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# INVESTIGATION OF WATER FLOW IN A BIOREACTOR LANDFILL USING GEOELECTRICAL IMAGING TECHNIQUES

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**SUMMARY:** This paper describes field investigations of leachate recirculation at a bioreactor landfill using geoelectrical imaging technique (i.e., electrical resistivity). The use of geoelectrical imaging techniques is an established practice for environmental investigations and monitoring of various landfill processes and in recent years also the bioreactor landfill concept has been emphasised. In the study, the electrical resistivity technique was evaluated and the increase in moisture content as a result of the start of leachate recirculation was investigated. In this paper results showing moisture migration through the bioreactor landfill are presented. Also result showing the resistivity technique being useful for biogas detection are shown.

## 1. INTRODUCTION

This paper describes field investigations of water recirculation at a bioreactor landfill using geoelectrical imaging technique (i.e., resistivity). The use of geoelectrical imaging techniques is an established practice for environmental investigations and monitoring of various landfill processes (e.g., Bernstone and Dahlin, 1997, Rosqvist et al, 2003, Cardelli and Di Filippo, 2004), and in recent years also the bioreactor landfill concept has been emphasised (Guerin et al, 2004, Moreau, et al., 2004). In the study, the electrical resistivity technique was evaluated and the increase in moisture content as a result of the start of leachate recirculation was investigated.

The bioreactor concept was developed to reduce and control the environmental impact of landfills and to utilise the energy potential of the waste, and in recent years the interest for bioreactor landfill techniques have been at a high level (Barlaz and Reinhart, 2004). The main principle of the bioreactor concept is to enhance waste biodegradation by recirculation of leachate in the waste mass, and consequently, the potential long-term risks will be reduced, and post operation costs will be decreased. Moreover, the enhanced waste biodegradation leads to an increase of biogas production for energy utilisation.

Spatial distribution of moisture content is recognised to be of great importance to the biodegradation and methane production in a bioreactor. The overall objective of the project was therefore to investigate the spatial distribution of water flow within a bioreactor landfill with leachate recirculation.

## **2. MATERIALS AND METHODS**

### **2.1 The Bioreactor landfill**

The field campaign was carried out at a bioreactor landfill at the Filborna landfill site, Helsingborg, Sweden. The bioreactor landfill was 120 by 60 meter, with a depth of approximately 16 meter. The bioreactor landfill was isolated from the surroundings by the use of low permeable clay as a bottom liner. During the construction of the bioreactor landfill it was built up in 5 meter layers, each layer covered with an intermediate cover of compost.

Horizontal pipes for leachate recirculation were placed in trenches together with gas collection pipes. The pipes for leachate recirculation were installed at the bottom of the trenches and the gas collection pipes in the upper part. Altogether 7 trenches for leachate recirculation and biogas collection pipes were installed with a 20-meter distance between the trenches (see Figure 1). At the bottom of the bioreactor landfill, a leachate collection system was installed and in the interior horizontal pipes for gas collection was installed.

### **2.2 The geoelectrical-imaging techniques**

Geoelectrical imaging techniques are envisaged to have three major applications in connection with ground and groundwater contamination around landfills: mapping for identification and delineation of contaminants, quality control of soil stabilisation/contaminant immobilisation, and long term monitoring afterwards. 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. In the study presented here in the use of geoelectrical imaging techniques for bioreactor landfill process monitoring have been addressed. The electrical resistivity is suitable for monitoring of water fluxes in landfills since it links with moisture content and ionic content in the water, as pointed out in Guérin et al., (2004).

The resistivity method is based on measurement of the potential distribution arising when electric current is transmitted to the underground via electrodes. The data acquisition was done as two-dimensional (2D) resistivity imaging, using the ABEM Lund Imaging System in a version that also allowed measurements of time-domain induced polarisation (IP) data in ten time windows. The system is computer controlled and consists of a resistivity-IP instrument, a relay-switching unit, four electrode cables, connectors and steel electrodes. The 2D imaging layouts used comprises around 80 electrodes, and measurement lines can be expanded via a roll-along technique. A gradient array electrode configuration was used in order to get good resolution (Dahlin and Zhou 2004). The measured data was processed with inverse numerical modelling (inversion) to produce model cross-sections of the resistivity and chargeability distribution of the ground using the software Res2dinv.



