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Start-up performance of a full-scale bioreactor landfill cell under cold-climate conditions

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Abstract

A 0.49-ha bioreactor landfill cell containing approximately 32,400 metric tons of municipal solid waste was constructed and operated at the Northern Oaks Recycling and Disposal Facility in Harrison, Michigan, USA. Design of this full-scale research cell included a network of 48 temperature and moisture sensors, leachate collection basins, and gas sampling ports, which provided for continuous temperature and moisture data and periodic measurements of both the quantity and composition of the leachate and gas produced. The data indicated that methane generation started approximately 3 months after filling in lifts that were placed during summer, but not until 8 months for those filled during the winter. Temperature data indicated that near-0 °C temperatures persisted within the lifts filled during winter for more than 6 months, and that gas production was minimal during this period. These results suggest that in addition to maintaining optimal moisture levels within the waste mass, temperature control must be a key design consideration in cold climates.

1. Introduction

In 2005, 245 million metric tons of municipal solid waste (MSW) were generated by US residents, institutes, and businesses. Of this, approximately 32% is recovered, recycled or composted, 14% is burned at combustion facilities, and the remaining 56% is disposed of in landfills. Thus, about 132 million metric tons of MSW is buried every year in the 1654 currently operating landfills (EPA, 2007a). To minimize the adverse effects to the environment, US regulations (Resource Conservation and Recovery Act, RCRA, 40 CFR Parts 239 and 258) require MSW landfills (termed Subtitle D Landfills under RCRA) to be designed with impermeable liners, leachate collection systems, and a low permeability cap to prevent liquid intrusion into the waste after closure, all of which are designed to prevent groundwater contamination. As a result, a properly designed, constructed and operated Subtitle D landfill is relatively dry, and biodegradation of solid waste is thought to be limited by moisture availability (Barlaz et al., 1990; McCreanor and Reinhart, 1999; Mehta et al., 2002; Pacey et al., 1999; Pohland, 1980; Reinhart et al., 2002; Townsend et al., 1996; Yuen et al., 2001). Nevertheless, degradation still occurs slowly, and such "dry tomb" landfills can be biologically active for many decades, producing emissions to the environment that must be monitored, controlled, and treated. In addition, an extended post-closure care period is required to maintain the final cap because of the settlement that occurs as organic material in the landfill continues to decompose.

Managing landfills as bioreactors has been suggested as an environmentally sound alternative, and a limited number of such cells have been approved by regulators on a case-by-case basis. The approach is analogous to that used

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in wastewater treatment – degradation is promoted in a controlled environment for the purpose of minimizing adverse effects when these reactions occur in receiving waters. Bioreactor landfills offer many environmental and financial benefits including accelerated stabilization of the waste which reduces the long-term potential for groundwater contamination and should allow for shorter post-closure care periods, accelerated methane production which makes recovery most cost-effective, and more rapid settlement which creates additional volume for waste disposal during the useful operating life (EPA, 2007b; Pacey et al., 1999; Reinhart et al., 2002; Reinhart and Townsend, 1998).

A few landfills or portions of landfills have been operated as bioreactors and a limited number of scientific studies have been performed. Most of these have involved increasing moisture levels through leachate recirculation and water addition to stimulate bioactivity (Augenstein et al., 1997; Barry and Demme, 1997; Dahl, 1998; Maier et al., 1995; Moore et al., 1997; Pagano et al., 1998; Townsend et al., 1994; Warzinski et al., 2000; Wilson et al., 2000). While valuable insights have been gained from these experiments, the knowledge base is still sparse, and many studies are limited by the constraints of working within a converted cell. At present, researchers and engineers do not have a complete scientific understanding of the key physical, chemical and biological processes that control bioreactor landfill performance, particularly for colder regions, nor can they rigorously evaluate whether bioreactor landfills can produce all claimed benefits or whether there may be unforeseen negative impacts.

