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AN EVALUATION OF THE POTENTIAL OF THE GEOELECTRICAL RESISTIVITY METHOD FOR MAPPING GAS MIGRATION IN LANDFILLS

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Abstract

Methane is a powerful greenhouse gas and growing concern regarding global climate changes over the last years has pointed out the need to quantify and control the leaking of methane into the atmosphere. Landfill gas is regarded as one of the major sources for methane migration to the atmosphere. In this study we present research work with the objective to evaluate the use of geoelectrical resistivity to detect gas migration in landfills. Extensive field experiments were conducted at the Filborna landfill site in Helsingborg, Sweden, in August 2008. In general, the resistivity measurements showed results corresponding to results reported from previous investigations in waste. However, also large variations in resistivity were indicated. Relatively high variability and high mean resistivity in the surface-near layers clearly indicate influence on the resistivity in the upper zone of the landfill. The variability and high resistivity may partly be explained by appearance and migration of landfill gas.

Introduction

Methane is a powerful greenhouse gas and growing concern regarding global climate changes over the last years has pointed out the need to quantify and control the leaking of methane into the atmosphere. Landfills are one important anthropogenic methane source among others, such as rice paddies, biomass burning and domestic animals (Chapin et al. 2002). There are two major advantages in collecting landfill gas, the environmental benefit of reducing the amounts of methane emissions to the atmosphere, and the economical considerations, i.e., when the energy in the landfill gas is used. In that respect landfill gas is regarded as being a renewable energy source.

Landfills are highly heterogeneous formations in which the migration of landfill gas can be expected to be highly non-uniform. Subsurface accumulation of gas causes the gas pressure to rise, which results in pressure differences throughout the landfill. The gas migrates from high pressure to low pressure zones under the soil surface (Crawford & Smith 1985). Gas flow follows the paths of highest permeability until the gas eventually finds its way into the atmosphere, generally through fissures and cracks. Theoretically, landfill gas is transported mainly horizontally due to the compaction of waste in layers. The rate of emission depends on several factors, but the most important is the soil moisture in the upper soil, since high soil moisture content in soil pores can more or less constrain gas from diffusing to the atmosphere. (Boeckx et al 1996).

To recover the energy potential and to mitigate the environmental impact from methane, effective techniques for landfill gas collection are crucial. The location of wells for landfill gas collection is important, and there is therefore a need for development of techniques to detect and locate the presence and migration of gas in landfills.

It has been pointed out that the electrical resistivity technique is suitable for monitoring of water fluxes in landfills since it links with moisture content and ionic content in the water (e.g., Guérin et al., 2004). In recent years resistivity has been used at landfills for various applications like mapping landfill cover (e.g. Leroux et al., 2007), detecting and mapping pollution plumes (e.g. Rosqvist et al. 2003), and for studies of moisture migration processes during leachate recirculation at bioreactor landfills (e.g. Marcoux, et al., 2007, Rosqvist et al, 2005, and Rosqvist et al, 2007). In those experiments growing resistive anomalies were observed at the same time as the moisture spread. Moisture movement explained low resistivity zones, whereas the presence and accumulation of gas was one plausible explanation for the irregular high resistivity zones. In the experiments it was concluded that resistivity could be used for detecting and localizing landfill gas.

As a consequence of the expected sequential nature of the release of landfill gas to the atmosphere, it is expected that the zones with landfill gas migration will signal themselves by large variations in resistivity. It is, however, also expected that the variations in resistivity will be related to soil temperature and moisture resulting in a complex situation for data analysis. Gas accumulations are expected to be visible as high resistivity zones in the data.

In this study we present research work with the objective to evaluate the use of geoelectrical resistivity to detect zones in municipal solid waste landfills where gas migration occurs.

Materials and methods

The field site

The field measurements were performed at the Filborna landfill site, managed by NSR AB in Helsingborg, Sweden. The measurements were conducted for three weeks in August 2008, with a main focus on the initial 5 days. In Figure 1 and 2, the experimental site is shown. The red and yellow plastic tape in Figure 1 shows the position of the lines where the resistivity was measured.