Figure 1. Plan of the bioreactor landfill showing the distribution pipes for leachate and the lines for resistivity measurements (Line 1 – 3)

### 2.3 The resistivity measurements

A 2-D resistivity and IP survey was performed in which three parallel lines, each 160 m long, were measured perpendicular to the leachate distribution pipes (Figure 1). The electrode distance was 2 m and multiple current source gradient array was used. A number of resistivity and IP-surveys were carried out with the cable layout in fixed positions. The study was described in detail in Lindhé (2003), and in this paper, only the results of the resistivity measurements are presented.

To get a picture of the bulk resistivity of the waste material in the bioreactor the fieldwork started with a background measurements. In the next step, leachate recirculation using only leachate from the bioreactor was started and the geo-electrical measurements continued. This phase of the experiment lasted for 8 days, when 40 m<sup>3</sup> of leachate was pumped into the recirculation system. Throughout the experiments only one out of seven distribution pipes were used for leachate introduction into the bioreactor landfill (see Figure 1). The average leachate recirculation during the first phase corresponds to 0,10 m<sup>3</sup>/h. However, the actual recirculation rate varied considerably due to practical problems with the supply of leachate to the distribution system.

In order to increase the water flux during the next phase leachate from other landfills were pumped into the leachate distribution system. During this phase the experiment lasted for 4 days, when 40 m<sup>3</sup> of leachate was pumped into the recirculation system. The average leachate recirculation during the first phase corresponds to 0,42 m<sup>3</sup>/h.

### **3. RESULTS**

#### **3.1 Background measurements**

The background measurements were performed without any covering plastic liner at the surface of the landfill. The measurements were carried out in the summer and therefore the surface of the landfill was dry due to high evaporation. The fieldwork was straightforward thanks to the good electrode grounding conditions and accessibility of the site. All the measured lines resulted in inverted images that consistently show similar structures.

In Figure 2, the light grey to white (high resistivity) parts near the surface of the bioreactor (resistivity between 50 to 200  $\Omega\text{m}$ ) are interpreted as an influence of the dry upper part of the bioreactor and a relatively dry soil layer at the surface. Stagnant or migrating biogas, trapped in the upper layer of the bioreactor landfill, may also contribute to the relatively high resistivity in the upper part of the bioreactor.

In the central parts of the sections, at depths of approximately 3 to 7 meters, the light to medium grey parts (resistivity between 3 to 30  $\Omega\text{m}$ ) are interpreted as the resistivity of the waste. In this part of the landfill the waste material is assumed to have high moisture content and high ion concentrations in the water phase resulting in the relatively low resistivity. The measured resistivities seems reliable when it is compared with results presented elsewhere, e.g., in Bernstone et al. (1998) who measured resistivities between 15 to 70  $\Omega\text{m}$  in a conventional waste landfill.

The depth of the bioreactor is approximately 16 meter and the bottom is located at approximately 55 meter in the sections. At the 55-meter level the boundary between the waste in the bioreactor and the bottom liner some anomalies could be interpreted as the bottom of the landfill. However, these anomalies are not obvious enough, and therefore the bottom of the landfill can not be clearly distinguished. The indistinct detection of the bioreactor bottom liner was believed to be due to the material in the bottom liner (clay) and the fact that the bioreactor was placed upon an old landfill. Both the clay layer at the bottom and the old waste layer have electrical resistivity similar to the waste mass in the bioreactor.

The trenches for the water recirculation and biogas collection pipes have a depth of 1,5 meter and were placed at 20-meter distances, and filled with wooden chips. The plastic pipes as well as the relatively dry wooden chips, not containing any ion rich leachate, have a high resistivity resulting in the light grey to white spots clearly shown in the sections (see Figure 2 and 3).

#### **3.2 Leachate recirculation experiment**

During the experiment 40 m<sup>3</sup> of leachate was pumped into the recirculation pipe in 8 days. The volume correspond to an average flow rate of 0,19 m<sup>3</sup>/h. It was however not possible to maintain a continuous flow through out the experiment due to practical problems with the system for leachate recirculation. During the measurements the bioreactor landfill was only covered with a permeable compost material, and in the beginning of the experiments some heavy rainstorms may have influenced the results of the measurements near the surface of the bioreactor. After these rainstorms the weather was hot and dry for the rest of the experimental period. The measurement resulted in good data quality thanks to good electrode grounding conditions and accessibility of the site.

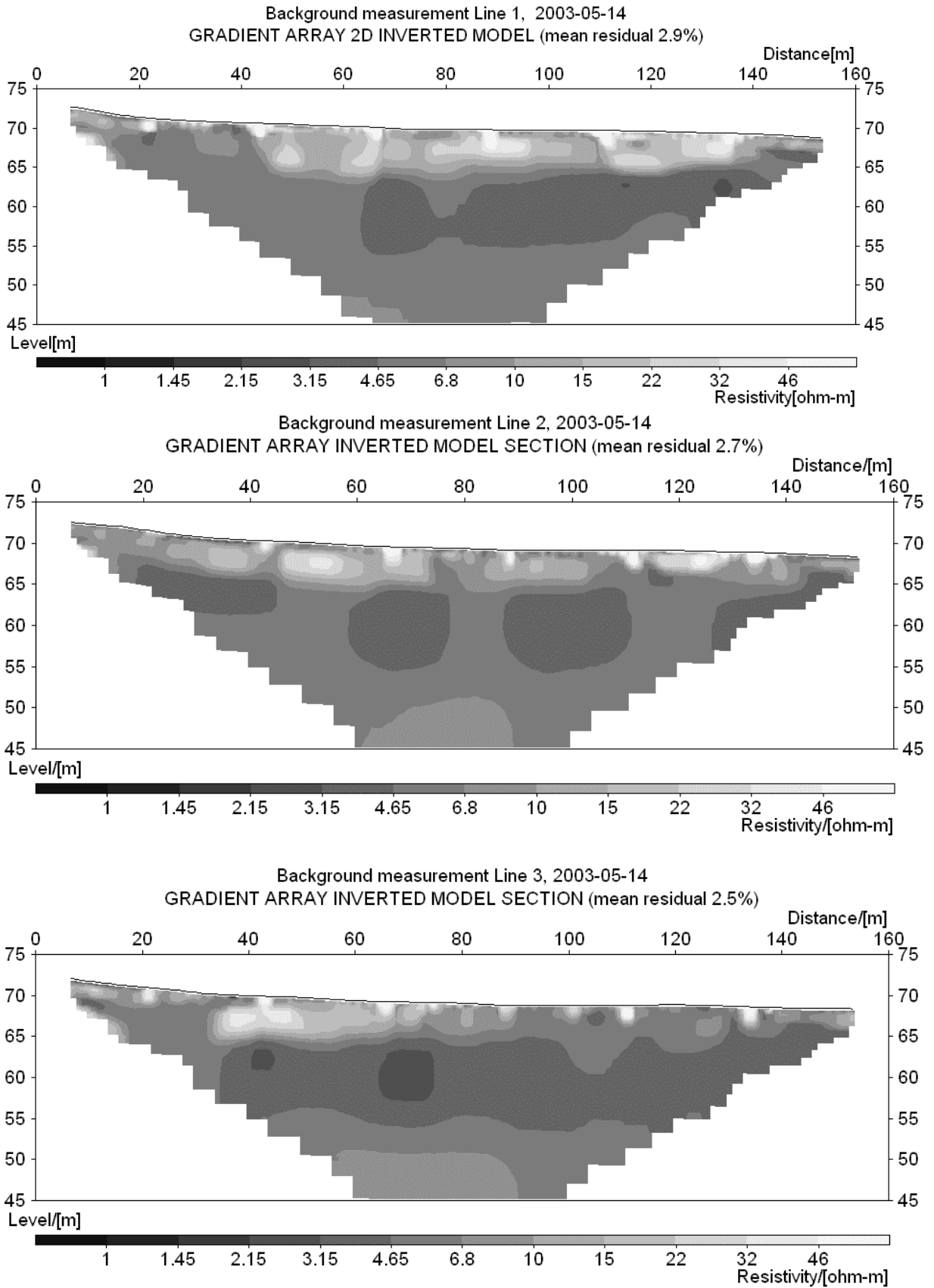


Figure 2. Results of the background measurements.

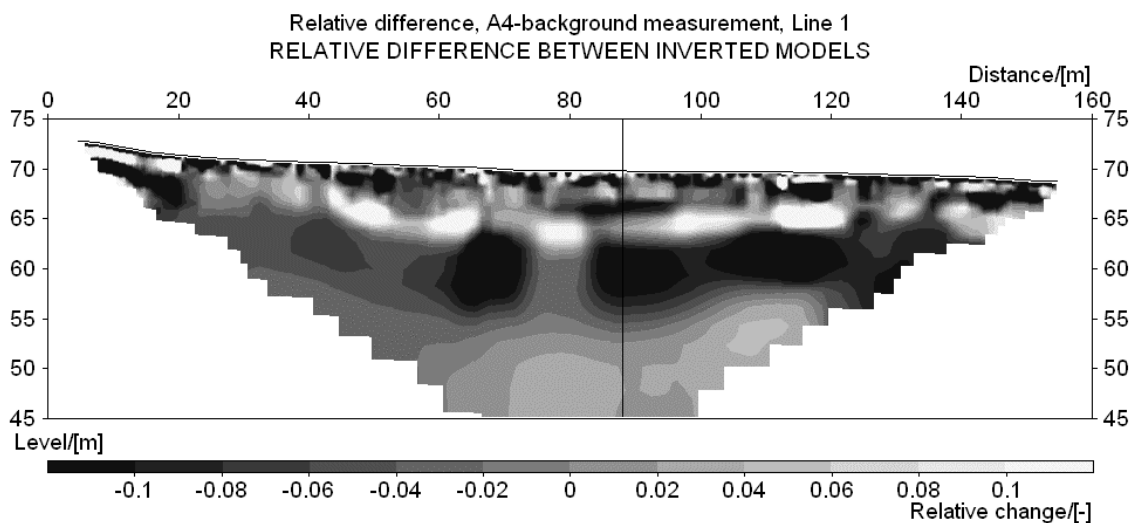
In Figure 3, the relative difference between the background measurements and the measurements after 40 m<sup>3</sup> of leachate had been pumped into the distribution system, are shown. In the sections the results are presented in a scale from -0,1 – 0,1, which corresponds to a relative difference from -10% to 10%. The results of the relative difference between the measurements can be summarised in the following:

- The resistivity has decreased near the surface (dark grey areas)
- Beneath the recirculation pipe (marked at 88 meter in Figure 3) the resistivity has decreased from the surface down to greater depth (Figure 3, Line 2 and 3)
- In all sections horizontal layer with increased resistivity are shown. In particular at approximately 5 meter depths.
- An increase in resistivity near the bottom of the bioreactor (light grey to white)
- When the sections are compared, pronounced differences in resistivity pattern can be observed

The decrease in resistivity at the location where the leachate was recirculated (at 88 meter) can be explained by the increase in moisture content. The results show a low resistivity “bulb” formed directly beneath the recirculation pipe (dark grey zones at Line 2 and 3 in Figure 3) suggesting horizontal and vertical distribution of leachate. At greater depth the resistivity is shown in a more narrow area, suggesting a vertical flow, also particularly evident at Line 2 and 3 in Figure 3.

The decrease in resistivity near the surface can be explained by rainfall that occurred in the beginning of the measurements. The decrease at greater depth can partially be explained by the leachate recirculation, but also other processes influencing the resistivity, such as temperature dependence, may explain the decrease in bulk resistivity.

Horizontal layers with increased resistivity are clearly shown in all sections. It is suggested that these layers are due to the stratified structure of the bioreactor with intermediate covers between waste layers of approximately 5 meter, leading to significant spatial variation in density and permeability in the bioreactor. It is believed that the stratified increase in resistivity is due to stagnant or migrating biogas in more permeable parts of the waste mass. Possibly also the biogas collection system effect the migration of the biogas. These results were not expected, but recent research has shown that presence of biogas may result in an increase in bulk electrical resistivity in waste landfills (Moreau, et al., 2004).



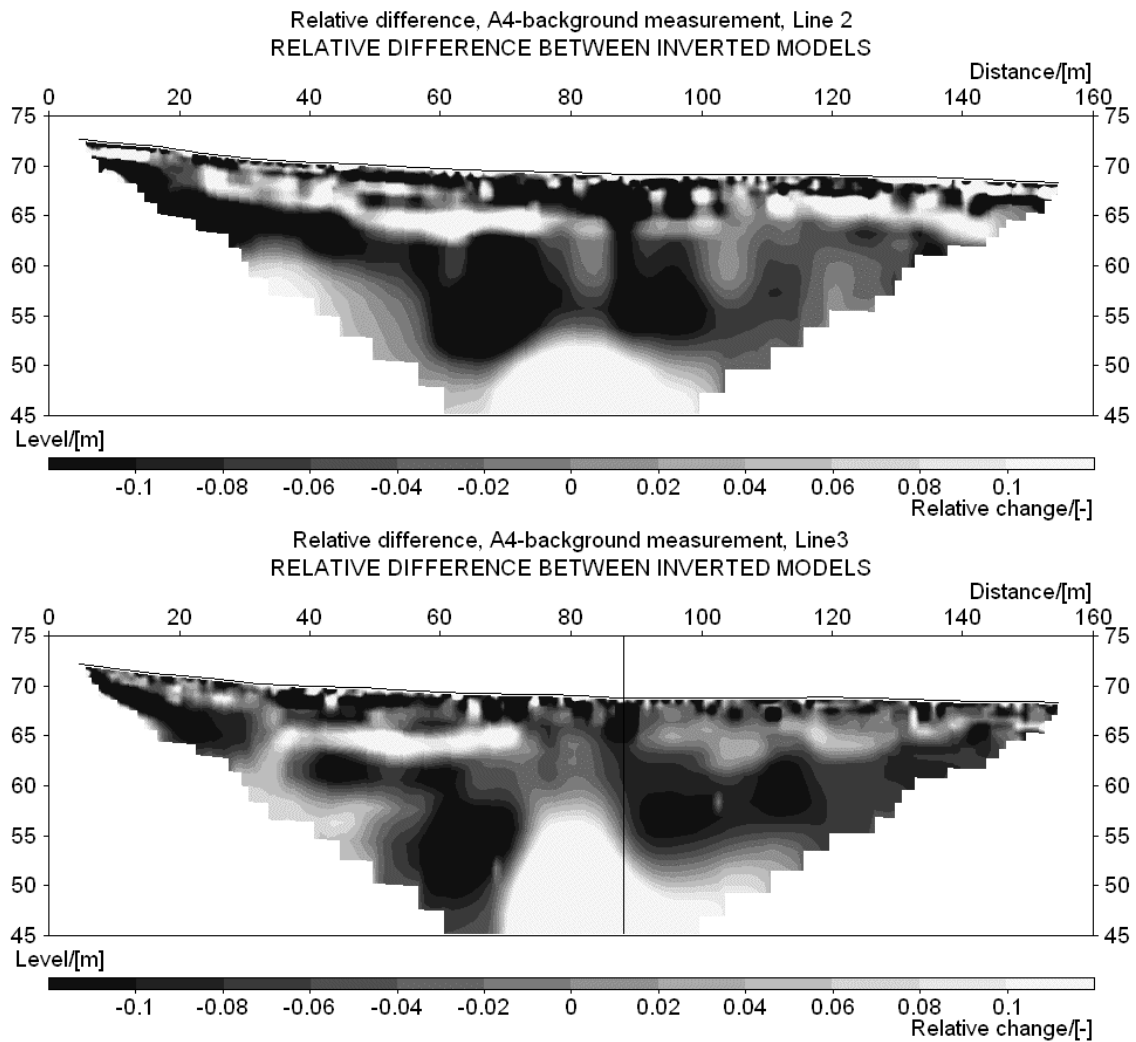


Figure 3. Relative differences between the background measurements and the measurements when 40 m<sup>3</sup> of leachate had been recirculated.

