MONITORING OF LEACHATE RECIRCULATION IN A BIOREACTOR LANDFILL : COMPARISON OF LYSIMETER AND RESISTIVITY MEASUREMENTS

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SUMMARY: One of the major challenges to run a landfill as a bioreactor with leachate recirculation is to insure homogeneous moisture distribution and movement through the waste. Parameters such as the radius of influence and leachate pathway are crucial to design the recirculation system (size, vertical and horizontal spacing) and determine a recirculation strategy (flow rate, frequency…). Today, there is no consensus on a cost effective, non destructive and reliable monitoring method that could be used on this purpose. On an R&D bioreactor landfill (VES landfill of Bouqueval, France) Veolia Environmental Services Research Centre has put in place two monitoring methodologies which can allow determining leachate pathways at a full scale. The first one is based on ERT (Electrical resistivity tomography). The second one is a new approach, based on the use of lysimeter chambers. Whereas the resistivity measurement is more a qualitative methodology, the lysimeter chambers could enable to measure a flux of leachate per surface unit, depending on the distance from the recirculation system. The set up of both monitoring equipments on a same injection system will allow evaluating the consistency of the two methods, and the drawbacks and advantages of each. This comparison is made at full scale, on several injection points, to assess the impact of waste heterogeneity within a landfill cell on leachate pathway, and consequently to test the representativeness of each equipment.

1. INTRODUCTION

According to Reinhart et al. (2002), the "bioreactor landfill attempts to control, monitor and optimise the waste stabilisation process rather than simply contain the waste as prescribed by most regulations". Leachate addition has been demonstrated repeatedly to have a stimulating effect on methanogenesis (Barlaz et al., 1990).

Homogenous spatial distribution of moisture content is indentified as one of the major challenges to run a landfill as a bioreactor (Rosqvist, 2005). Lessons learned from a number of field studies presented in the literature highlighted two problems: first that short circuiting can prevent achievement of full wetting of the landfill (Zeiss and Major, 1993) and second that the recirculation systems may be under-dimensioned and have limited impact on the moisture content of the total waste cell (Reinhart and Townsend, 1998). In consequence, parameters such as the radius of influence and leachate pathway are crucial to design the recirculation system (size, vertical and horizontal spacing). As yet, there is no consensus on the best way to recirculate leachate within a bioreactor landfill.

As, today, few operational data from full scale field trials are available, liquid infiltration system design is mainly based on models using traditional hydrodynamic laws and hydro-physical properties of soil. This approach assumes a uniform, homogenous porous material and therefore is a poor base for modelling the process of liquid flowing through a heterogeneous waste mass. In consequence, it is necessary to undertake on-site evaluation of the leachate distribution during leachate injection.

Such monitoring is also crucial for determining an injection strategy. Parameters such as flow rate and injection frequency for a particular injection system are indeed peculiar to the in-site waste body itself, and have to be adapted with time to the evolution of the waste mass properties due to waste biodegradation and restructuration.

Whereas severals methods have been tested for R&D projects to measure moisture within a waste cell, no cost effective, non destructive and reliable method is commonly and widely used for the day to day monitoring of bioreactors. Imhoff et al (2007) reviewed monitoring methods, which have been tested for measuring moisture in landfills, and divided them into two categories, depending on the monitoring objective:

- For measuring the moisture content of refuse in the field, only the Partitioning Gas Tracers Test (PGTT) was found successful by the authors. However PGTT directly measures the water saturation S_w, and bulk density and porosity of the waste have to be estimated to deduce its moisture content from S_w because measuring these properties on field is difficult and inaccurate.
- For tracking infiltration fronts, electrical resistance, Time Domain Resistivity (TDR), and Electrical Resistivity Tomography (ERT) were reported to have shown satisfying results. These methods are however mostly qualitative, as calibration is difficult in heterogeneous material.

Veolia Environmental Services Research Centre is currently developing a new methodology on a full-scale R&D Bioreactor landfill, in order to both follow the leachate front and to determine the quantity of leachate alloted to each waste area. This methodology relies on the use of lysimeter chambers.

