Environmental Research & Technology, Vol. 1 (2), pp. 13-17, 2018

Turkish JournalPark ACADEMIC

Environmental Research & Technology

http://dergipark.gov.tr/ert

RESEARCH ARTICLE

Straightforward assessment of horizontal leachate injection system using frequency domain electromagnetic induction method

Rémi Clément[1,*], Marine Audebert [2], Simon Loisel[3], Sylvain Moreau [2]

[1]Irstea, UR REVERSAAL, centre de Lyon-Villeurbanne, 5 rue de la Doua CS 20244, 69625, Villeurbanne, FRANCE
[2]Irstea, Hydrosystems and Bioprocesses Research Unit, 1 rue Pierre-Gilles de Gennes, CS10030, 92161 Antony, FRANCE
[3]SAS Les Champs Jouault, Lieu-dit Les Champs Jouault, 50670 Cuves, France, 92161 Antony, FRANCE

ABSTRACT

In municipal solid waste landfills operating as bioreactor process, leachate recirculation is the key process for increasing moisture content in order to optimize the waste biodegradation. Given that liquid flows exhibit a complex behaviour in very heterogeneous porous media, in situ monitoring methods are required to assess horizontal leachate injection system. Among the physical measurements available, the authors propose a prompt geophysical investigation using Frequency Domain Electromagnetic Method (FDEM). During leachate injection event, this technique highlights changes in electrical conductivity of the waste deposit cell induced by variations of water content. Measurement procedure and preliminary monitoring results are presented applied to a waste deposit cell operated as a bioreactor. First results suggest that this technique is suitable for a quick assessment of horizontal leachate injection systems at industrial scale.

Keywords: Geophysics, leachate recirculation, frequency domain electromagnetic method, bioreactor

1. INTRODUCTION

The concept of bioreactor landfill is studied and tested since 1970 in the US and for more than two decades in Europe. This technology aims at enhancing the waste biodegradation in municipal solid waste landfills (MSWL) by optimising water content. Many studies have pointed out the potential benefits of the bioreactor approach: for example, (i) a quicker stabilization of organic matter can be achieved [1] and (ii) the rate of biogas production goes up inducing a more efficient energy recovery. In situ operation of a bioreactor landfill requires a monitoring and control of the operating parameters [2]. The anaerobic methanogenesis is enhanced by a high water content that can only be reached by adding leachate to waste [3]. Indeed, after waste deposit cell closure, the waste mass is generally too dry to insure an optimal biodegradation and leachate recirculation appears as a solution. Different methods of water measurements in landfills are available and some of them were presented by Imhoff [4]. However, the optimization of leachate injection systems is a particular case which remains a challenge for bioreactor landfill operators.

In the literature, many studies deal with the assessment of leachate injection system using geophysical method [5-9]. Among them, Electrical Resistivity Tomography (ERT) has been widely used for leachate injection monitoring because the electrical resistivity is very sensitive to the water content variation. This method provides 2D or 3D electrical resistivity distribution and can be employed in time-lapse mode to study the infiltration dynamics. However, ERT is rarely used by the landfill operators because implementation of electrodes measurement needs to be located in contact with waste mass under the geomembrane cover. Post-processing numerical tools are also complex to obtain the electrical resistivity distribution [10, 11]. Moreover, recent papers have shown electrical resistivity distribution plenty of artefacts where no changes are expected, leading to false interpretations of the ERT results [5], [12-14]. Industrial community requires an easier method without contact and complex post-processing analysis to investigate the first 4-5 meters of waste mass. Frequency Domain Electromagnetic Method (FDEM) is a popular geophysical method widely used for soil surveying, which has been outlined by McNeill [15]. This method is based on the electrical

Corresponding Author: remi.clement@irstea.fr (Remi Clement)
Received 5 February 2018; Received in revised form 16 March 2018; Accepted 16 March 2018
Available Online 1 April 2018
Doi: ISSN:

conductivity (in S.m^{-1}) measurement (inverse of electrical resistivity in ohm.m). FDEM seems well adapted to focus on leachate diffusion, very conductive (5-10 mS/cm), compared to the waste mass less conductive , comprised between 0.1 and 2 mS cm^{-1} [16-20]. No article describes the validity of the FDEM method to assess the leachate injection systems and this paper demonstrates its relevance in delimiting the lateral extent of the infiltration zone at the industrial scale.

