as 0.01.
Figure 6. Median methane flux from the S1 study. For this semi-log graph, 6 values <0.01 g/m²/d are plotted at 0.01.

The methane concentration depth profiles show the zone of maximum oxidation ranging from about 30 cm (squares 2D and 4B) to 80 cm (squares 4D and 6D) (Fig. 7). The deeper zone of oxidation is better because there is more opportunity for oxidation to occur if the flux increases. However, even the 30 cm oxidation depths appear to effectively remove methane.
Figure 7. Methane concentration profiles in the S1 study. The boundary markers for the compost profiles indicate the bottom of the compost, the bottom of the glass gravel, and the bottom of the landfill cover soil. The boundary marker for the no-cover profiles indicates the bottom of the landfill cover soil.
Second Biocover Study

Flux and isotope samples were taken for about 6 months before ("pre" samples) and after ("post" samples) applying mulch on July 22, 2004. Both Deep and Shallow Mulch reduced median methane flux by 96% and 81% respectively in comparison to flux before mulch placement (Table 2). In contrast the No Mulch area increased median flux by 106%. The Deep Mulch oxidized the greatest fraction of methane (38.8%) in comparison to Shallow Mulch (1.9%) and No Mulch (14.8%). The No Mulch area, however, did better in mass of methane oxidized, with its median after July 22, 22 times greater than Deep Mulch and 27 times greater than Shallow Mulch. This was due to the 86 to 98 times greater flux of methane coming from the No Mulch area.

Table 2. Site 4 methane flux and oxidation for three treatments (deep, shallow, and no mulch) before application of mulch ("pre," Feb 9 ‘04 to July 21 ‘04) and after ("post," July 22 ‘04 to Jan. 19 ‘05)†.

<table>
<thead>
<tr>
<th></th>
<th>Deep (60 cm) Mulch</th>
<th>Shallow (30 cm) Mulch</th>
<th>No Mulch</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>pre</td>
<td>post</td>
<td>pre</td>
</tr>
<tr>
<td>Methane Flux</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g/m²/d)</td>
<td>mean</td>
<td>median</td>
<td>mean</td>
</tr>
<tr>
<td></td>
<td>75.32</td>
<td>22.63</td>
<td>19.10</td>
</tr>
<tr>
<td></td>
<td>22.55</td>
<td>0.96</td>
<td>0.85</td>
</tr>
<tr>
<td>Oxidation (%)</td>
<td>mean</td>
<td>median</td>
<td>mean</td>
</tr>
<tr>
<td></td>
<td>12.2</td>
<td>6.8</td>
<td>18.2</td>
</tr>
<tr>
<td></td>
<td>32.2</td>
<td>38.8</td>
<td>15.1</td>
</tr>
<tr>
<td>Methane Oxidized (g/m²/d)</td>
<td>mean</td>
<td>median</td>
<td>mean</td>
</tr>
<tr>
<td></td>
<td>1.09</td>
<td>0.95</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>26.9</td>
<td>0.70</td>
<td>9.54</td>
</tr>
</tbody>
</table>

† The pre sampling locations are in the same area but not usually in the same place as the post locations.

Flux from the mulched areas declined after mulch application and has risen slightly since December (Fig. 8 and 9). The mean and median lines for the Shallow Mulch area separated after mulch application, and two or three sample locations show much higher flux (Fig. 9). This may indicate that mulch application concentrated flux in a few locations. Flux from the No-Mulch area increased in early July (Fig. 10), possibly due to application of more soil cover in a nearby area of the landfill which forced gas to escape through the thinly covered experimental area. The median fluxes from Deep and Shallow Mulch areas show a clear lower trend in comparison to the pre-mulch samples, and in comparison to No-Mulch area after July 22 (Fig. 11).
Figure 8. Methane flux from the S4 study, deep mulch biocover. For this semi-log graph, 5 values <0.01 g/m²/d were plotted as 0.01.

