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Portable infrared spectroscopy for the rapid monitoring of leaks in geomembrane lined landfill caps

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ABSTRACT: Infrared spectroscopy using a novel portable multi-channel analyzer was used to trace and exactly locate the source of high methane concentrations over a landfill cap. Due to the presence of roads, culverts, and steep slopes the leaks were found some distance away from the maximum gas concentrations over the cover. The maximum gas concentrations could be very localized – within a few centimeters. The same technique was used to rapidly locate leaks and to exactly locate maximum methane concentrations over a 6 ha landfill cap in 1.5 days. The technique is being developed for large areas of newly installed bottom liners

1 INTRODUCTION

The New Source Performance Standard (1997) regulations are being implemented in the United States. They involve the periodic monitoring of methane concentrations in landfill gas (LFG) above capped landfills. Surveys must be performed on a parallel grid pattern with a spacing of about 15 m or 30 m. This allows coverage of about 40 ha per day. The sources of LFG concentrations exceeding 500 ppm must be found and sealed. There is concern that in locations where there are haul roads, culverts, and steep slopes, the leak in the liner may be several metres away from the maximum gas concentration above the liner. With significant gas pressure under many caps it is not practical nor safe to expose a large area of liner while looking for the hole.

The conventional geoelectric method (Peggs 1993) used for precisely locating leaks in bottom geomembrane liners of landfills and lagoons cannot easily be used on landfill caps when the cap geomembrane is not welded to the bottom liner in the top-of-sideslope anchor trench. The electrical method relies on the geomembrane being an insulating layer between the conductive medium over the geomembrane and the conducting medium below the geomembrane. If current can flow around the edge of the cap, the small currents flowing through the holes being sought cannot be identified. In addition an electrical survey can only survey approximately 1 ha of geomembrane per day.

A multichannel channel gas analyzer, developed and used for locating leaks in natural gas transmission pipelines from a moving vehicle or a helicopter, has been applied to sourcing LFG leaks and performing rapid comprehensive LFG surveys over landfill caps.

2 EQUIPMENT

The multi-channel analyzer leak detection system (LDS), developed by Apogee Scientific is a three-channel instrument capable of measuring methane (CH_4), total hydrocarbons (HC) and carbon dioxide (CO_2) concentrations at sub part per million (ppm) concentrations and at a rate of 10 samples per second. The CO_2 and HC channels are not typically used for landfill applications, although they could be used to distinguish between LFG and an exhaust plume from a truck, for instance.

Ambient air is collected approximately 100 mm above the ground, passed through a filter to remove particles and other debris from the air stream, and carried to the LDS through 32 mm diameter hose. The time between sampling and analysis depends on the length of the hose but is approximately two seconds.
The instrument is shown in Figure 1. The air is drawn into the long square cross section tube. The infrared beam is generated in the main box, passed through the air/gas in the long tube, reflected by a mirror at the end of the tube back through the air/gas, then monitored by detectors in the main box. The LDS is coupled to a Global Positioning System (GPS) receiver to determine instrument/hose location, and has a computer-based data acquisition system for data logging and display. The computer monitor simultaneously displays methane, total hydrocarbon, and carbon dioxide concentrations as they are analyzed. The raster on the computer monitor holds the results for sixty seconds before being replaced by new data.

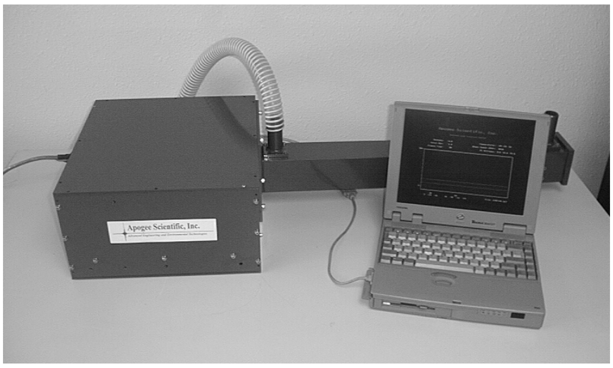

Figure 1. Leak detection system.

3 SOURCING LEAKS IN CAPS

A conventional LFG survey using a flame ionization detector (FID), performed on a parallel grid spacing of 15 m, had identified four hydrocarbon (assumed to be all methane) concentrations exceeding the limiting 500 ppm. However, due to the presence of steep slopes, roads, culverts, and drainage ditches, the site owner was concerned that the source of the gas would not be directly below the high concentration. The LDS was used to rapidly and continuously assess local gas concentrations (primarily methane) and to assist in the directional excavation towards the source of the leak.