2. MATERIALS AND METHODS

2.1. Experimental site description

The experimental landfill site is located in Cuves, France, (e.g. Fig 1-a and b) and is managed by the company SAS Les Champs Jouault. It is a non-hazardous municipal waste landfill fully operated as a bioreactor. The waste deposit cell spreads across more than 5000 m², 100 m long, 50 m wide, 15 m at its maximum height and approximatively 65,000 t of household waste were landfilled (e.g. Fig 1-c). The layering structure of the MSWL cell consists in a 1-m soil cover overlaying a layer of waste for a total thickness up 10–15 m. The bottom of the MSWL cells consists in a 0.5 m layer of granular drainage materials (e.g. Fig 1-c) and the whole cell is lined by a double seal barrier: a passive one composed by a clay layer (e.g. Fig 1-d) and an active one using HDPE geomembranes. The waste deposit cell is composed by a drainage system at the bottom, biogas extraction system into the waste mass and biogas and leachate mixed landfill horizontal trenches installed at the top of the cell (e.g. Fig 1-d). Biogas extraction is performed continuously using pumping systems which keep the waste deposit cell in depression. Then biogas is conducted to a biogas valorisation system. At the bottom of the waste deposit cell, a pumping system is switched on periodically (or automatically when the leachate level exceeds a level of 30 cm) and discharges the leachate to the storage tank. The study is managed in the waste deposit cell 4 operated between September 2011 and July 2012 (e.g. Fig 1-b).

2.2. Leachate injection monitoring using FDEM

FDEM profiling has been widely used for environmental surveying [21-23] and many devices are available for electrical conductivity measurements. In our study, the EM31 (Geonics Ltd) was chosen to study leachate infiltration. Basically, EM31 device generates a primary electromagnetic field in the first coil named Transmitter coil (at frequency of 9800 Hz, e.g. Fig 2), which induces electrical currents in the soil with the same frequency. These currents generate a secondary electromagnetic field, which is monitored by the receiver coil. Under known conditions as “low induction numbers EM condition”, the secondary field is proportional to the ground current and is used to compute the electrical conductivity for the volume of soil profiled [22, 24]. In theory, the investigation depth is linked to the distance between the transmitter and the receiver (Tx–Rx) and the coil orientations used (vertical or horizontal dipole). The EM31 device has a fix horizontal coil spacing of 3.66 m which provides an investigation between 3 to 5 m deep.

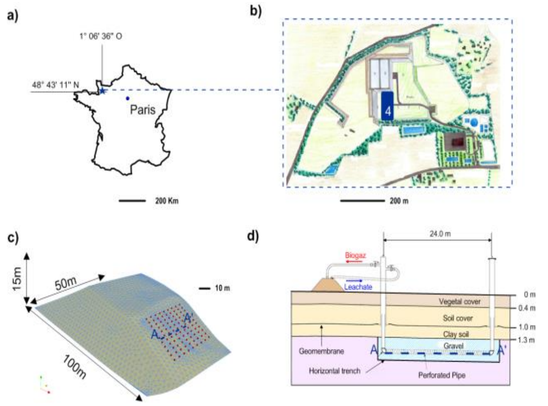

Fig 1. (a) Location (b) industrial site description (c) geometry of experimental waste deposit cell, location of FDEM measurement (red point) and perforated pipe (AA’) (d) mixed horizontal trenches for biogas collection and leachate injection

Electromagnetic measurement was performed at the surface of the waste deposit cell (e.g. Fig 1-c), during leachate injection event: 87 m^3 were injected in 7 hours using the leachate injection system shown in Fig 1-d. Different locations were necessary to map the resistivity measurements recorded by EM equipment (following the numeration of each station - Fig 2-b). One of the problems is to move the equipment to the same plots for each sequence during leachate injection monitoring. To achieve our measurements, we followed this procedure: (i) we calibrated the device according to the manufacturer's recommendations described here (http://www.geonics.com/), (ii) we chose to acquire a sequence of 99 fixed stations around the perforated pipe every 30 min (e.g. Fig 2-b), (iii) we always kept the same orientation coils (transmitter in the East and receiver in the West) and (iv) the FDEM device position was always parallel to the ground. The 99 points were required 12 min.