In order to design the experimental set-up, a preliminary study based on ERT measurements has been undertaken. The final experimental set-up will also comprise ERT measurements, so that the cross-comparison of the two methodologies enables to evaluate the validity of each method.

2. ERT METHOD

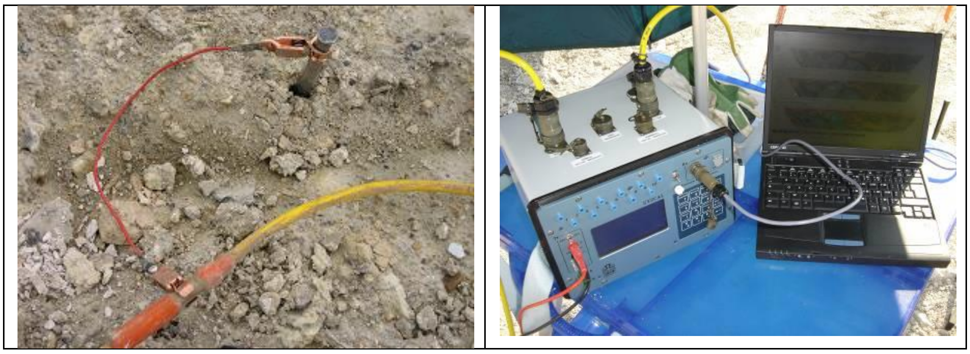
2.1 Presentation of the ERT method

ERT is based on measurement of the potential distribution arising when electric current is transmitted to the underground via electrodes. This methodology allows non-invasive measurements of electrical resistivity, whose temporal variations are, among others, linked to water content, ionic content and temperature (Guéguen and Palciauskas, 1997; Guérin et al., 2004). Grellier et al. (2005) and Moreau et al. (2003) showed that this method enables to detect changes in the waste moisture distribution during leachate recirculation events, by comparing interpretations of resistivity measurements at different time steps in 2-D resistivity sections. This is particularly efficient with highly conductive leachate injected in more resistive waste material: typical resistivities of bulk waste materials is around 30-70 Ω.m when unsaturated (Bernstone et

al ; 2000).
Whereas this methodology showed satisfying and consistent results for tracking infiltration fronts, it has not been compared to quantitative monitoring methods, to extrapolate quantitative flux from resistivity variations. Moreover, because it is not a direct measurement of the moisture variations, inversions are needed to transform the received signal (apparent resistivities) into interpreted resistivity values. Noise sources (for example changes in temperatures - Rosqvist et al; 2000) can alter the received signal and make it hard to interprete resitsivity variations. An additional monitoring method could help interpreting resistivity inversions, by detecting potential noise on resistivity measurements. It could also help defining the relationship between resistivity variations and quantitative fluxes of leachate received by waste.

2.2 Preliminary ERT study

For the present program, a preliminary study of the selected injection system has been carried out with ERT, in order to evaluate the radius of influence and design the futur monitoring set-up (spacing between the lysimeters and positionning of the final ERT probes).
Sets of ERT probes have been installed to follow resistivity variations within the waste mass around different injection points, in order to determine the leachate distribution during injection trials. The selected disposition of the probes, with an electrode spacing of 2 m, allowed to measure apparent resistivity to a depth of around 10 m. Dipole-dipole and pole-dipole configurations have been tested. Electrodes were set up in a 20 cm clay layer, not directly in the waste, in order to have a better connection between the electrodes and the ground.
A fast resistivity-meter was used (Syscal Pro, Iris Instrument). This instrument enables to measure resistivities of a cross-section in few minutes, thus allowing following the leachate plume as it develops. The measured data was processed with inverse numerical modelling to produce resistivity model cross-sections, using the software Res2Dinv (Loke and Barker, 1996).