The equipment was calibrated for methane concentrations between 10 and 1000 ppm. The length of hose used was about 33

m. The data were also presented as an audio signal through headphones so the hose operator was not required to constantly monitor the computer display.

3.1 Paved road at edge of cap

The initial survey had identified a discrete hot spot of 2000 ppm hydrocarbons between the edge of an asphalt-paved road and a concrete-lined drainage ditch around the edge of the cap. Surveys along the edge of the road generated traces typified by that in Figure 2. Concentration peaks up to 2700 ppm were found over a distance of about 40 m. On the cap side of the ditch peaks to 1800 ppm occurred over 5 m, but within the extremities of those at the edge of the road.

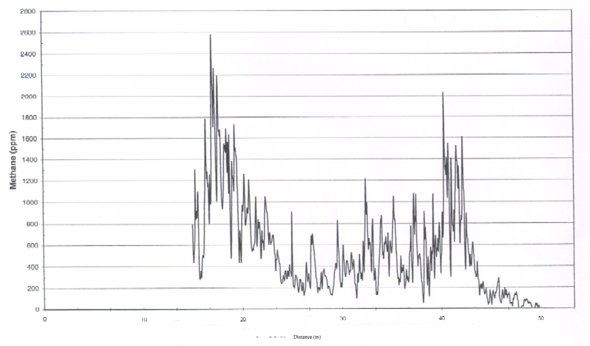

Figure 2. Methane concentration along edge of road

There was no discrete peak at the marked exceedence location. However, as shown in Figure 2, there were several discrete peaks at other locations. These peaks were very localized – to within 20 or 30 mm.

The cap geomembrane was excavated and exposed along the affected length for the placement of a gas extraction pipe underneath the geomembrane. When the geomembrane was exposed the hot spots on the cap side of the concrete ditch were no longer evident. A hot spot was found at a tear (Figure 3) in the protection geotextile. The geotextile was removed and a small puncture hole, approximately 2 mm in diameter, was found in the geomembrane about 300 mm away from the tear. Since the peak in the gas concentration was at the tear in the geotextile, not above the puncture hole, it appeared that the dirt-filled geotextile was acting as a significant barrier to gas permeation.

Figure 3. Tear in geotextile (folded over) and puncture hole in geomembrane (circled)

The gas extraction pipe was installed and another methane concentration trace made over the originally affected area. There was no evidence of significant methane leakage.

3.2 Dirt road on slope of cap

On a dirt road running across the slope of the cap surveys found a short distance of high concentrations (3000 ppm) on the upslope side of the road compared to a longer distance of lower concentrations (1600 ppm) on the downslope side. Just off the down slope side of the road the peaks were at the same locations but they did not exceed 300 ppm, as shown in Figure 4.

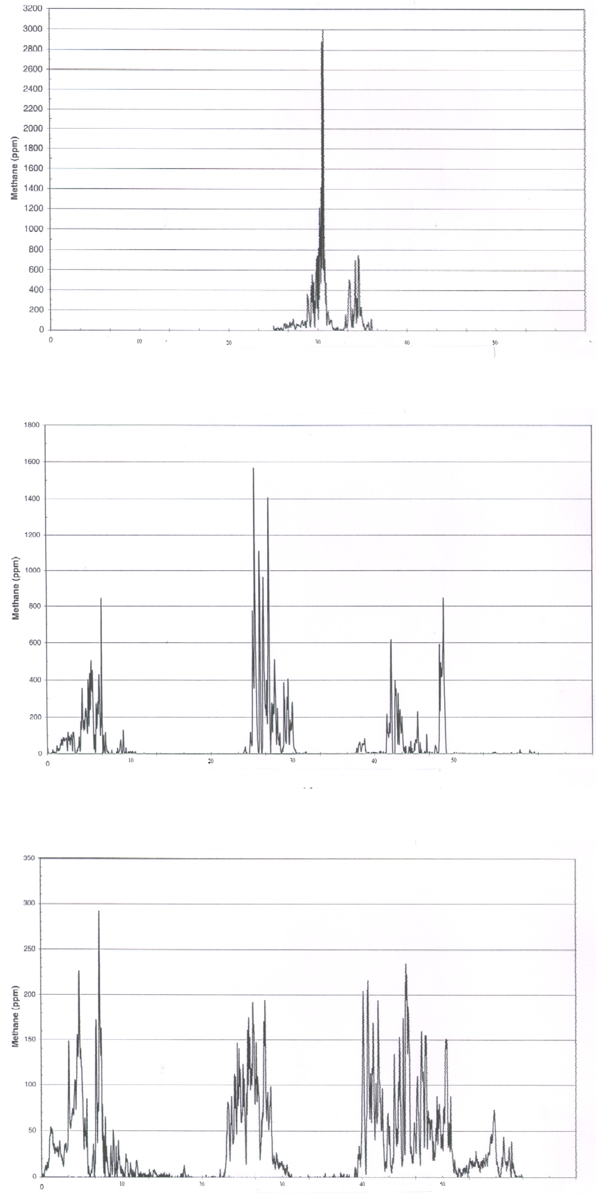

Figure 4. Surveys along upslope edge (top), downslope edge (middle), and slope below road (bottom).

Excavation along the north edge of the road exposed a high density polyethylene (HDPE) gas pipe running up and down the slope at one of the hot spots. Further excavation of the pipe down the slope did not reveal any discrete leakage through the geomembrane but did show an approximately 4000 ppm reading around the pipe as the excavation progressed down the slope. It was apparent that gas sources further down the slope were simply being conducted up the slope in the sand layer around the pipe.

An additional hot-spot (3000 ppm) at an animal hole was excavated. No leak was found, but there was once again a higher concentration of methane in the sand layer just above the liner along the downslope edge of the excavation.

The geomembrane was uncovered on the upslope side of the road as the LDS was used to follow the highest gas concentrations. Approximately 3 m from the hot spots a 40 mm cut (Figure 5) was found in the liner, where the methane concentration was about 10,000 ppm. Note that the geomembrane itself was only exposed at the cut where the LDS indicated the peak LFG concentration. The cut was patched and the soil replaced. The hot spots on the downslope side of the road were reduced to

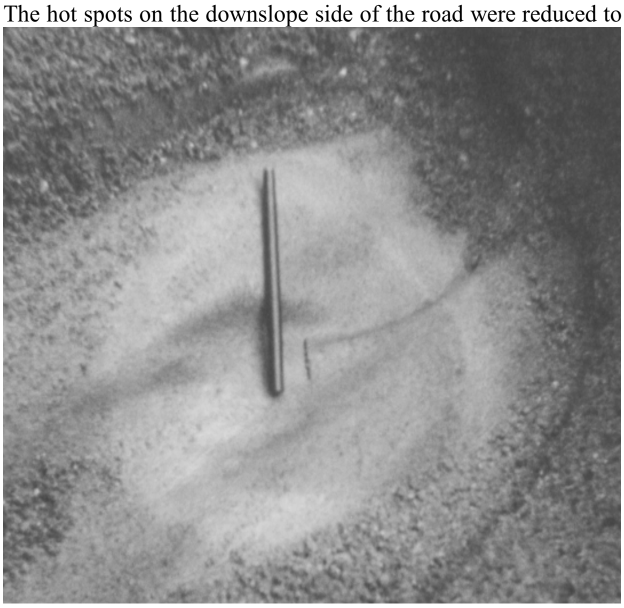

Figure 5. Cut in geomembrane

It is evident that a significant amount of methane can permeate through the drainage medium above the geomembrane while being retained by soils that have penetrated an overlying geotextile.

4 GENERAL LFG SURVEY

At the second site the geomembrane cap was not attached to the bottom liner but overlapped it like an umbrella. Thus it was not possible to perform an electrical survey on the cap. There were also many metal pipes penetrating the cap that precluded an effective geoelectric survey.

Erosion of drainage sand during a heavy rainstorm on the newly-installed 7 ha municipal solid waste landfill cap exposed equipment damage in the geomembrane. The owner's engineer and state regulators required that a survey be performed over the complete cap (and its 39 penetrations) to ensure there was no more damage. The geomembrane was covered by approximately 600 mm of sand and 150 mm of vegetative soil.

Prior to the survey the gas extraction system had been switched off, or reduced, to ensure that there would be a positive pressure of gas under the liner during the survey, clearly a condition that would not occur under the finished closure conditions.

4.1 Survey procedure

The LDS equipment was set up in a four wheel drive van with the hose opening positioned below the front bumper about 100 mm above the ground. It was calibrated to detect between 1 and 10,000 ppm of methane. A preliminary survey was made along the perimeter roads to establish adjacent background conditions and to evaluate sources of methane from outside the cell that might contribute to monitored values. No major sources of methane outside the cell were observed.