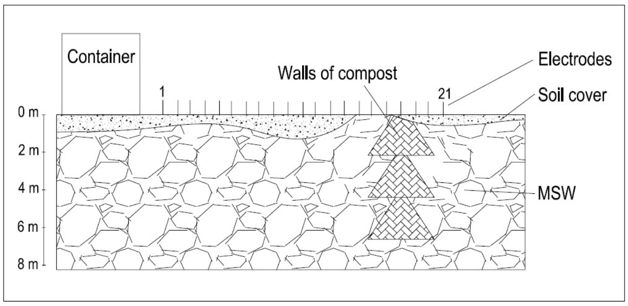

Figure 1: Photo showing the experimental site at the Filborna landfill.
Figure 2: Section of the experimental site at the Filborna landfill (sketch)

The experimental site was located in a sloping hill (Figure 1). As shown in Figure 2, an intermittent soil cover of an irregular thickness around 0 – 0.5 meter covered the waste layer. MSW and industrial waste had been deposited in the landfill from autumn 2005 until summer 2007 resulting in high gas recovery from the gas extraction system at the site. Field investigation concluded that the groundwater table was at depth greater than 16 meter.

In addition to the general heterogeneous structure of the waste in the landfill, a subsurface body of compost material was situated along the experimental site as shown in Figure 2. The compost body consisted of soil and wood chips and was assumed to have a relatively high porosity and it was thus assumed to have high gas permeability.

Resistivity measurements

Geoelectrical imaging techniques are envisaged to have several applications in connection with monitoring of landfill sites including groundwater investigations around landfills, for example, mapping for identification and delineation of contaminants, quality control of soil stabilisation/contaminant immobilisation, and long-term monitoring. Leakage from municipal and mining waste deposits is generally associated with high ion concentrations and hence very low resistivities. This makes geoelectrical-imaging techniques particularly interesting for leachate migration inside and around landfills.

Resistivity is a geoelectrical imaging method that is based on the measurement of the potential distribution arising when electric current is transmitted to the underground via electrodes. In our experiments resistivity monitoring was carried out along nine parallel lines with the ABEM Lund Imaging System multi-electrode system (Dahlin and Zhou, 2004). The lines were separated by 2 meter and with an electrode spacing of 0,5 meter, resulting in a 16 by 20 meter experimental site. The system is computer controlled and consists of a resistivity instrument, a relay-switching unit, four electrode cables, connectors and steel electrodes. The resistivity measurements were monitored using a remote controlled system and designed for 3D-measurements and 3D-interpretation. All data for each complete set of measurements were inverted using Res3Dinv, and a true 3D-model was computed for each measurement.

Gas emission measurements

A hand-held Siemens AG, CT PS 8 laser system, developed for field-based remote detection of emission of natural gas, was used for methane detection at the landfill surface (see also Ljungberg et al., 2009). The laser system operates with an infrared laser and is a backscatter system. The laser beam is transmitted and records the concentration of methane gas along a beam length, where the laser beam is reflected from a background surface, and the laser gives a mean concentration along the relevant measurement distance from the laser to the backscatter surface. The laser system is designed with a laser for detecting natural gas, i.e. gas with a methane content of 96-98 per cent as opposed to a methane content of 40-60 per cent for landfill gas. The lower methane content of landfill gas makes it less detectable compared with natural gas.

Additionally, methane emissions were measured with the static chamber method. Air samples were collected from the chambers with syringes, and analyzed in a laboratory through separation by gas chromatography (GC, Shimadzu 17A) and detection by flame ionization detection (FID).

Pore pressure measurements

Pore pressure was measured with BAT MKIII Vadose sensors, installed at depths of 1,5m below the soil surface. Since the ground water level was at several meters depth at the experimental site, presence of gas in the soil was assumed to be indicated by high pore pressure values. The positions of the sensors were based on early resistivity data. Sensor F1 was located in a zone where resistivity values were high at 1,5m depth, while F2 was placed in a zone with low resistivity values (see figure 3).

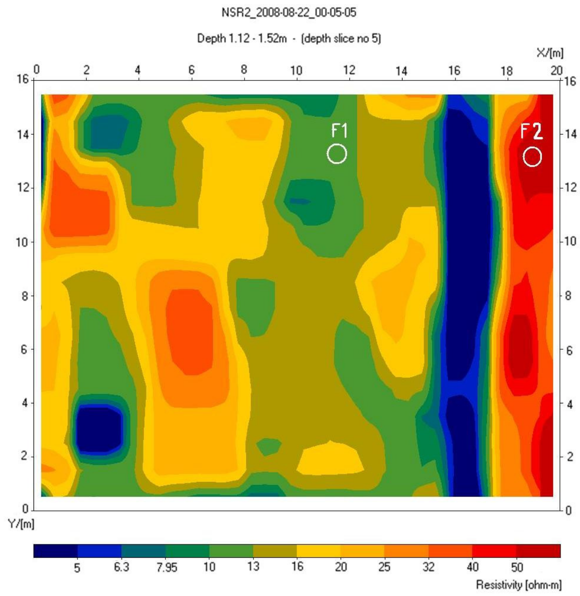

Figure 3: Positions of the pore pressure sensors at 1.12-1.52m depth on a resistivity profile.

Results and discussion

Resistivity

Figure 4 shows a 3D-modell of the resistivity measurements at the Filborna landfill, conducted on August 18, 2008. The inverted resistivity data varied from very low (under 3 Ωm) to relatively high (over 500 Ωm) resistivity values. However, most of the resistivity data were in the same range as previous investigations on MSW has shown, varying between very low resistivity and up to approximately 50 Ωm. At the surface, the positions of the electrodes are visible as red dots in Figure 3. This is an artifact arising during the inverse modelling procedure, which most likely could be reduced by an optimization of the software settings or of the software code.

Three main areas of difference in resistivity were observed. One area with low resistivity (below 10 Ωm), that agrees well with the position of the subsurface compost wall (green area to the right in Figure 3). The second area, to the left of the subsurface compost wall, shows resistivity values in a range up to approximately 50 Ωm. The third area, characterized by high resistivity values, appears at a zone near the surface above the subsurface compost wall. In this area resistivity values over 500 Ωm were registered. This area is particularly interesting since the high resistivity values may indicate gas migration near the subsurface compost wall.

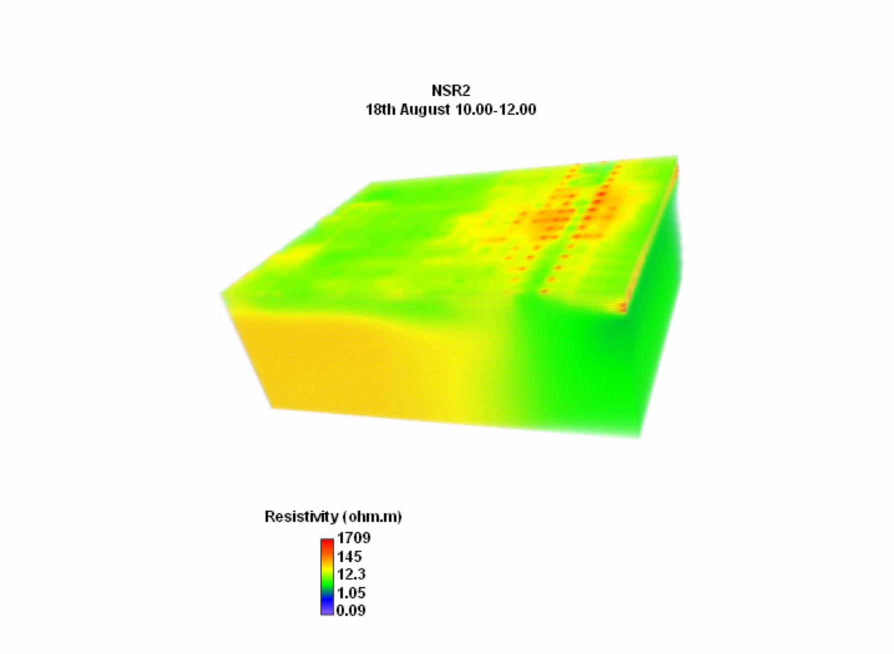

Figure 4: 3D-modell of the resistivity measurements at the Filborna landfill, conducted on August 18, 2008.

