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White Paper Series: Municipal Solid Waste Landfills – Advancements in Technology and Operating Practices

Increasing Landfill Gas Collection Rates

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White Paper for Evaluating Revisions to the Municipal Solid Waste (MSW) Landfills New Source Performance Standards (NSPS) and Emission Guidelines (EG)

- This series of white papers examines ways to improve the NSPS/EG for MSW landfills using new information and new technology to further control and reduce landfill gas (LFG) emissions.
- Topics include applicability (size of landfill), controls (emission rates and timing of controls), operating practices (cover practices, active face), waste composition (organic waste), and monitoring (technology).

Topic: Increasing LFG Collection Rates

This paper describes techniques that can be used to increase LFG collection including revising the methodology for well decommissioning, mitigating the presence of leachate in collection wells, adding more comprehensive well monitoring, identifying and addressing damaged wells and pipes, and using wellhead tuning systems. This paper describes the challenges of enhancing gas collection from landfills through various technologies and methods. It examines variations in LFG emissions due to changes in atmospheric conditions and fluctuations in adjacent well performance. It highlights the critical role of LFG wellhead tuning in reducing LFG emissions, particularly in response to changes in atmospheric conditions.

LFG is typically composed of approximately 50 percent carbon dioxide (CO_2) and 50 percent methane (CH_4) by volume, with a small fraction (less than 1 percent) consisting of other elements including hydrogen sulfide and nonmethane organic compounds (NMOC). Although the NSPS/EG regulate LFG in terms of NMOC emissions, this paper focuses on methane emissions.

LFG collection efficiency varies over time based on landfill design and operational practices. Studies (Spokas et al., 2006; Barlaz et al., 2009) have shown that in landfills with effective covers and gas collection and control systems (GCCSs), collection efficiency ranges between 50–95 percent in the United States. LFG collection efficiency depends on various factors including the degree of waste compaction, LFG collection system coverage, and landfill cover system construction (U.S. EPA, 2009). This paper describes some improvements in landfill design and operational practices that could be implemented to reduce LFG emissions by increasing LFG collection. The impacts of daily, intermediate, and final landfill cover systems on GCCSs are discussed in other papers.

Another significant issue addressed in this paper is the need for more frequent monitoring of gas collection wells to take any required corrective action faster. Lastly, this paper explores the presence of liquid in the waste column and the GCCS—both of which can hinder methane collection from landfills—and identifies ways to overcome these obstacles.

Rationale and Possible Results

According to the EPA Landfill Methane Outreach Program (LMOP), approximately 91 percent of MSW landfilled in the United States is disposed in landfills that are known to have a GCCS in place (U.S. EPA, 2023). Current data on gas collection efficiency highlight the need to explore potential improvements in this area to further reduce emissions from landfills, particularly methane. Data reported under 40 CFR part 98, subpart HH of EPA's Greenhouse Gas Reporting Program for 2022 indicate that collection efficiency averages 73 percent.

The collection efficiency of a GCCS can be affected by multiple factors, including wells located in areas of the landfill with low LFG flow, damaged or poorly performing wells, and atmospheric conditions.

Construction of a GCCS (see drawing at left in Figure 1) begins with wells, which are installed vertically, horizontally, or both throughout the landfill. These wells consist of perforated pipes that allow gas to enter and be collected. The placement of wells is strategic to ensure maximum gas capture across the landfill. The collected gas from the wells is transported through a network of pipes. Smaller lateral pipes connect the wells to a main header pipe. This header pipe serves as the primary conduit, gathering gas from multiple wells and directing it toward the gas processing or flaring area. Blowers play a crucial role in moving the gas through the system. They create a vacuum that pulls the gas from the wells, through the pipes, and toward the processing unit. The vacuum ensures that the gas flow is consistent and that it is efficiently extracted from the landfill. Vacuum systems are integral to maintaining the correct pressure in the collection system. They ensure the gas is continuously drawn from the wells, preventing it from escaping into the atmosphere. The entire system is designed to be airtight, with regular monitoring and adjustments to optimize gas capture and prevent leaks.

