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Potential of Geoelectrical Imaging Techniques for Detecting Subsurface Gas Migration in Landfills - An Experiment

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SUMMARY

We measured eleven regularly spaced resistivity profiles over a ten by ten meter experimental plot where high landfill gas (LFG) emissions had been recorded on the surface. The measurements were repeated seven times during four days which made it possible to trace the development of resistive areas. The LFG emissions at the surface of the landfill were estimated with laser absorption spectroscopy and static chamber measurements at the same time as resistivity surveying. By studying the changes of resistivity with time it was indicated that the gas migration in the waste mass was a relatively fast process, changing within only a few hours. Our presentation will focus on details regarding temporal and spatial changes of measurement.

Introduction: background and general considerations

Growing concern regarding global climate changes over the last few years has pointed out the need to quantify the uncontrolled leaking of landfill gas (LFG) from landfills to the atmosphere. LFG consists of nearly 50% methane and 50% carbon dioxide. Both are strong greenhouse gases and landfills are estimated to account for a very significant part of all anthropogenic emission of methane (Chapin *et al.* 2002:343). Methane can be used for production of electricity and heating, and constitutes in that respect a valuable resource. Landfills release up to 60 %, or more of the total amount of methane produced into the atmosphere, depending on their age and the technology used. Therefore there is a need for more efficient recovery of methane at landfills and in that respect information about the distribution of LFG in space and time is essential. Due to differences in composition and degree of degradation in the waste, LFG is produced at different places and rates a landfill. Once it is generated it starts to move due to differences in pressure (advection or pressure flow) and to differences in concentration (diffusion). Gas production gives rise to transport from high-pressure to lower pressure areas. The pressure pattern inside the landfill is complicated, due to the number of parameters involved. The topsoil can be a barrier for gas transport, especially if it is wet, as well as the compacted horizons between layers deposited at different times. The atmospheric pressure changes in time, resulting in differences in the LFG release to the atmosphere. Rise of the groundwater level tends to push the gas towards the surface (Crawford & Smith 1985; O'Leary & Walsh 2002). The temperature should also be considered. Transport by advection is typically rapid and sequential and takes place where the gas permeability is high, that is, via the paths of least resistance. Diffusion is the exchange of gas molecules from high concentration areas to low concentration areas. Transport by diffusion is typically slower than advection and takes place continuously, also mainly via the paths of least resistance. As a consequence of its horizontal structure, LFG transport inside a landfill is expected to take place mainly horizontally, until the LFG eventually penetrates the soil cover and reaches the atmosphere. As discussed above, patterns of gas transport are difficult to predict a priori. Therefore, to optimise the LFG extraction systems in landfills the location of LFG wells is critical.

In recent years gas migration in landfills seems to have been detected by resistivity measurements at bioreactor landfills; local decreases in resistivity in places were recorded as well as local increases during experiments of recirculation of leachate in bioreactors (Rosqvist *et al.*, 2005; Rosqvist *et al.*, 2007). One plausible explanation for the resistivity increase is gas accumulation. Furthermore, the electrical resistivity in soils depends on porosity, water content and texture, as well as on ion content and temperature, and these parameters are also those controlling the material's permeability. It was concluded that resistivity imaging could possibly be a viable method to study gas migration in landfills.