In Figure 5 the mean resistivity and coefficient of variation at different depths at the Filborna landfill during measurements in August 11 to 18, 2008 are shown in 17 layers, representing different depths from 0,1 to 13,6 meter. The resistivity values were relatively high at the surface (50 Ωm) with a rapid decrease down to approximately 20 Ωm at one-meter depth. At depths below two meters the mean resistivity stabilizes at 25 Ωm. The inert soil cover probably influences the relatively high resistivity values at the surface layers.

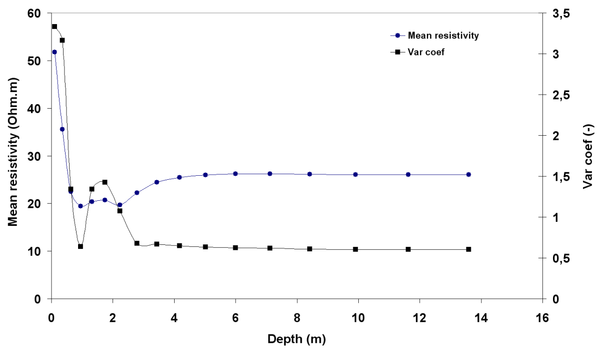

Figure 5: Mean resistivity and coefficient of variation at different depths at the Filborna landfill during measurements in August 18 to 22, 2008.

The coefficients of variation show a similar pattern as the mean resistivity with high coefficient of variation at the surface (over 3) and low and stable coefficient of variation at depths below 2 meters (0,7 to 0,6). Moreover, at the layers between 1 and 2 meter a local peak is shown with coefficient of variation rising from approximately 1 to 1.5.

The main focus in the study was on the temporal and spatial variability in the resistivity data, as it was assumed that large variability in the data could indicate gas migration in the waste mass. Figure 6 shows a 3D-plot of the coefficient of variation for the inverted resistivity data at the Filborna landfill site for the measurements conducted during August 18 to 22, 2008. The coefficient of variation varies from very low values, below 0.01 (blue and green areas in Figure 6) to higher values (yellow and red areas in Figure 5). The high variability in the data in the uppermost layers and a decrease in variability with depth, which is shown in Figure 5, is also indicated in Figure 5.

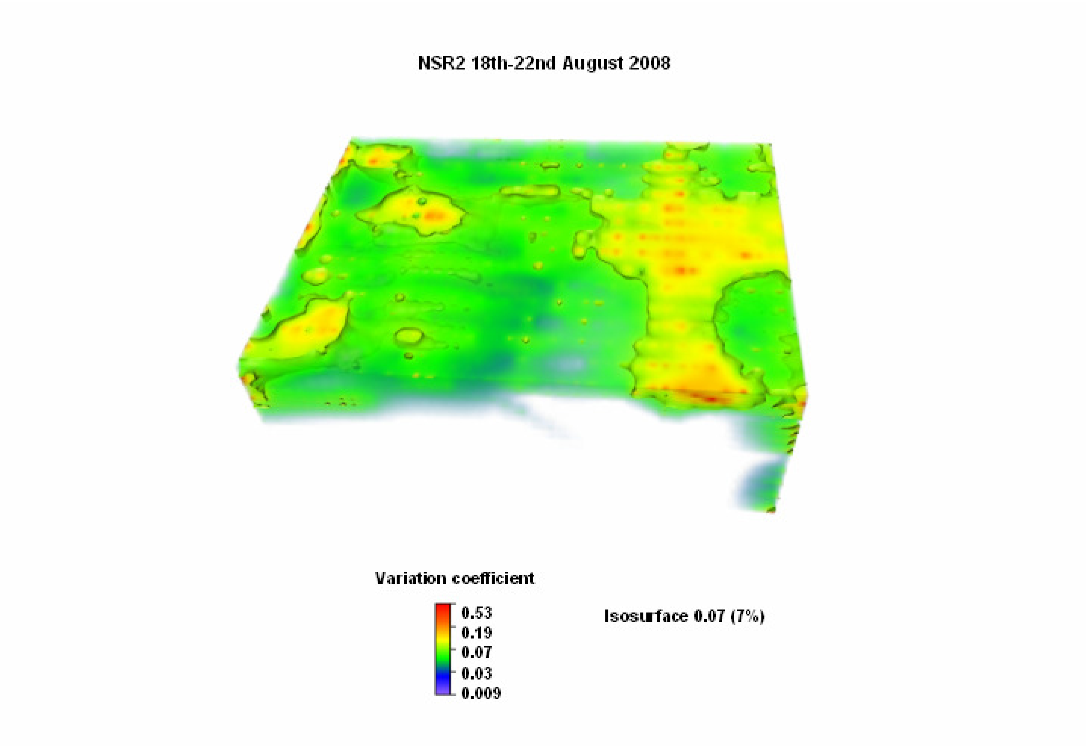

Figure 6: A model of the coefficient of variation for the resistivity measurements at the Filborna landfill during August 18 to 22, 2008.

The temporal variation in resistivity for a limited area of the upper soil is shown in figure 7. The correlation between the variations in resistivity and soil temperature suggests that the gas in the soil pores is affected by the variations in temperature. A possible explanation is that the pore gas pressure increases with increasing soil temperature, resulting in higher resistivity values.

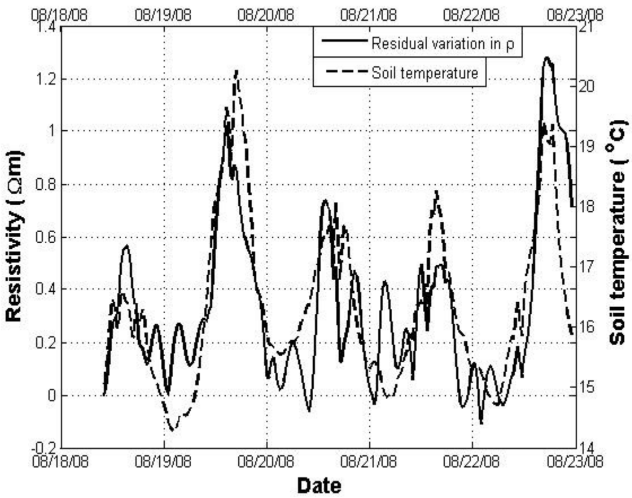

Figure 7. Example of temporal variations in resistivity and soil temperature.

Gas emission measurements at the surface of the landfill

In Figure 8, laser-scanning results show high levels of methane gas concentrations at the surface along the subsurface compost wall (200 – 600 ppm; red area). Also an area of concentrations at lower levels was measured at the test area (70 – 100 ppm; green area). The high levels of methane gas concentrations along the subsurface compost wall are particularly interesting since they correspond well with the resistivity measurements showing high resistivity (Figure 4), and high variability in resistivity data in the same area (Figure 6).

The positions of the static chamber measurements are also seen in figure 8. The results showed that the average methane emission from the two chambers furthest to the right in figure 6 was 322mg/m^2/s. Average methane emission from the other four chambers was -3mg/m^2/s. Negative methane emissions indicate that the gas emitted into the chamber consists of mostly carbon dioxide.

Thus, when measurements at the surface (Laser system and static chamber) were compared with the subsurface measurements (resistivity) the same pattern of methane migration was observed.