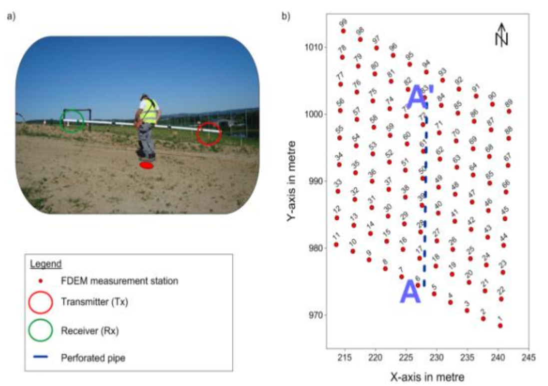

Fig 2. a) FDEM equipment during prospection b) location of FDEM fixes stations and acquisition sequence

3. RESULTS & DISCUSSION

Fig 3 presents the resistivity value ρa0 (inverse of the conductivity, in ohm.m), measured by the EM31 device before starting the infiltration. The injection system is symbolized by a blue line (from A to A') and is located at the position X of 227 m. The resistivity values are comprised between 6 and 11 ohm.m with an increase of up to 14 ohm.m at the end of injection pipe.

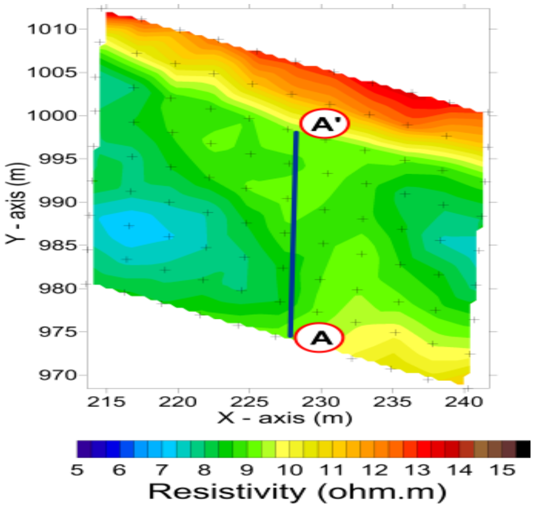

Fig 3. Map representing the resistivity values (in ohm.m) recorded before infiltration

Fig 4 shows electrical resistivity variations $\Delta\rho_a$ for ten time steps (a to j) recorded before, during and after the leachate injection and expressed as follows:

$$\Delta\rho_a = \left[\frac{\rho_{at}}{\rho_{ao}} - 1\right] \times 100 \qquad (1)$$

where ρ_{at} and ρ_{a0} (in mS m^{-1}) are the apparent electrical resistivity of the data sets at time t and of the initial data sets at t0, respectively. Each electrical resistivity variation map has been plotted using Kriging interpolation method. To assess the measurement noise linked to the geophysical device used and to the environment around the waste mass studied, three acquisitions were carried out before infiltration where no resistivity changes are expected (e.g. Fig 4 – a and b).

For all the points on the field, $\Delta\rho_a$ values were calculated before recirculation and varied between 0 and 7%. It corresponds to a classical variation range of $\Delta\rho_a$ observed on the field for this kind of geophysical survey and allowed us to consider only the variations higher than 7% as reliable.

During the injection event, we can observe a decrease in resistivity around the leachate pipe and for each time step (e.g. Fig 4 – c to h). This area corresponds to the leachate infiltration and is delimited by a black line (corresponding to the non-reliable variation range of -7%). Between the third and the eighth time step (respectively 30 min and 7 h after the beginning of the injection), the size of this area increases and the variation in resistivity is comprised between -7 and -25%. At each time step, the resistivity variation is increasingly lower. Eight hours after the beginning, the leachate injection was stopped. For the two last maps (e.g. Fig 4 - i and j), we can observe that the size of the infiltration area decreases compared to the previous steps. Moreover, the resistivity variation increases with a variation range comprised between -7 and -16% for the ninth step (e.g. Fig 4 – i) and between -7 and -13 % for the tenth step (e.g. Fig 4 – j). These electromagnetic measurements of electrical resistivity variations are in accordance to the physical process studied: the size of the infiltration area increases during the leachate injection and decreases just after the end of injection.

According to these results linked to the hydraulic conditions tested, we can assess approximatively the maximum lateral extent of the infiltration area which goes from 220 m to 237 m, corresponding to 7 m on the left of the injection system and to 10 m on its right. Due to the slope of the waste deposit cell (e.g. Fig 1-c); it makes sense that the infiltration is larger on the right of the injection system than on the left. We can also observe that the vertical extent of the infiltration area does not exceed the length of the injection system.