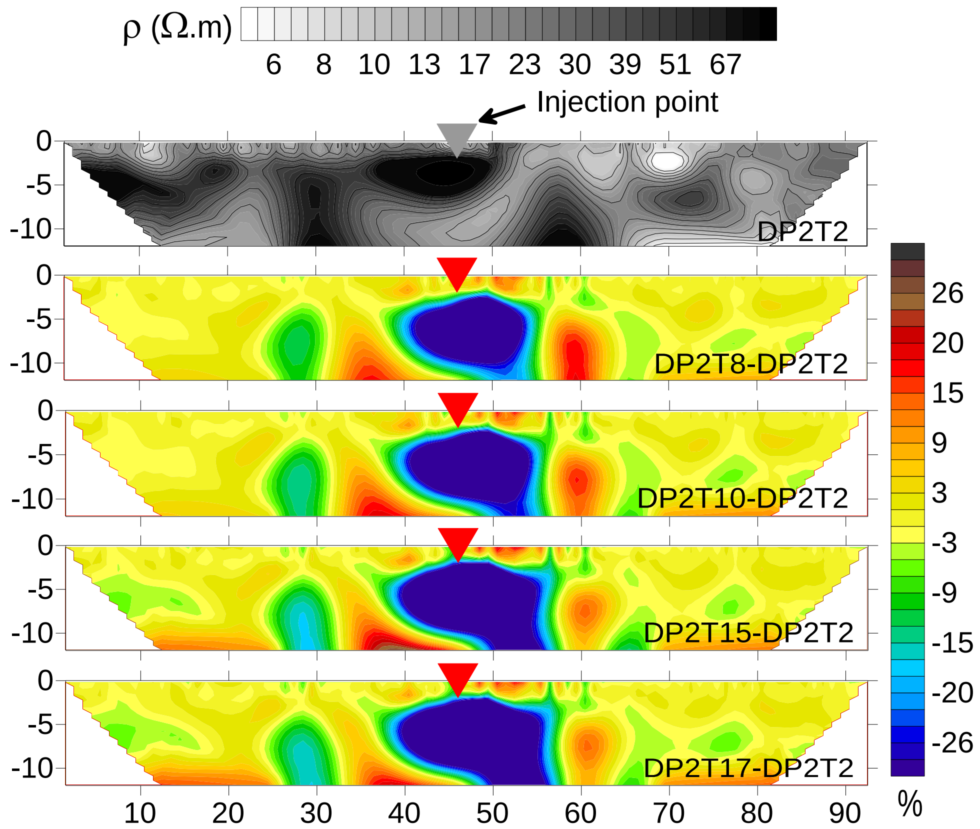


Picture 1 : Experimental set-up of the ERT measurement

Two surveys of three identical injection points have been undertaken. At each injection trial, approximatly 50 to 70 m^3 of leachate have been injected at a flowrate varying between 10 and 20 m^3/h.

2.3 ERT results of the preliminary study

All the measurements resulted in inversion that showed consistently similar results. One typical inversion is presented in Graph 1.



Graph 1 : Preliminary ERT study of the plume of the recirculation system: Interpreted resistivity variations compared with an electrical imaging before the beginning of injection

The first electrical imaging (in black and white on Graph1) has been carried out just before the beginning of injection and is used as reference. It represents the interpretation of the resistivity section which has been measured around the injection system - the recirculation system being located at the surface, in the middle of the section. The following electrical imagings represent variations of interpreted resistivity over a one day period, calculated with the following formula: 100 x ln (ρ_i / ρ_{ref}), with ρ_i the interpreted resistivity at the time i and ρ_{ref} the reference interpreted resistivity (before the beginning of the leachate injection).

The expansion of a plume of negative resistivity variations can be observed around the injection point. This plume is symmetrical around the injection axis, with a width of approximately 15 to 20 m at its maximum (located at a depth between 5 and 10m). At a greater depth the field data was demonstrated (through modelisation) to be less reliable due to the decrease in data resolution with depth.

Based on these measurements, the radius of influence of the injection system is estimated at 10 m.

