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Case study comparison of functional vs. organic stability approaches for assessing threat potential at closed landfills in the USA

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ABSTRACT

Municipal solid waste (MSW) landfills in the USA are regulated under Subtitle D of the Resource Conservation and Recovery Act (RCRA), which includes the requirement to protect human health and the environment (HHE) during the post-closure care (PCC) period. Several approaches have been published for assessment of potential threats to HHE. These approaches can be broadly divided into organic stabilization, which establishes an inert waste mass as the ultimate objective, and functional stability, which considers long-term emissions in the context of minimizing threats to HHE in the absence of active controls. The objective of this research was to conduct a case study evaluation of a closed MSW landfill using long-term data on landfill gas (LFG) production, leachate quality, site geology, and solids decomposition. Evaluations based on both functional and organic stability criteria were compared. The results showed that longer periods of LFG and leachate management would be required using organic stability criteria relative to an approach based on functional stability. These findings highlight the somewhat arbitrary and overly stringent nature of assigning universal stability criteria without due consideration of the landfill's hydrogeologic setting and potential environmental receptors. This supports previous studies that advocated for transition to a passive or inactive control stage based on a performance-based functional stability framework as a defensible mechanism for optimizing and ending regulatory PCC.

1. Introduction

Municipal solid waste (MSW) landfills in the United States are regulated under Subtitle D of the Resource Conservation and Recovery Act (RCRA). Under RCRA, an owner or operator (hereafter, owner) of a closed MSW landfill is responsible for its maintenance, monitoring, and condition for 30 years after final closure or for an alternative period as necessary to protect human health and the environment (HHE). Protection of HHE is demonstrated when potential threats are reduced to acceptable levels at the relevant point of exposure (POE), typically the closest property boundary location at which a human or ecological receptor could be exposed to contaminants and receive a dose via a potential migration pathway as defined under RCRA (U.S. EPA, 1993). Recent guidance for evaluating the end of post-closure care (PCC) at RCRA landfills recommends a performance-based approach and provides a framework for the use of monitoring, modeling, and statistical analysis to determine whether landfill contaminants (primarily leachate) would pose a threat to HHE at the POE (U.S. EPA, 2016). Under RCRA, however, final authority for determining what PCC period is sufficient to protect HHE is delegated to the state level. States are tasked with approving procedures for demonstrating the end of PCC while owners are responsible for collecting the requisite data for making such demonstrations. As a result, despite the performance-based emphasis of the federal regulations, definition as to what constitutes completion of PCC differs between states, with some (notably Kansas and Wisconsin) favoring measurements in source leachate, landfill gas (LFG), and/or in-situ waste, while others (notably Florida and Washington) favor assessment of potential threats posed by landfill emissions.

Laner et al. (2012) reviewed several approaches for assessment of potential threats to HHE posed by MSW landfills and guidance on making decisions regarding PCC completion. These approaches can be divided into two categories: (1) those seeking demonstration of organic stabilization or a relatively inert waste mass, and

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(2) those that focus on functional stability, which considers long-term emissions in the context of threat potential in the absence of active controls as measured at a point between the landfill and the POE. What is lacking in the literature is an evaluation of the threat potential of a closed landfill with a long-term database on LFG production and leachate quality, detailed site geology to determine potential exposure pathways, and use of state-approved methodologies for assessment of threat potential. After briefly reviewing alternative approaches for evaluating threat potential (with a focus on regulation at the state level in the USA), this study uses a 20-year dataset from a closed MSW landfill in the northeastern USA to compare outcomes based on evaluation of both organic stability and functional stability.

2. Methodologies for assessing landfill threat potential

2.1. Organic stability

Approaches based on organic stability require near-complete degradation of the waste mass to an inert state as the appropriate end-point for PCC. While this approach may offer maximum protection of HHE, and theoretically eliminates the potential threat of waste reactivation under future unmanaged conditions, it implies perpetual care under a regulated program without regard to cost (Scharff et al., 2011). In attempting to define and measure organic stability, solids buried in a landfill have at least two characteristics of concern: (1) extent of biodegradation, and (2) leaching potential. The extent of biodegradation can contribute to an assessment of remaining LFG production and settlement, while the leaching potential can contribute to an assessment of future leachate quality. While it could be argued that characterization of buried solids is critical, trends in LFG production, waste settlement, and leachate generation may provide suitable surrogates for solids characterization such that solids sampling is not necessary.