Thus, this result on the horizontal infiltration area can help landfill operators to assess their injection system. For example, different flow rates can be tested to calculate distance between each injection system to avoid location without injection impact or location wetted by two leachate pipes.

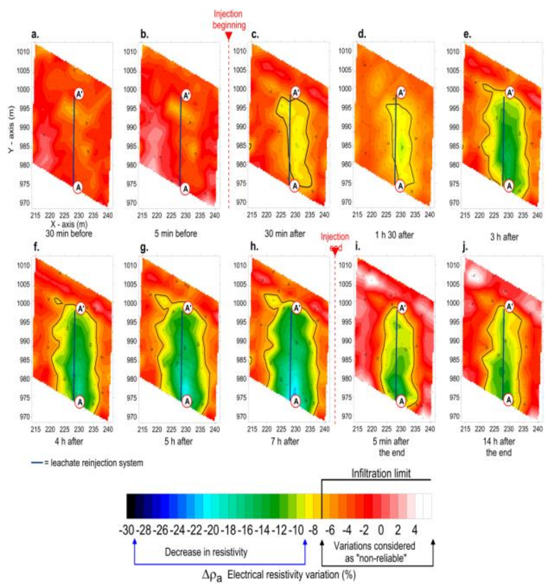

Fig 4. 10 maps of electrical resistivity variations during 10 h of leachate injection

4. CONCLUSIONS

Through this short paper, the authors showed the ability to use the FDEM for assessing leachate injection systems. The FDEM is a fast acquisition and non-intrusive method without contact and complex data post-processing. With the suggested protocol used, the authors have shown that it is possible to monitor the evolution of the electrical resistivity of waste mass linked with the variation of the water content and conductivity of the injected leachate. They estimated lateral propagation of the infiltration in the upper horizon layer of the waste deposit cell (0-5m with depth investigation of selected equipment) and can concluded on the injection system efficiency. The company SAS Les Champs Jouault will use this device for assessment of their injection systems to check their functioning. Equipment used in this study does not allow a deeper investigation?, and consequently are not adapted to study large industrial sites. For larger sites, new equipment has been recently developed and allows deeper exploration. These results open new perspectives for industrial application of the FDEM; however, to refine the lateral position of the leachate infiltration, work on the analysis of the FDEM sensitivity with different equipment and exploration depth will be required.

ACKNOWLEDGEMENT

This work was conducted by IRSTEA (National Research Institute of Science and Technology for Environment and Agriculture) with EM field data sets recorded on the SAS Les Champs-Jouault landfill site. Experimental work was supported by the company Les Champs-Jouault, Feder and the Région Basse Normandie.

REFERENCES

[1]. J. Pacey, D.R. Reinhart, D.L. Hansen, G.T. Townsend, and W. H. Johnson, "Landfill bioreactor – an innovation in solid waste management," *in 22nd Annual LFG Symposium.*, 1999.

[2]. D.R. Reinhart and T.G. Townsend, Landfill Bioreactor Design & Operation. New York, USA: Lewis Publishers, 1998.

[3]. D.R. Reinhart and A.B. AlYousfi, "The impact of leachate recirculation on municipal solid waste landfill operating characteristics," *Waste Management & Resource*. Vol. 14 (4), pp. 337–346, 1996.

[4]. P.T. Imhoff, D.R. Reinhart, M. Englund, R. Guérin, N. Gawande, B. Han, S. Jonnalagadda, T.G. Townsend, and R. Yazdani, "Review of state of the art methods for measuring water in landfills," *Waste Management,* Vol. 27 (6), pp. 729–745, 2007.

[5]. R. Clément, M. Descloitres, T. Günther, L. Oxarango, C. Morra, J.P. Laurent, and J.P. Gourc, "Improvement of electrical resistivity tomography for leachate injection monitoring," *Waste Management,* Vol. 30 (3), pp. 452–464, 2010.

[6]. R. Clément, L. Oxarango, and M. Descloitres, "Contribution of 3-D time-lapse ERT to the study of leachate recirculation in a landfill," *Waste Management*, Vol. 31 (3), pp. 457–467, 2011.

[7]. R. Guérin, M. L. Munoz, C. Aran, C. Laperrelle, M. Hidra, E. Drouart, and S. Grellier, "Leachate recirculation: moisture content assessment by means of a geophysical technique," *Waste Management,* Vol. 24 (8), pp. 785–794, 2004.