Figure 9. Methane flux from the S4 study, shallow mulch biocover. For this semi-log graph, 7 values <0.01 g/m²/d were plotted as 0.01.
Figure 10. Methane flux from the S4 study, no mulch area. For this semi-log graph, 2 values <0.01 g/m²/d were plotted as 0.01.

Figure 11. Median flux for three treatments in the S4 biocover study.

The methane profiles show most of the oxidation occurring in the soil layer for the Deep Mulch and the No-Mulch area (Fig. 12). For the Shallow Mulch most of methane oxidation occurs in the mulch layer.
Figure 12. Methane concentrations at various depths in the three areas of the S4 biocover study. The boundaries for Deep Mulch and Shallow Mulch are the bottom of the mulch, the bottom of the glass gravel, and the bottom of the landfill soil cover. The boundary of the No-Mulch area is the bottom of the landfill soil cover.
Biofilter Research

In addition to removal of methane and other landfill gasses from large areas using biocovers, there is a need to remediate gasses coming from vent pipes and other point sources. We are studying ways to do this using high-efficiency biofilters.

A schematic diagram of the first biofilter study is shown in Fig. 13. Pure methane (100%) is being fed through the bottom of the columns, simulating the methane influx from the solid waste in landfill through the cover soil. Top of the column is open to allow air diffusion into the compost. Gas ports were installed vertically from the surface of the compost at certain depth. Gravel was placed in the bottom of each column to disperse methane evenly at the bottom of each column. Different variables which would influence methane oxidation are observing during the test, such as water content and soil temperature.

![Fig. 13 Schematic of biofilter](image)

Three thicknesses of compost columns, 15cm, 30cm, and 45cm were built to find out which thickness might be the optimum thickness. Fig. 14 shows the oxidation rate calculated by mass balance (difference of flux between influent and effluent divided by the influent flux). Thicker compost has higher oxidation rate. The oxidation rate of 15cm column dropped dramatically with time. Fig. 15 shows the volumetric water content decrease with time. The volumetric water content of 15cm column decreased faster.
than the other two columns. In thicker columns, the compost’s water holding capacity is very good. After about two months in Florida, the volumetric water content is still above 49%. In the 15cm column, the dramatic decreasing of oxidation is due to desiccation of the compost. Methane is leaking out from sidewall cracks. Such desiccation cracks did not extend throughout the whole sample length for the 30 and 45 cm columns. Once the edges of the compost were compacted against the sidewall, the oxidation rate increased back to values observed at the start of the experiment.

Fig. 14 Oxidation of methane through three compost columns

Fig. 15 volumetric water content in three compost columns
A second biofilter is in the preliminary design phase. It is designed to maintain the correct balance of water and air porosity to maximize methane oxidation without the use of power for blowers, etc. The biofilter will have a water container at the bottom, and the texture of the overlying media will be adjusted to keep the water content within an optimum range. We are currently testing the soil moisture characteristic for various materials for this biofilter.

Summary and Future Plans

Two different biocover studies are on-going. Both biocover treatments have reduced methane flux relative to before application and relative to non-treated areas. However, the trend in methane oxidization is not clear; in some cases biocovers did not increase the fraction of methane oxidized. This paradox may be due to the partial blocking of gas flow by the biocovers, resulting in less flux with or without methane oxidation. This possibility will be studied by more detailed evaluation of gas pressure and flux surrounding the biocovers.

Methane concentration profiles with depth indicate maximum loss of methane occurs from 100 cm to 20 cm depth. Biocovers generally increased the thickness of the reactive layer.

Long-term flux, oxidation, and probe sampling of the two biocover sites will continue. In depth analyses of the data, including correlations to soil moisture, soil temperature, and barometric pressure, will be conducted.

The biofilter tests have shown that a 30cm depth of compost can remove 70 to 100% of applied methane, whereas a 15cm depth tends to dry out, crack, and allow gas to bypass the filter. At least one full-scale biofilter will be installed and tested at the Leon County Landfill.