There is also a need to develop improved design parameters and operating guidelines as bioreactor landfills will require strategies to establish and maintain higher moisture levels, to efficiently collect gas produced at higher rates, to mitigate potential negative effects associated with faster settlement, and to assess whether various approaches to liner and cap construction might be advised. The US Environmental Protection Agency's (EPA) Project XL Bioreactor Landfill projects are designed to study many of these issues (EPA, 2007a). Approximately 20 full-scale demonstration projects are in progress in North America. A summary of several projects can be found in SWANA (2002).

In this study, a 0.49-ha full-scale bioreactor landfill cell was instrumented at the Northern Oaks Recycling and Disposal Facility (NORDF) in Harrison, Michigan, USA. The system is unique in that it is equipped with a three-dimensional monitoring system that allows collection of critical data related to waste, leachate, and gas characteristics from multiple interior points within the cell. This allowed investigation of the heterogeneity of moisture content and moisture distribution, waste temperature, leachate characteristics, and gas composition. Construction and filling of the cell was completed in Spring 2003. The system has been monitored continuously since then. This paper has presented the monitoring system design, installation, and initial data related to leachate, gas, settlement, and temperature collected at the site.

Two key aspects of this bioreactor cell are: its relatively dense network of sensors and monitoring equipment installed while the cell was being filled, and the focus on temperature issues in conjunction with moisture. This data was used to assess the effectiveness of bioreactor landfills in colder climates.

2. Bioreactor landfill design and construction

NORDF in Harrison, MI, opened in December 1992 on a 129.5-ha site, of which 30.8 ha are permitted for waste filling. The facility accepts approximately 454 metric tons of MSW per day, 5 days a week, and has a regulatory permit to recirculate leachate. Approximately 75% of the leachate collected on site is recirculated either to the bioreactor cell or to the working face of other cells (Zhao et al., 2003). The average temperature at Harrison is 6.2 °C. Total annual precipitation is 757 mm including a total snowfall of 1890 mm. The average temperatures are −0.9 °C, 5.3 °C, 18.3 °C, and 7.5 °C for winter, spring, summer, and fall, respectively. The low temperature in winter is −12.9 °C and the high temperature in summer is 27.2 °C.

The bioreactor cell was constructed on an undisturbed soil foundation, 3.0 m below the original grade, with a footprint of approximately 0.49 ha (Fig. 1). It employs a Subtitle D double composite liner system (geocomposite, high-density polyethylene (HDPE) geomembrane and geosynthetic clay liner (GCL) for both primary and secondary liners) with 30-cm-thick sand over the liner layers for leachate drainage. Leachate is collected with 15-cm-diameter perforated HDPE pipes and transferred to a sump dedicated to the bioreactor cell. A 1.8 m high temporary berm was installed on the north side to retain the leachate within the cell. The cell overlays an existing conventional cell on the south side. To further ensure isolation of the bioreactor cell from the existing waste, an overfill liner system was also installed on the top of the intermediate cover with a slope of 3 horizontal to 1 vertical over the existing cells. This system consists of (from top to bottom): a 30-cm-thick sand layer, 1-mm-thick geomembrane made up of very flexible polyethylene (VFPE), and a 30-cm-thick clay layer. The bioreactor cell was designed to be 18 m in height having six 3-m-thick lifts. After placement of the final lift, the cell was closed with a geomembrane cover in July 2003 (Zhao et al., 2003). The filling of the cell started on July 12, 2002 and the cell was closed with installation of the cap on June 25, 2003. A total of 32,400 metric tons of MSW and 18,800 metric tons of cover soil were compacted in the cell. The internal volume of the cell at completion was about 56,800 m^3.

A key consideration in the design of the cell was to achieve relatively uniform and elevated moisture levels without exceeding the regulatory limit of 30 cm of liquid head on the liner. To accomplish this, three leachate injection/recirculation system design configurations were implemented. All leachate injection pipes were installed on top of the compacted daily cover (sand). The waste was not trenched for pipe installation. The configurations were as follows: