Waste Management 55 (2016) 38–48

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Monitoring extent of moisture variations due to leachate recirculation in an ELR/bioreactor landfill using resistivity imaging

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ARTICLE INFO

Article history:
Received 20 July 2015
Revised 20 February 2016
Accepted 24 February 2016
Available online 2 March 2016

Keywords:
Bioreactor landfill
Leachate recirculation
Moisture monitoring
Resistivity imaging
Lateral moisture extent

ABSTRACT

Bioreactor or enhanced leachate recirculation (ELR) landfills are designed and operated for accelerated waste stabilization, accelerated decomposition, and an increased rate of gas generation. The major aspects of a bioreactor landfill are the addition of liquid and the recirculation of collected leachate back into the waste mass through the subsurface leachate recirculation system (LRS). The performance of the ELR landfill largely depends on the existing moisture content within the waste mass; therefore, it is of utmost importance to determine the moisture variations within the landfill. Traditionally, the moisture variation of the ELR landfill is determined by collecting samples through a bucket auger boring from the landfill, followed by laboratory investigation. Collecting the samples through a bucket auger boring is time consuming, labor intensive, and cost prohibitive. Moreover, it provides the information for a single point within the waste mass, but not for the moisture distribution within the landfill. Fortunately, 2D resistivity imaging (RI) can be performed to assess the moisture variations within the landfill and provide a continuous image of the subsurface, which can be utilized to evaluate the performance of the ELR landfill. During this study, the 2D resistivity imaging technique was utilized to determine the moisture distribution and moisture movement during the recirculation process of an ELR landfill in Denton, Texas, USA. A horizontal recirculation pipe was selected and monitored periodically for 2.5 years, using the RI technique, to investigate the performance of the leachate recirculation. The RI profile indicated that the resistivity of the solid waste decreased as much as 80% with the addition of water/leachate through the recirculation pipe. In addition, the recirculated leachate traveled laterally between 11 m and 16 m. Based on the resistivity results, it was also observed that the leachate flow throughout the pipe was non-uniform. The non-uniformity of the leachate flow confirms that the flow of leachate through waste is primarily through preferential flow paths due the heterogeneous nature of the waste.

1. Introduction

Engineered landfilling is considered to be the most common, economical, and environmentally acceptable method of all of the solid waste disposal systems in most areas of United States. A total of 249.9 million tons of solid waste was generated in the United States in 2010, with 136 million tons (54.3% of the total generated waste) of that solid waste discarded into the landfills (USEPA, 2010). Most of the landfills in the US are designed and operated according to the principle of Subtitle D of RCRA (Federal Register, 1991) and utilize very low permeability containment liner, intermediate cover, and final cover systems that minimize the moisture infiltration and retention inside the solid waste mass. Due to the absence of adequate moisture, solid waste decomposition occurs at a suboptimal rate that can take even a century for complete decomposition (Ham, 1993). As a result, the dry concept, involving a long post-closure monitoring period, complicates the entire operation from both operational and economical standpoints. Also, any future development on top of the landfill becomes unattainable during the active and post-closure monitoring periods.

The post-closure monitoring period and the associated maintenance expenses can be reduced by achieving a rapid decomposition rate (Barlaz et al., 1990; Reinhart and Townsend, 1997; Pacey et al., 1999; Warith, 2002). The fundamental process behind waste stabilization, using the bioreactor or wet concept, is the addition of

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http://dx.doi.org/10.1016/j.wasman.2016.02.035
0956-053X/

moisture and recirculation of generated leachate back into the landfill to create a propitious environment for the biological decomposition of the organic matter in the solid waste landfill. A bioreactor or wet landfill is designed and operated for rapid municipal solid waste (MSW) decomposition, enhanced gas production, and waste stabilization. In favorable environmental conditions, biological stabilization of the waste in a bioreactor landfill is expected to accelerate faster than that in a conventional or dry landfill.

The preliminary concept of bioreactor landfills was first proposed and studied in the early 1970s by Pohland (1975), and the economic and environmental benefits of a bioreactor landfill have been studied by several researchers: Barlaz et al. (1990), Hossain (2002), Hossain et al. (2003), Reinhart and Al-Yousfi (1996), Townsend et al. (1996), Reinhart and Townsend (1997) and Pohland and Kim (1999). The potential benefits of the bioreactor landfill include (1) the majority of the settlement takes place before placement of the final cover, reducing the risk of damaging the final cover; (2) increased effective MSW density and landfill capacity; (3) reduced leachate treatment costs; (4) increased rate of gas production; and (5) accelerated MSW decomposition, shortening the regulated post-closure monitoring period and reducing the overall cost of the landfill. However, the presence of excessive moisture (more than 55%) may result in oversaturation inside the waste mass that may weaken the structural strength of organic matter and inhibit oxygen movement, resulting in an anaerobic condition (Law et al., 2010). In addition, the presence of perched water inside the waste mass may pose a potential threat for the side slope, resulting in slope failure. It is a challenging task to maintain the optimum moisture level to ensure uniform moisture distribution throughout the landfill.

