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The influence of moisture enhancement on landfill gas generation in a full-scale landfill

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ABSTRACT

The objective of this study was to investigate the influence of different moisture enhancement strategies on landfill gas generation in a full-scale solid waste landfill. Moisture enhancement strategies included leachate recirculation and liquid waste addition that were implemented to promote in situ waste decomposition. Waste mass disposed at the landfill and measured gas flow rates in the gas collection system were partitioned among four phases of the landfill that were operated with different moisture enhancement strategies. The gas collection system included extraction points in gas wells as well as in leachate clean-out pipes and leachate recirculation trenches. The measured gas flow rates were modeled with the U.S. EPA LandGEM to optimize the first-order decay rate (k). Model simulations were completed with an assumed constant methane generation potential and gas collection efficiency. The optimized k for the Site-Wide analysis was 0.078 1/yr, which was elevated relative to the default k = 0.04 1/yr for conventional solid waste landfills. Optimized k values for the four phases ranged between 0.025 and 0.127 1/yr. The optimized k values increased with increasing aggressiveness of the moisture enhancement strategy. Although unique relationships between k and parameters reflecting moisture enhancement (e.g., water content) were not identified, this case study can provide guidance on moisture enhancement techniques that result in increased landfill gas generation and improved solid waste decomposition.

1. Introduction

Enhanced in situ biodegradation of municipal solid waste (MSW) can be achieved via operating landfills as bioreactors. Bioreactor landfills have been shown to promote enhanced waste decomposition and landfill gas (LFG) generation, in situ leachate treatment, increased landfill settlement, and reduced post-closure care (Reinhart and Basel Al-Yousfi, 1996; DeAbreu, 2003; Bareither et al., 2010; Townsend et al., 2015; Bareither et al., 2017). Landfill-based waste management requires estimates of LFG emissions, methane (CH_4) in particular, to assess compliance with regulatory air quality thresholds. Furthermore, landfills operated as bioreactors require estimates of LFG generation to assess enhanced waste stabilization (e.g., in support of an organic stability assessment, Bareither et al., 2017) or to assess value in LFG-to-energy projects.

In anaerobic bioreactor landfills, moisture is added to the waste to improve environmental conditions for waste biodegradation (Reinhart et al., 2002; Benson et al., 2007; Townsend et al., 2015). Moisture is commonly added via leachate recirculation or supplemental liquids, which often include on-site rinse water, gas condensate, commercial and residential liquid wastes, and solidified liquid wastes (e.g., Bareither et al., 2010; Bareither et al., 2017). The impacts of varying moisture enhancement strategies, which include the amount, type, and frequency of addition to the solid waste mass, have been evaluated in full-scale landfills (e.g., Yazdani et al., 2006; Benson et al., 2007; Bareither et al., 2010). However, landfills are heterogeneous systems with spatial and temporal variation in waste composition, moisture content, and temperature. Thus, CH_4 emissions from landfills can exhibit temporal and spatial variability that reflect variability in moisture enhancement strategies (Barlaz et al., 2010; Abichou et al., 2011; Bareither et al., 2012; Feng et al., 2016).

Landfill gas generation and emissions are commonly estimated with first-order decay (FOD) models (Reinhart et al., 2005; Thompson et al., 2009; Mou et al., 2015; Lan Vu et al., 2017). In the U.S., the U.S. Environmental Protection Agency's (EPA) Landfill Gas Emission Model (LandGEM) is the industry standard used to assess landfill emissions and assist landfill operators with waste stabilization and gas-to-energy projects (US EPA, 2005; Tolaymat et al., 2010; Townsend et al., 2015; Bareither et al., 2017). A key

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parameter in LandGEM is the first-order decay rate (k), which has been shown to increase in landfills operated as bioreactors relative to conventional landfills (Reinhart et al., 2005; Faour et al., 2007; Barlaz et al., 2010; Amini et al., 2012; Kim and Townsend, 2012; Wang et al., 2013; Fei et al., 2016). Common practice has been to use LandGEM to estimate a single k for an entire landfill. Although this approach is effective and can quantify a level of enhanced gas generation for an entire site, landfills often are operated in phases that can include unique operational conditions. In particular, varying moisture enhancement strategies in different phases can have unique impacts on gas generation.

The objective of this study was to model LFG generation at a landfill that included varying moisture enhancement strategies to evaluate how the strategies influenced gas generation. Landfill gas modeling was completed for the entire site (i.e., Site-Wide analysis) and four distinct phases of the landfill. Moisture enhancement was completed primarily via leachate recirculation and liquid waste addition.

2. Materials and methods

A full-scale landfill operated in the state of Wisconsin under the Organic Stability Rule (OSR) (Section NR 514.07(9), Wis. Adm. Code), herein named Landfill T, was evaluated in this study. The OSR was introduced in 2007 by the Wisconsin Department of Natural Resources to encourage landfill owners and operators to reduce degradable organic material within landfills after closure with a goal of reducing post-closure care (Bareither et al., 2017). Actions implemented at Landfill T in compliance with the OSR included leachate recirculation, liquid waste addition, and delayed final cover placement. Data obtained from Landfill T included monthly measurements from 1995 to 2015 of the waste disposal, MSW fraction of the waste, leachate recirculation volumes, liquid waste disposal volumes, gas flow rates, and CH_4 fraction of the collected gas. With exception of MSW disposal, all data could be partitioned to specific phases of the landfill. Computer-aided drawing (CAD) files that included topographic maps of were made available from 2002 to 2015. These CAD files were used to estimate the volume and subsequently the mass of MSW placed in each of the four unique phases at Landfill T.