[8]. H. Rosqvist, T. Dahlin, and C. Lenhé, "Investigation of water flow in a bioractor landfill using geoelectrical imaging techniques," *in tenth International Waste Management and landfill Symposium,* 2005.

[9]. M. Audebert, R. Clément, J. Grossin-Debattista, T. Günther, N. Touze-Foltz, and S. Moreau, "Influence of the geomembrane on time-lapse ERT measurements for leachate injection monitoring.," *Waste Management*, Vol. 34 (4), pp. 780–790, 2014.

[10]. T. Günther, C. Rücker, and K. Spitzer, "Three-dimensional modelling and inversion of dc resistivity data incorporating topography – II. Inversion," *Geophysical Journal International,* Vol. 166 (2), pp. 506–517, 2006.

[11]. M. H. Loke, J. E. Chambers, D. F. Rucker, O. Kuras, and P. B. Wilkinson, "Recent developments in the direct-current geoelectrical imaging method," *Journal of Applied Geophysics,* Vol. 95, pp. 135–156, 2013.

[12]. R. Clement, M. Descloitres, T. Gunther, O. Ribolzi, and A. Legchenko, "Influence of shallow infiltration on time-lapse ERT: Experience of advanced interpretation," *Comptes Rendus Geoscience,* Vol. 341 (10–11), pp. 886–898, 2009.

[13]. K. Singha and S. M. Gorelick, "Saline tracer visualized with three-dimensional electrical resistivity tomography: Field-scale spatial moment analysis," *Water Resources Research*, Vol. 41 (5), 2005.

[14]. M. Descloitres, J. P. Laurent, C. Morra, R. Clément, L. Oxarango, and J.P. Gourc, "Monitoring resistivity in non-hazardous waste landfill using Time Domain Electromagnetism (Drôme, France)," *in International Conference EAGE "Near Surface 2008,"* 2008.

[15]. D.J. McNeill, Electromagnetic terrain conductivity measurements at low induction numbers. GEONICS, Technical Note TN-6. [Online]. Available: www.geonics.com, 1980.

[16]. I. San and T. T. Onay, "Impact of various leachate recirculation regimes on municipal solid waste degradation," *Journal of Hazardous Materials.* Vol. 87 (1–3), pp. 259–271, 2001.

[17]. B. Olofsson, H. Jernberg, and A. Rosenqvist, "Tracing leachates at waste sites using geophysical and geochemical modelling," *Environmental Geology,* Vol. 49 (5), pp. 720–732, 2006.

[18]. Q.Y. Zhou, C.P. Ling, J.G. Liu, Y.W. Xue, R.Li, and Y. Y. Zhang, "The electrical resistivity tomography for column bioreactor ," *3rd International Conference o3rd International Conference on Engineering for Waste and Biomass Valorisationn Engineering for Waste and Biomass Valorisation*, May 17-19, 2010, 2010.

[19]. S. Grellier, R. Guérin, H. Robain, A. Bobachev, F. Vermeersch, and A. Tabbagh, "Monitoring of Leachate Recirculation in a Bioreactor Landfill by 2-D Electrical Resistivity Imaging," *Journal of*

Environmental Engineering and Geophysics, Vol. 13 (4), pp. 351–359, 2008.

[20]. S. Moreau, F. Ripaud, F. Saidi, and J.-M. Bouyé, “Laboratory test to study waste moisture from resistivity,” *Proc. ICE - Waste Resour. Manag.* Vol. 164 (1), pp. 17–30, 2011.

[21]. D. C. Nobes, M. J. Armstrong, and M. E. Close, “Delineation of a landfill leachate plume and flow channels in coastal sands near Christchurch, New Zealand, using a shallow electromagnetic survey method,” *Hydrogeology Journal,* Vol. 8 (3), pp. 328–336, 2000.

[22]. J. A. Doolittle and E. C. Brevik, “The use of electromagnetic induction techniques in soils studies,” *Geoderma,* Vol. 223–225, pp. 33–45, 2014.

[23]. D. V Fitterman and M. T. Stewart, “Transient electromagnetic sounding for groundwater,” *Geophysics,* Vol. 51 (4), pp. 995–1005, 1986.

[24]. W. M. Telford, L. P. Geldart, and R. E. Sheriff, Applied Geophysics, 2nd Edition. Cambridge University Press, 1990.