The rate of solid waste decomposition significantly depends on the moisture content of the waste. The moisture distribution and the extent of leachate recirculation are the primary concerns when attempting to optimize the performance of a bioreactor landfill. A leachate recirculation system installed in a bioreactor landfill is designed to distribute the moisture uniformly throughout the landfill. However, due to high heterogeneity and anisotropy of MSW and the different compaction levels in the landfill, the moisture distribution may not be uniform. Furthermore, moisture has a tendency to follow the preferential channel to reach the leachate collection system, further complicating the attainment of a uniform moisture distribution. It is therefore vital to monitor the movement of moisture and the direction of the flow after leachate recirculation to determine the efficiency of the installed recirculation system.

Traditionally, the moisture variations of the ELR landfill are determined by collecting samples through bucket auger borings from the landfill, followed by laboratory investigation. However, collecting the samples through bucket auger borings is time consuming, labor intensive, and cost prohibitive (Shihada et al., 2013). Moreover, it provides the information of a single point within the waste mass and lacks information pertaining to the moisture distribution in the landfill. Several indirect methods such as time domain reflectometry (TDR), neutron probes, partitioning gas tracers, electrical resistance sensors, fiber optic sensors, and electrical resistivity tomography were reported in literature by Reddy and Kulkarni (2011), Imhoff et al. (2007), Kumar et al. (2009), and Manzur et al. (2001). Sensors or probes are highly invasive and provide the information for a specific location. Therefore, a series of sensors, along with a large cable network, need to be installed to determine the overall moisture distribution in the landfill. In addition, special expertise is required to select appropriate sensors suitable at various ionic contents and pH levels of leachate. Installation of sensors also involves paying particular attention to preventing damage to the sensors and connection wires from the movement of on-site heavy equipment used for active landfilling. Therefore, monitoring moisture content using sensors can be a feasible option for the closed landfill sections, but it becomes very cumbersome for the active landfill sections. Fortunately, 2D resistivity imaging (RI) can be performed to investigate the moisture variations within the landfill (Gawande et al., 2003; Guérin et al., 2004). The 2D RI provides a continuous image of the subsurface and can be utilized to investigate the moisture variations and evaluate the performance of the ELR landfill (Grellier et al., 2008).

The resistivity imaging (RI) test has been a very popular site investigation and characterization tool for different geotechnical and geo-environmental applications over the years (Kalinski and Kelly, 1993; Dahlin, 2001; Khan et al., 2012). Different factors affecting the resistivity of the soil and solid waste were studied by several researchers, and it was observed that electrical resistivity varies with the water content, temperature, ion content, particle size, resistivity of the solid phase, permeability, porosity, clay content, degree of saturation, organic content, and pore water composition present in the materials (McCarter, 1984; Abu-Hassanein and Benson, 1996; Giao et al., 2003; Grellier et al., 2006a, 2006b; Samouëlian et al., 2005; Kibria and Hossain, 2012; Clement et al., 2010; Ekwue and Bartholomew, 2010). Shihada et al. (2013) conducted a laboratory study which indicated that the electrical resistivity of solid waste is a complex property that depends on the moisture content, composition, unit weight, porosity, pore fluid composition, temperature, decomposition and organic content. However, the changes of the resistivity highly depend on the moisture content, temperature, and porosity, and the effects of the other parameters on resistivity that have not been well established for solid waste (Grellier et al., 2007). In addition, no study has been conducted in field scale to determine the spatial extent of the moisture after leachate recirculation of the bioreactor landfill. The spatial extent of the moisture variation is important, as it represents the moisture variation within the landfill and can be effectively utilized to evaluate the performance and design of optimum spacing of the horizontal recirculation pipes.

During this study, the 2D resistivity imaging technique was utilized to study the moisture variations and performance of a leachate recirculation system of an ELR landfill. The objective of the current study was to determine the vertical and horizontal extents of the moisture variations during the recirculation process of an ELR landfill, using the 2D resistivity technique. The study was conducted at the City of Denton landfill in Denton, Texas, USA. A horizontal recirculation pipe was selected and monitored for 2.5 years, using the RI technique. The moisture distribution and movement of the horizontal recirculation system were evaluated based on the variations of the 2D RI results.

2. Material and methods

2.1. Site description

The City of Denton Landfill is located in Denton County, Texas, USA and began operating in 1986. The facility accepts approximately 300,000 kg (300 tons) of waste per day, six days a week.

The entire landfill contains 7 different cells (cells 0–6), as illustrated in Fig. 1. Cell 0 (also known as 1590A) is the old cell, containing a 1 m thick pre-subtitle D (compacted clay) liner system and is operated as a conventional landfill. Cells 1–6 are designed with subtitle D liner systems, containing a combination of 0.6 m thick low permeability clay (1×10^{-7} cm/s), a 60 mil HDPE geomembrane, and a 0.6 m protective soil layer as the bottom liner system. The landfill received the regulatory permit to operate as a bioreactor landfill in May 2009. Currently, leachate recirculation is performed in Cell 2 (2A, 2B and 2C) and the southern part of Cell 3 (3A).

The landfill was constructed on an undisturbed foundation soil, 4.57 m (15 ft.) below the original grade, with a footprint of 615,122