3. PRESENTATION OF THE LYSIMETERS

3.1. Methodology

Lysimeter have been used in the soil science discipline to undertake infiltration tests (application: mines sites for example). This methodology, based on the burial of collection pots within the soil body, allows both a direct quantification of local infiltration and sampling for water quality analyses. Adapting this technique to landfill body seemed particularly promising in the context of bioreactor study:

- as a non-intrusive, easy to set-up and non expensive measurement of the leachate front, it could be an interesting monitoring method for assessing the efficiency of an injection system;
- as a direct measurement, lysimeters could be used to bring supportive information to indirect methods such as ERT;
- as a quantitative method, hydric balances can be realised to evaluate the increase in local waste moisture content due to leachate recirculation ;
- finally, as lysimeters give access to local leachate quality, spatial and time evolution of leachate composition can be evaluated.

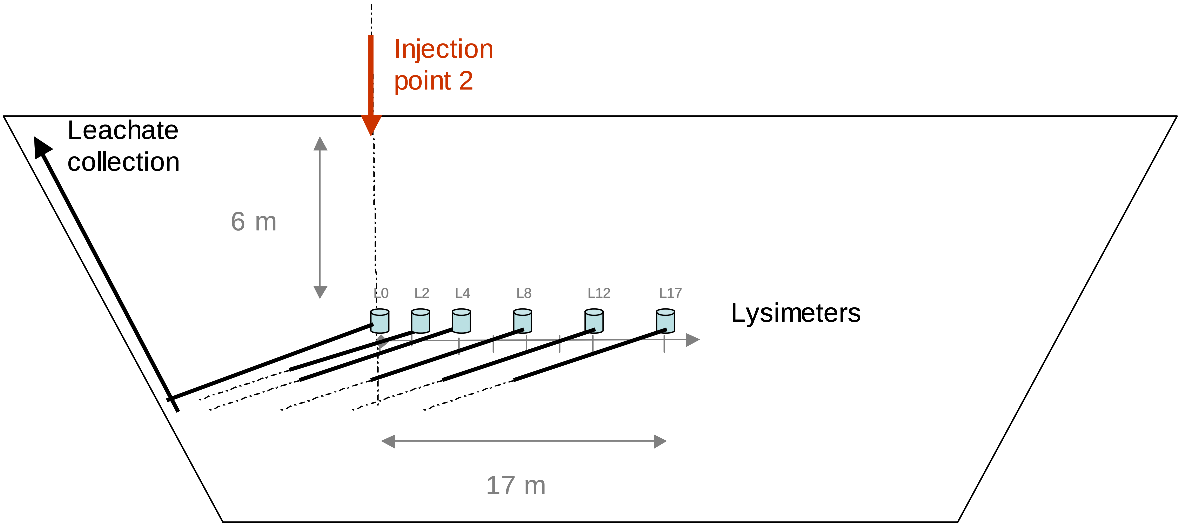
A comprehensive monitoring system has thus been put in place for this study, in order to undertake:
(1) a short- and long-term evaluation of the lysimeters as a monitoring method for bioreactor : on-site evaluation of the radius of action of an injection system, of the hydraulic conductivity of the waste, of the impact of the leachate retention by waste on its composition.
(2) a cross-comparison of ERT and lysimeters methods.

3.2. Instrumental set-up

For the present study, the lysimeters are composed of 1 m^3 HDPE tanks, filled with a drainage material (20 to 40 mm gravel). Each lysimeter has a HDPE collection pipe, which enables separate leachate collection. The tanks are free-draining and allow drainage to a manhole where a pump enables both to measure leachate quantities with time and to sample leachate for quality analyses. The HDPE collection pipe runs with a slope of 1.5%, to avoid that the flow is refrained by potential differential settlements.

Picture 2 : Lysimeters set up in the landfill cell

Owing to the results of the preliminary ERT study, it has been decided to dimension the lysimeters as follows: two clusters of 8 (cluster A) and 6 (cluster B) lysimeters have been installed at a depth of 6 m underneath two injection systems (respectively injection point 1 and 2) with distances ranging from 0 to 17 m from the vertical of the injection points, as presented in Graph 2. Indeed, as the expected radius of influence (defined as the distance from the vertical of the injection point) of the selected injection system is around 10 m, most of the lysimeters are located in this area; the farthest one, at 17 m from the injection point, is a blank. The 6m depth has been selected as a compromise between the maximum depth that can be monitored by the ERT with a proper data resolution (7 to 10m) and the minimum depth with a significant radius of influence (6 to 10m), as determined by the preliminary ERT study.
The two injection system (injection point 1 and 2) are also followed by geophysical monitoring, to allow the comparison of the two methodologies.



Graph 2 : Plot of the lysimeter set-up (cluster B)

Cluster B has two additional lysimeters (LB4b and LB4c) installed at the same distance than L4a from the injection point: this allows measuring triplicates, in orderd to assess the repeatability of this method. The influence of preferential pathways could also be dertemine through these triplicates. Table 1 presents the localisation of the lysimeters, the reference being the vertical of the injection points.

Table 1: Listing of the lysimeters in cluster A and cluster B

Distance from the injection point	Cluster A	Cluster B
0 m	LA0	LB0
2 m	LA2	LB2
4 m	LA4	LB4a LB4b, LB4c
8 m	LA8	LB8
12 m	LA12	LB12
17 m	LA17	LB17

At each cluster site, a foot print area of approximately 20 m x 3 m was staked out and the waste excavated to a depth of about 1.5 m, to place the lysimeters. The excavated material was stockpiled for later backfilling. This backfilling is crucial to recreate the general landfill conditions. The compaction rate of the waste surrounding the lysimeters should be equivalent from the compaction above, in order:

(1) to avoid future settlements due to the placement of compacted material over a loose material ;
(2) to avoid preferential pathways and water channelling.

4. FUTURE EXPERIMENTAL SET-UP

Following the installation of the lysimeter clusters, two 3 m layers of waste is been placed above. The injection systems as well as the ERT probes will be installed on the bioreactor surface, approximately 6 m above the lysimeters.

In order to assess possible perturbation caused by the set up of the lysimeters underneath the injection points 1 and 2, a third injection point, without lysimeters underneath, will be monitored by geophysical measurement only.

The ERT probes will have the same positioning as for the preliminary test. This will allow a measurement of the resistivity within a 10 m layer.

The future survey will comprise :

- injection of approximately 60 m^3 of leachate, with a flow rate of 15 m^3/h ;
- recording of the cumulated volume in each lysimeter with time ;
- ERT measurement with time (during the injection and after, to follow the drainage);
- leachate samples from each lysimeter to evaluate the potential spatial and temporal variations of the leachate quality;
- tracer study to measure the leachate retention time and evaluate a hydraulic conductivity.

In parallel, simulation of an injection system with the same characteristics will be realised through the MATAABIO model (Chenu, 2007). Field results obtained by the lysimeters can help refining the knowledge on local wastes properties (in particular the hydraulic conductivity, which has a high impact on simulation results) determined by laboratory experiments.

5. CONCLUSIONS

This R&D program on the monitoring of bioreactor landfills has been initiated with a preliminary field study to dimension the experimental set-up : ERT measurements allowed to design the positioning of the lysimeters.

Due to operational constraints, the set-up of the R&D equipment has been delayed and first testing trials will only start in early summer. Though, further results should be presented at the Sardinia 2007 Symposium. With a cross-comparison of ERT and lysimeters to monitor an injection system, will enable to assess the ability of these two non destructive monitoring methods to accurately and reliably detect leachate pathways throughout the waste mass.

The expected results will evaluate a non expensive, direct and non-intrusive monitoring method, which might be used for industrial leachate injection monitoring, and should bring supportive information to the ERT method for tracking infiltration fronts.

Expected outcomes of the lysimeters method are also :

-the ability to quantify the repartition of leachate and thus the possibility to realise local hydric balances, in order to evaluate the impact of the recirculation on local waste moisture content;
-the ability to determine leachate retention time and its impact on water quality.

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