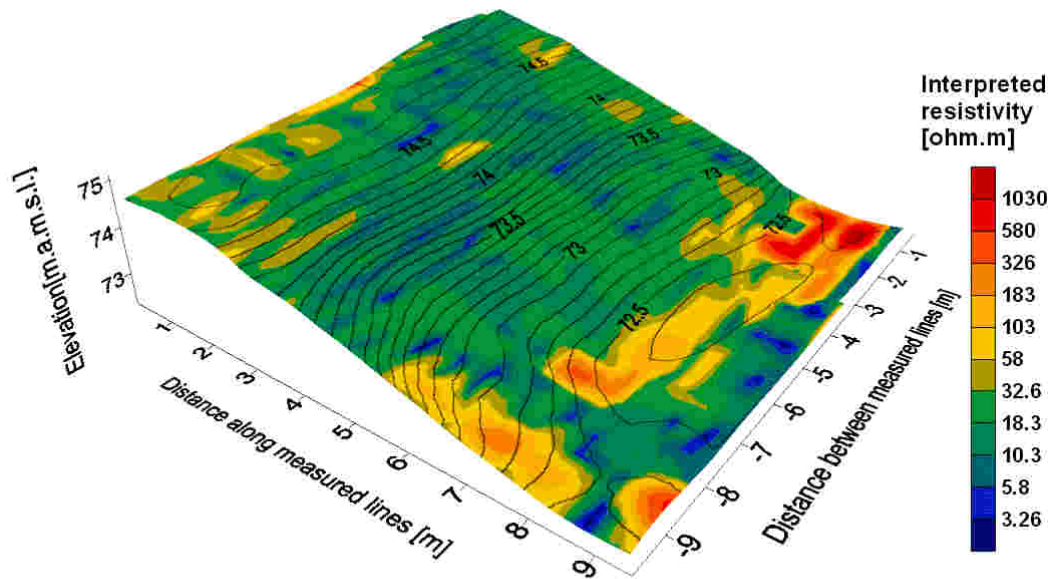
Three-dimensional resistivity measurements and results

The ABEM Lund Imaging System makes it possible to acquire 3-dimensional data sets efficiently as a series of parallel lines, than can be interpreted in the same 3-dimensional resistivity model with Res3Dinv[®].

We measured eleven regularly spaced resistivity profiles with forward and reverse pole-dipole array over a ten by ten meter experimental plot where high LFG emissions had been recorded on the surface. The measurements were repeated seven times with time intervals varying from 6 hours to one week. The weather was rainy and the electrodes were kept in place along the time of the measurement. The results made it possible to trace the development of resistive areas.

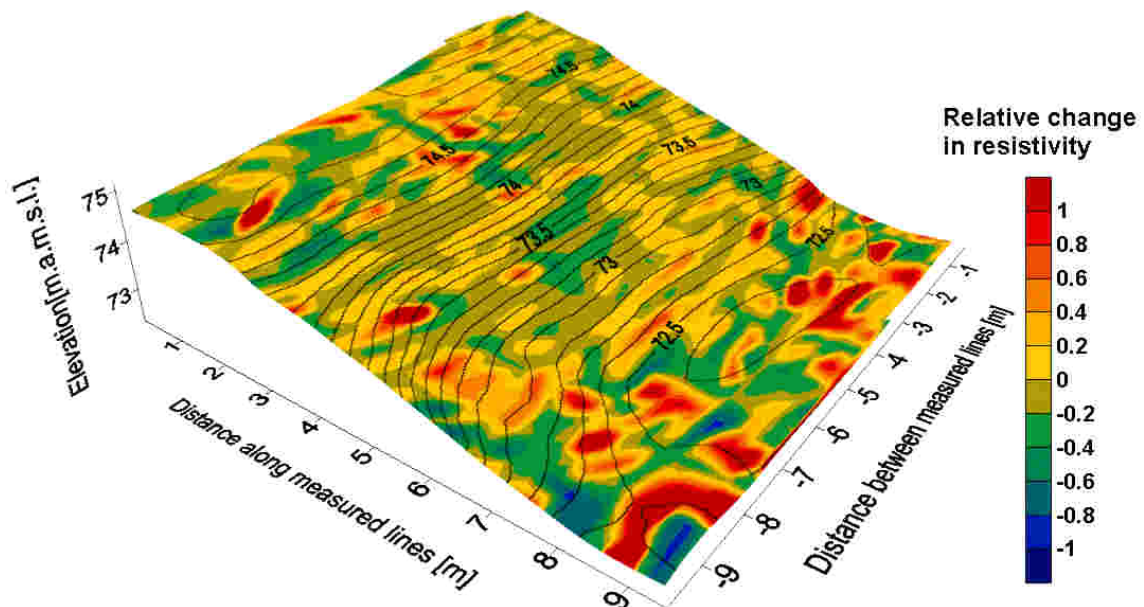
The results were processed with Res3Dinv[®] using the L1-norm, and differences between time steps were calculated between separately inverted 3D model to track changes in time. In addition time-lapse inversion was carried out with Res2Dinv[®]. Topography was included in

the inversion by means of using a distorted finite element grid. We present here some background measurements and some maps of the changes in resistivity. The changes in resistivity are all reported relatively to the first measurement (figure 1).



Interpreted resistivity for the first time step in the first layer

Figure 1. Background measurements: interpreted resistivity map in the first interpreted layer.



Interpreted resistivity changes between the third and the first time step

Figure 2. Relative changes in the interpreted resistivity after 24 hours.

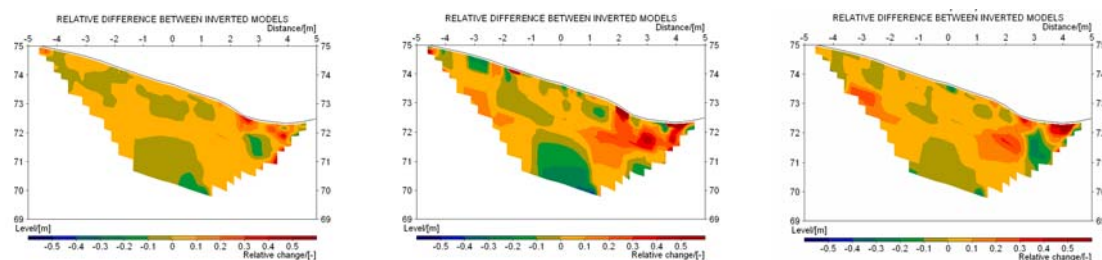


Figure 3. Relative changes observed on line B after 6, 24 and 30 hours.

The studied area is located on a slope (approx. 20% in average) between two parts on the landfill, an upper part and a lower part. Since topography was included in the finite element model used in the inversion, the effect of it should be accounted for (see e.g. Mendoza and Dahlin 2008). The depth of investigation is limited by the short electrode spacing (1 m) and the length of the lines (10 m). The figure 1 shows the resistivity in the first interpreted layer, together with the topography.

Relative changes in the interpreted resistivity with time were observed. We present here the results for the first layer after 24 hours (figure 3) and the results after 6, 24 and 30 hours on line B (figure 3).

Relatively rapid changes in resistivity are evident. They seem to be localised at the foot of the slope and to zones where it is steepest.

Relation to gas emissions

The LFG emissions on the plot were estimated at the same time as resistivity with both laser absorption spectroscopy and static chambers measurements, and the results have been compared with the resistivity. These methods for estimating gas emissions do not yield exactly the same results: the first one is more sensitive to the gas flow and yields an average over time and surface, and the second one is more sensitive to concentration and yields an average over time very localized in space.

We have observed that some areas where the resistivity increases coincide with areas where emission of gas has been observed with either one of the methods, but the correlation has not been clearly established everywhere. It should, however, be noted that the other methods give results for the particular point of time when it was recorded which differs from each other and from the time of resistivity measurements, and since a very large temporal variation in release of LFG has been observed differences should be expected.

Further investigations

Using 3D interpretation of resistivity measured along parallel lines and looking at changes with time we have been able to see some correlation of resistivity decrease with the localization of gas emissions at a landfill. Other possible explanations to the changes in resistivity are variations in moisture or in temperature, which may in turn to a significant extent be linked to gas emissions.

We project to repeat the same kind of resistivity measurements over a similar landfill area, together with measurement of gas emission, temperature and moisture in the soil. The goal is to see if similar changes can be observed and to be able to give a better assessment of their cause.

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