If organic stability is to be assessed by measuring the residual biodegradation and leaching characteristics of the waste mass, then a plan to collect samples representative of the entire waste mass is required. Several practical issues must be considered, including whether solids sampling is feasible, representative, and cost-effective. Assuming representative samples can be recovered, a wide range of tests are available to assess organic stability in terms of how much residual carbon can be mineralized and how quickly (Wagland et al., 2009). The biochemical and physical parameters used to determine the rate of stabilization have historically been cellulose, lignin, pH, volatile solids, biochemical methane potential, and respiratory index (Shanmugam and Horan, 2009; Lesteur et al., 2010; Laner et al., 2012). However, there is little guidance on target levels and representability of samples.

In the USA, some states have adopted regulations defining the end of PCC in terms of organic stabilization. The Kansas Department of Health and Environment (DHE), for example, considers equilibrium in leachate and LFG, defined as a condition where trends in the flow and composition of emissions from the waste mass are statistically constant, as being representative of stable waste and the basis for modifying or terminating PCC (Kansas DHE, 2014). Under the organic stability rule (OSR) promulgated by the Wisconsin Department of Natural Resources (DNR), landfill owners are required to submit a plan to significantly reduce the residual amount of degradable organic matter within 40 years after closure. Flexibility is afforded in the selection of waste stabilization strategies, including diversion of biodegradable material, mechanical or biological pretreatment, and/or in-situ treatment (e.g., liquids addition, leachate recirculation, and in-situ aeration). Under the OSR, organic stability means that LFG production has effectively ceased, organic pollution of landfill leachate is insignificant, the organic fraction of the waste mass will not readily decompose when placed in ideal moisture and temperature conditions, there is no longer measurable settlement, and financial risks associated with undecomposed waste are minimized (Wisconsin DNR, 2007). However, metrics for solids sampling or settlement monitoring are not specified; instead, demonstration of organic stability relies solely on LFG indicators. A recent study by Bareither et al. (2017) assessed the effectiveness of the OSR as implemented at ten landfills. Enhanced in-situ degradation of waste by moisture addition (i.e., bioreactor operations) was the primary strategy for compliance with the rule, with organic waste diversion comprising only a small component. Implementing the rule was generally found to have resulted in more rapid waste decomposition with no apparent deleterious environmental impacts, although some landfill owners observed that several practices could be revised to better support the effectiveness of organic stability plans (e.g., inclusion of metrics to aid the transition from active to passive systems for managing LFG emissions). As such, the OSR is largely beneficial in promoting strategies for long-term threat reduction but appears inadequate in defining actionable criteria that will allow a landfill owner to complete PCC.

2.2. Functional stability

An alternative to organic stability is functional stability, which describes a closed landfill that does not pose a threat to HHE at the POE in the absence of active control systems (Morris et al., 2013). Functional stability has been implemented in the "Evaluation of Post-Closure Care (EPCC) Methodology," which relies on conservative impact assessments to define long-term monitoring and management requirements (Morris and Barlaz, 2011). Using this approach, the central elements of a PCC program (leachate and LFG management, groundwater monitoring, cover maintenance), can be demonstrated to be complete, if appropriate, or optimized to focus on providing environmental protection using more passive measures that reduce energy consumption and costs. Proactive landfill management techniques that reduce the residual pollution potential (Beaven et al., 2014; Brand et al., 2016) and landfill designs based on fail-safe engineering (e.g., achieving long-term equilibrium based on gravity flow) for the future unmanaged condition (Stentsøe et al., 2001; Hall et al., 2007) are rewarded by offering increased flexibility in eliminating active PCC controls. Regardless of whether such proactive measures are adopted, however, the rationale behind functional stability is that termination or reduction of PCC activity can be achieved in a more technically and economically appropriate way by focusing on long-term landfill performance in the context of the threat posed by emissions rather than on in-situ waste characteristics.

Demonstrating functional stability using the EPCC methodology involves analyzing trends in LFG generation, cover settlement, and leachate and groundwater quality to demonstrate that LFG production is stable or decreasing, settlement is essentially complete, leachate quality is stable or improving, and that emissions of leachate or LFG will not unacceptably impact HHE via potential pathways to air, groundwater, surface water, or the vadose zone. As such, the characteristics of the receiving environment and defined end-use for the landfill property are important inputs. Reductions in leachate management are based on periodic assessment of potential threats posed by uncontrolled leachate releases. In the context of LFG management, the EPCC methodology originally focused on regulatory requirements for control of subsurface methane migration and odors. Later, Morris et al. (2012) updated the methodology to consider the best available control technology (BACT) for LFG management in terms of surface emissions and air quality, as well