2.1. Landfill T characteristics

Landfill T is a non-hazardous solid waste landfill with a total area of 26.2 ha and design capacity of 7.2-million m^3 of solid waste. Landfill T was selected for this study based on data availability, implementation of waste moisture enhancement under an active Research Development and Demonstration (RD&D) permit from the U.S. EPA (US EPA, 2016), and willingness of landfill personnel to assist in the analysis. Waste disposal at Landfill T commenced in January 1995 and the landfill is currently in operation. Common solid waste disposed included MSW, power plant ash, papermill sludge, and foundry waste. The non-MSW waste streams were mixed with the MSW during disposal.

A site plan of Landfill T is shown in Fig. 1. The landfill consists of delineated phases, Phase 1 through Phase 7, which have been operated with different moisture enhancement strategies. The phases at Landfill T were filled with waste sequentially and concurrently. This means that although the general order of waste filling was from the oldest phase (Phase 1) to the youngest phase (Phase 7), there was concurrent waste disposal in multiple phases. Phases 1 & 2 had limited moisture enhancement, whereas moisture enhancement increased in Phase 3 & 4 through Phase 7 with varying levels of aggressiveness, type of liquid added, and influence on LFG generation. The focus in this study regarding the effects of

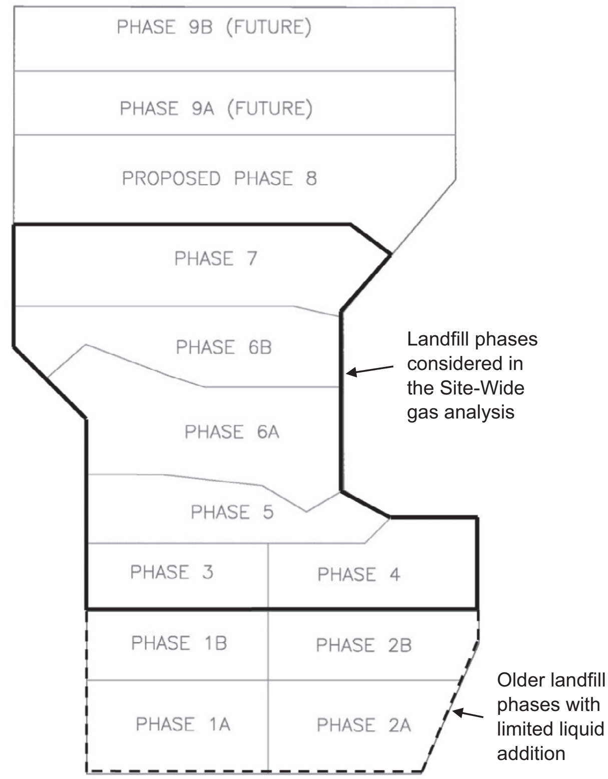

Fig. 1. Plan view of Landfill T. Notes: Phases 3&4, 5, 6, and 7 were composited for the Site-Wide gas analysis; Phases 1 and 2 (A & B) has limited liquid addition and were not considered for the gas analysis conducted in this study.

moisture enhancement on LFG generation included Phase 3 & 4, Phase 5, Phase 6, and Phase 7. The Site-Wide LFG analysis presented herein represents a composite analysis of these four phases (i.e., Phases 3 & 4 through Phase 7).

2.2. Solid waste disposal

The start and end of waste filling, areal extent, rate of waste disposal, and estimated total MSW disposed for each phase are summarized in Table 1. Temporal trends of the average daily filling rate of MSW and percent contribution of MSW for the total waste disposed at Landfill T are shown in Fig. 2. The rate of MSW disposal and percent contribution of MSW initially increased and then remained approximately constant between 1998 and 2007. From 2008 to the present, the disposal rate of MSW decreased and subsequently remained constant near 180 Mg/d. However, the percent contribution of MSW has been increasing since 2010 and approximately 90% of total waste disposed in 2015 was MSW. The decrease in the mass of MSW disposed after 2007 was attributed to the economic recession and waste volume swap agreements between Landfill T and surrounding landfills.

Monthly MSW masses placed in Landfill T were used to compute the rate of disposal (Fig. 2) and total mass of MSW placed in a given month for the Site-Wide landfill gas analysis. However, data were not available to determine the amount of waste disposed in a given phase during operation. Masses of MSW placed in specific phases at Landfill T were estimated via a CAD-based volume analysis (Nwaokorie, 2017). Estimates of total waste volumes were determined through assessment of triangulated irregular network (TIN) surfaces created from waste surface contour lines in AutoCAD Civil 3D (Autodesk Inc., San Rafael, CA, USA). Each TIN surface represented a quarterly survey at Landfill T, and subsequent TIN