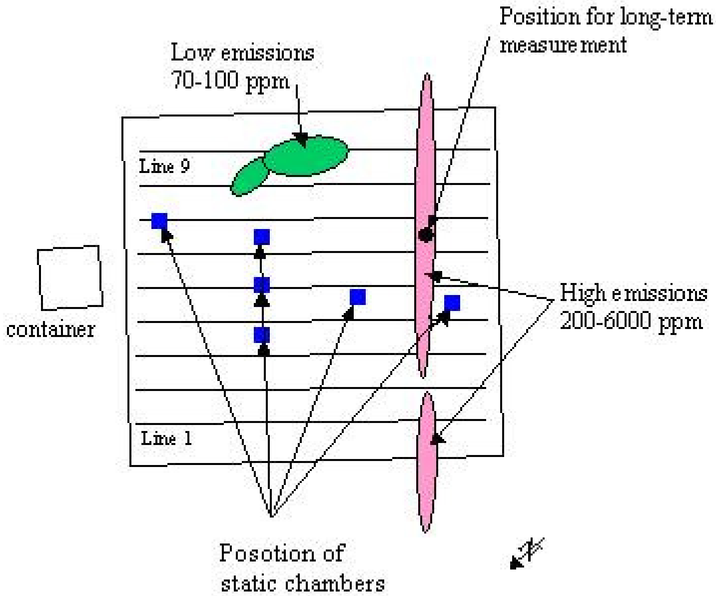

Figure 8: Laser-scanning results and static chamber position at the Filborna landfill site

Pore pressure measurements

Figure 9 shows the results of the pore pressure measurements. An initial overpressure of 7 mH_2O was measured at sensor F1, where after the pore pressure gradually declined to 3,5 mH_2O. This can be an indication of gas presence in the high resistivity zone where sensor F1 was installed. Possible reasons for the decline in pore pressure could be gas migration to other parts of the landfill, or leakage through the bentonite sealing surrounding the BAT sensor. The pore pressure measured at sensor F2 was relatively stable at around 0 mH_2O throughout the measurement period. The results support the assumption that high resistivity values can indicate gas.

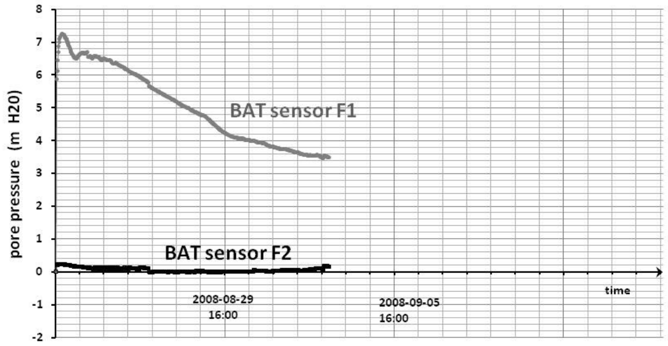

Figure 9: Pore pressure results from sensor F1 (high resistivity) and sensor F2 (low resistivity).

Conclusions

In this study we present research work with the objective of evaluating the use of geoelectrical resistivity technique to detect landfill gas migration. Extensive field experiments were conducted at the Filborna landfill site in Helsingborg, Sweden, in August 2008.

In general, the resistivity measurements showed results corresponding to results reported from previous investigations in waste. However, large variations in resistivity values were also indicated. Relatively high variability and high mean resistivity in the surface-near layers clearly indicate influence on the resistivity in the upper zone of the landfill. The variability and high resistivity may partly be explained by the presence and migration of landfill gas. However, other factors such as temperature, soil moisture and organic content in the waste may influence the resistivity and variability in the data.

The pore pressure results support the assumption of a link between gas presence and high resistivity values. When methane measurements at the surface (Laser system and static chamber) were compared with the subsurface measurements (resistivity measurements) the same pattern of possible landfill gas migration was observed. It is therefore concluded that the resistivity technique has a potential for mapping of landfill gas migration. The relationship is however complex and site-dependent, but given a good combination of information from different field data, it appears to be possible to image the migration of gas inside a landfill.

It is suggested that future R&D work should aim at a better understanding of the potential in geo-electrical methods for detecting landfill gas migration. In particular, gas migration at greater depth and at larger surface areas should be addressed. Also other processes such as, temperature and moisture content should be addressed. The R&D should also further investigate the interaction between subsurface processes and the landfill gas migration through soil cover of landfills.

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