To allay concerns about potential low gas permeability of the compacted soil layer, a hole was dug through about 225 mm of soil down to the sand layer. The end of a 3 m length of 5 mm diameter tubing was buried at the bottom of the hole. The other end of the hose at the surface was connected to a canister of propane gas. The soil above the buried end was compacted, by foot, in four lifts. A small amount of propane (500 ml/min) was fed through the hose and allowed to saturate the soil for about three hours. This leak rate is extremely small when compared to the leak rate expected from even a small tear in the liner. The propane is also heavier than air, unlike methane which is lighter than air.

When the soil had saturated, handheld survey traverses, monitoring total hydrocarbons (HC) were made across the downwind direction at different distances from the simulated "leak". A traverse was also made in an orthogonal direction, from downwind to upwind of the "leak", but with sideways sweeps of the hose.

The calibration traverses (Figure 6) show that an increase above background levels (about 2 ppm) could be detected about 2 m downwind. The leak was even easier to detect at a distance of about 1 m downwind. The propane concentrations varied up to 160 ppm.

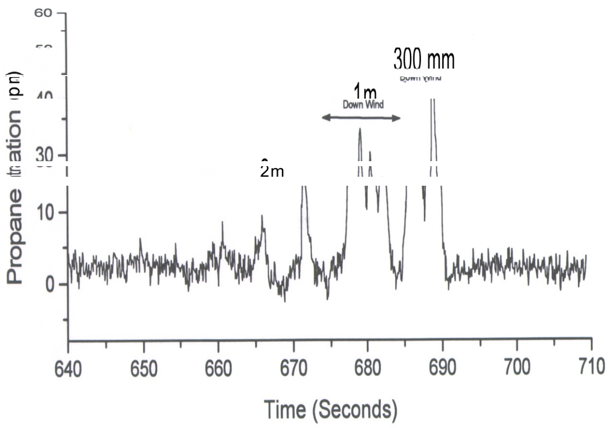

Figure 6. Traverse down and upwind of calibration leak

Thus the soil layer does not prevent the passage of a significantly measurable amount of gas, even a gas that is heavier than air. At equilibrium, the soil layer effectively acts as a large reservoir and source of gas. Therefore, if the calibration gas had been methane, its plume above the soil surface would have extended even further than did the plume for methane. When the calibration leak was removed the gas-saturated soil continued to emit gas for an extended period.

The production survey was then performed over the surface of the cap on a parallel grid pattern with a spacing of about 1.7 m. at speeds up to almost 16 kph. Multiple passes were made at measurements significantly above background, the GPS constantly recording the location of the vehicle. Multiple passes were necessary to ensure that leak-indicating signals remained constant over the background noise that varied with wind speed and direction. Many concentration spikes were found to be inconsistent and were therefore ascribed to background noise. Most of the consistent signals occurred around gas wells and other penetrations through the cap geomembrane. There were no significant consistent signals through the liner away from penetrations. Significant methane concentrations downwind of leaking wells were detectable at distances of over 10 m as shown in Figure 7. Figure 8 shows the path of the survey and the locations of the different high concentrations.