#### 4. DISCUSSION AND CONCLUSIONS

The fieldwork was performed under good conditions resulting in high quality field data showing a fairly consistent picture of the waste mass in the bioreactor landfill. For example, the trenches for leachate recirculation and biogas collection systems shown at the resistivity section indicated the measurements to be consistent and reliable. However, at greater depth (approximately 10 – 20 meters) the field data was shown to be less reliable due to the decrease in data resolution with depth. For example, the bottom of the bioreactor landfill could not be clearly detected. The indistinct detection of the bioreactor bottom liner was also due to the material in the bottom liner (clay) and the fact that the bioreactor was placed upon an old landfill. Both the clay layer at the bottom and the old waste layer have electrical resistivity similar to the waste mass in the bioreactor.

In the bioreactor the resistivity of the relatively wet waste mass at depth was measured to be in the range of 3 to 30  $\Omega\text{m}$ , which is in the same range (Guérin et al., 2004) or somewhat lower (Bernstone and Dahlin, 1997), than results presented elsewhere. High water content and ionic content, and high organic content can partly explain the relatively low resistivity in the



bioreactor. Also the temperature may influence the outcome of the measurements (Guérin et al., 2004).

The main objective with the study was to investigate the spatial distribution of recirculated leachate in a bioreactor landfill at field scale. The experiment could successfully detect the distribution of recirculated leachate through the waste mass by comparing interpretations of resistivity measurements at different time steps (i.e., relative differences) in 2-D resistivity sections. The results presented in the resistivity sections indicated the moisture movement to be both horizontal and vertical. The results suggest the leachate flow to occur as a slow matrix flux combined with rapid vertical flow, which is in accordance with previous investigations on water flux through waste mass (e.g., Rosqvist and Destouni, 2000).

An interesting result of the experiment was the detection of biogas migration in the bioreactor. Occurrence of biogas in horizontal zones of high resistivity was indicated by high electrical resistivity. It is suggested that these zones are due to the stratified structure of the intermediate covers in the bioreactor leading to significant spatial variation in density and permeability. Also the location of the biogas collection system in the bioreactor is important for the biogas migration pattern. This phenomenon was not reported in the literature when the field experiment and interpretation was performed. However, in recent years the phenomenon has been recognised and a study has been reported (Moreau, et al., 2004). In Moreau, et al., (2004) variation in electrical resistivity indicated biogas migration and an interpretation of leachate recirculation effects on biogas migration was proposed.

Geo-electrical techniques provide an interesting technique for landfill process monitoring and it is therefore suggested that the techniques should be developed in order to achieve a better understanding of leachate and biogas migration in bioreactor landfills as well as in conventional MSW landfills. However, to achieve a better understanding of the leachate and biogas flux in landfills it is suggested that a 3-D interpretation of electrical resistivity data measured in field should be performed. Moreover, to improve the field data in future investigations it is suggested that the leachate recirculation should be held constant through out the experiment and that the surface of the bioreactor should be covered during the whole experiment.

Based on the results of the geo-electrical measurements, it is suggested that the technique provide an interesting possibility for development of bioreactor and MSW landfill monitoring and process control. For future R&D, it is suggested that moisture migration through the waste mass should be investigated and clarified. For a better understanding of moisture migration through the waste mass and the spatial flow pattern in the waste mass, a combination of tracer test and geo-physical measurements are suggested, where simultaneous investigations of water flow parameters (e.g., hydraulic conductivity) and spatial distribution of the water flow can be performed. As pointed out in Guérin et al., (2004), in future investigation also the influence of temperature on the electrical resistivity should be clarified.

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