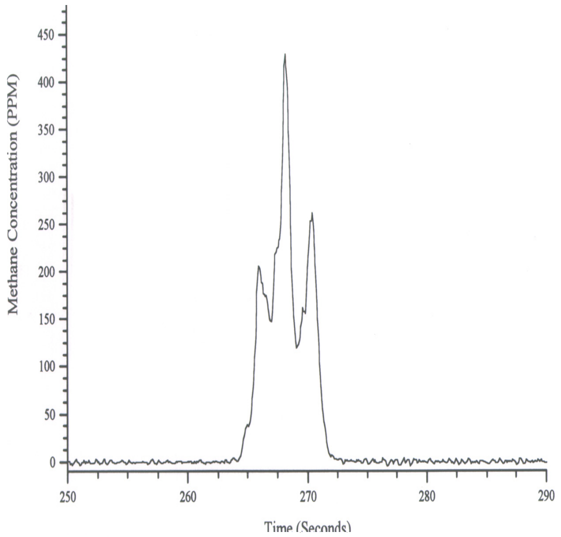

Figure 7. Traverse 10 m downwind of 3000 ppm leak

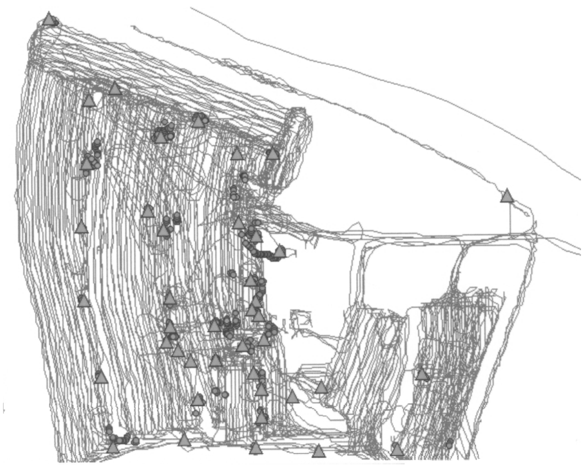

Figure 8. Survey path and leak locations

Following the initial full survey, each well, each liner penetration, and each significant signal spike, was more closely surveyed, moving the sampling hose by hand, to more exactly locate the source of the leak. Background levels upwind of the feature were first measured to ensure that methane was not generated elsewhere. Then the ground around the pipe, the boot, flexible couplings, clamps, valves, test points, and valve outlets was surveyed to locate the point of maximum methane concentration.

All methane leaks occurred at boots around the pipes, or around the concrete blocks in which the pipes were set. There was also a leak at a manhole in the center of the cap. Conversely, several penetrations had no leaks and one concrete block had no peripheral leaks

The highest concentrations at the boots varied from 2000 to about 12,000 ppm. No leak indications were found in the geomembrane itself. The peak concentrations around the concrete pads were generally above 8,000 ppm, and were always at the corner closest to the leachate collection well.

To ensure that leaking gas was not simply building up in the sand layer under the soil and venting up the sides of pipes, a hole was dug down to the sand layer close to a concrete block and methane concentrations measured at different depths in the hole. Concentrations at any given depth varied between zero and about 20 ppm. There was no evidence of a distinctly high concentration in the sand or immediately below the soil layer

The complete survey was performed in 1.5 days – a geoelectric survey, had it been practical, would have taken about 7 days.

5 DISCUSSION

Both of these surveys confirm the ability of this infrared spectroscopy technique to rapidly and effectively identify the sources of low concentrations of methane and total hydrocarbons on landfill caps and therefore to locate holes in cap geomembranes. Holes as small as 2 mm are detectable. However, it is interesting to note that high gas concentrations may be very discrete and that performing routine surveys on a parallel grid spacing of 15 or 30 m will likely not detect all high concentrations. Much closer spacing is required to achieve the desired objective. Then having found a high concentration it is quite possible that the actual leak through the geomembrane cap could be several metres away, depending on the nature of the drainage layer, the condition of cushion and separation geotextiles layers, adjacent slopes, and the availability of cover soil features and other structures that provide a venting pathway to the surface.

Performing the first survey was easy because the van containing the equipment remained stationary while the sampling hose was moved around by hand. In the second survey movement of the van carrying the equipment was unrestricted at the start of the survey but became more restricted as gas gathering pipes were placed on the surface. With a simple topography and no restrictions on movement to a four wheel drive truck or an all-terrain vehicle it is estimated that such a survey could cover much more than 100 ha per day. The equipment could be made to be portable by two people.

Clearly, there is an opportunity for using such a technique, rather than the much slower geoelectric technique, to very rapidly survey newly-laid large-area bottom liners for landfills, evaporation ponds, heap leach pads, gypsum stacks, and reservoirs, provided a signature gas is available, or could be generated, underneath the geomembrane as it is laid. Such a gas might be nitrogen. Since most damage to geomembranes is done when the cover soil is placed on the geomembrane, a slow release gas could be used to perform the survey over a cover layer of about 500 mm. Such trials are ongoing.

6 CONCLUSION

An infrared spectroscopy method for rapidly locating leaks in landfill geomembrane caps has been demonstrated. Punctures about 2 mm in diameter and cuts about 40 mm long can clearly be identified. However, the leak in the geomembrane may be quite removed from the location of maximum gas concentration above the cover soil. Due to the discrete location of some leaks it may be necessary to perform routine surveys on a parallel grid spacing of no more than about 2.5 m.

7 REFERENCES

United States Environmental Protection Agency, 1997, 40 CFR, Chapter 1, Subchapter C, Part 60, Subpart Cc, Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills.

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