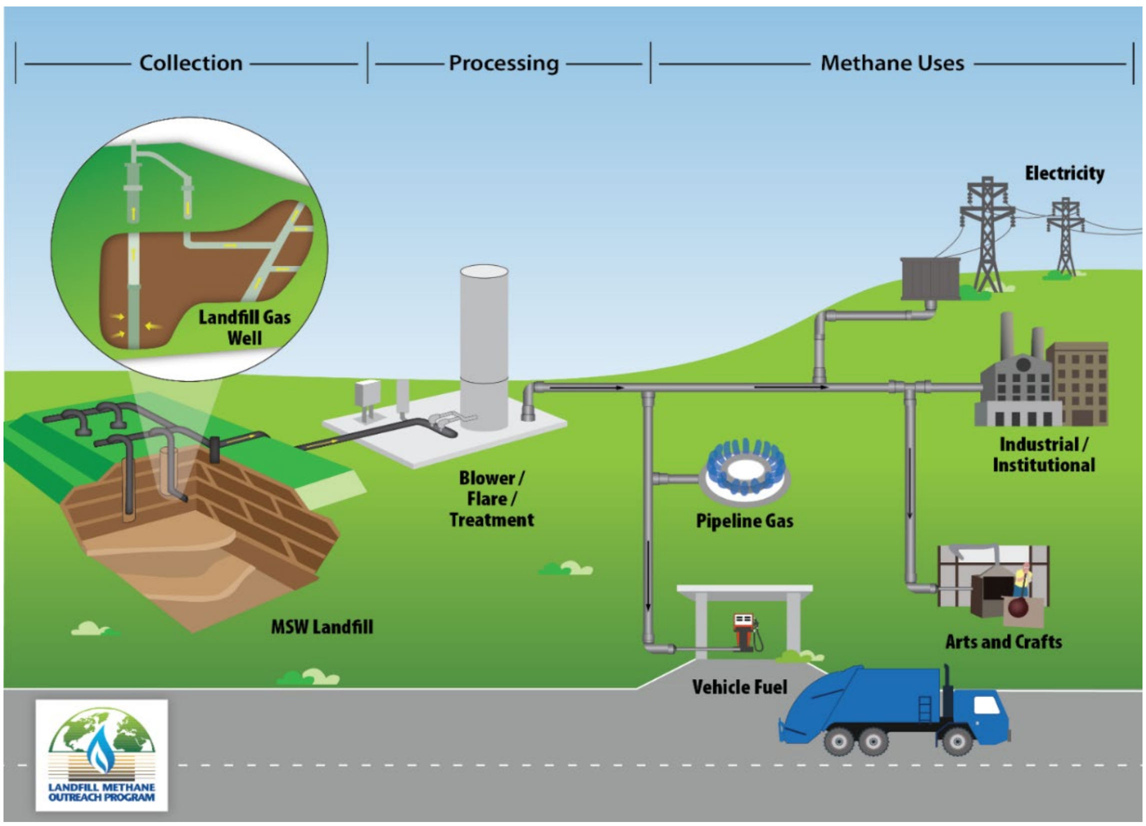


Figure 1. Graphic of LFG Collection, Processing, and End Uses (U.S. EPA, n.d.)

Once the LFG reaches the processing area, it is directed to a flare, an energy recovery project, or both. The methane within LFG can be used as an energy source to generate electricity, used directly as an energy source for heating, or converted to renewable natural gas (RNG).

The NSPS/EG allow a GCCS to be capped, removed, or decommissioned if certain criteria are met (40 CFR 60.762(b)(2) and 40 CFR 60.33f(f)). However, emissions occur both before and after the operational lifespan of a GCCS. An effective strategy to enhance methane capture could be to apply a more robust approach for well decommissioning. For example, potential regulation changes could allow the vacuum to be minimized for a well that is below a certain methane flow rate (LFG flow rate multiplied by methane content in LFG). Follow-up surface emissions monitoring could be implemented near the well to show that decommissioning of the well would not lead to significant methane emissions.

Gas collection wells must be protected from activities that could cause damage (e.g., construction, vehicles), elevated temperatures within in-situ waste, and from liquid within them. Wells might be damaged during landfill cell development or due to activities near working face areas. Moreover, to ensure that methane is being collected, monitoring collection well performance parameters (such as methane content, balance content, gas flow, and applied vacuum) is essential. Landfill operators often encounter problems with liquids (i.e., leachate and gas condensate) accumulating in gas collection wells, which results in a decrease in gas collected. Liquid in the collection system (wells or piping) can impede gas flow, potentially leading to the buildup of heat and pressure. Therefore, it is crucial to address the management of both gas and liquids in landfills.

The influence of atmospheric conditions or fluctuations in well performance on landfill emission has been extensively studied, highlighting a vulnerability in current gas collection practices. Higher gas emissions are directly associated with specific atmospheric conditions (including lower barometric pressure conditions) or failure in gas collection well performances. Innovations in well technology aim to adjust to these changes, thereby reducing their impact on emissions.

Investigations

A literature review was conducted to identify GCCS practices that could improve collection efficiency and reduce landfill methane emissions. The investigations encompassed in this paper represent a comprehensive review of existing research papers and regulatory terms from various state and international bodies that have studied improvement of GCCS. This review is intended to gauge potential actions that could improve methane collection.

In this assessment, EPA also points to potential revisions to the NSPS/EG, discusses the potential advantages and drawbacks associated with adjusting gas collection practices, and outlines further steps for in-depth evaluation. This exercise is pivotal in understanding how potential changes in regulatory standards could enhance efforts to more effectively control methane emissions from landfills.

Review of Temporal Methane Emission Variations and Importance of Methane Capture

Methane emissions from landfills vary due to multiple factors across different timescales. Annually, changes in waste disposal rates and characteristics can significantly impact emissions, as seen in a U.S. landfill study by Foster-Wittig et al. (2015), where methane emissions tripled over two years due to increased waste disposal rates. Seasonally, emissions can fluctuate dramatically, with emissions in winter up to five times higher than in summer, attributed to the lower activity of methane-oxidizing bacteria in cold temperatures (Stern et al., 2007; Chanton & Liptay, 2000). Gebert et al. (2011) also noted that soil moisture and temperature critically affect microbial activities and gas transfer, particularly in wet conditions.

On shorter timescales, atmospheric conditions play a significant role in methane emission rates. Studies by Czepiel et al. (2003) and Gebert et al. (2011) observed a negative correlation between atmospheric pressure and methane emissions, while Xu et al. (2014) noted emission fluctuations in roughly 10-day cycles with atmospheric pressure changes. Hourly variations are influenced by air temperature and wind speed, with Delkash et al. (2016) finding that a 40 percent increase in wind speed could significantly increase methane emissions. Delkash et al. (2022) further identified that wind speed is most correlated with emissions under neutral atmospheric stability, while air temperature has a greater impact under unstable conditions. Figure 2 illustrates the diurnal pattern of methane emissions at a landfill in the southeastern United States, highlighting that landfills tend to experience higher emissions during daytime and reduced emissions at night.

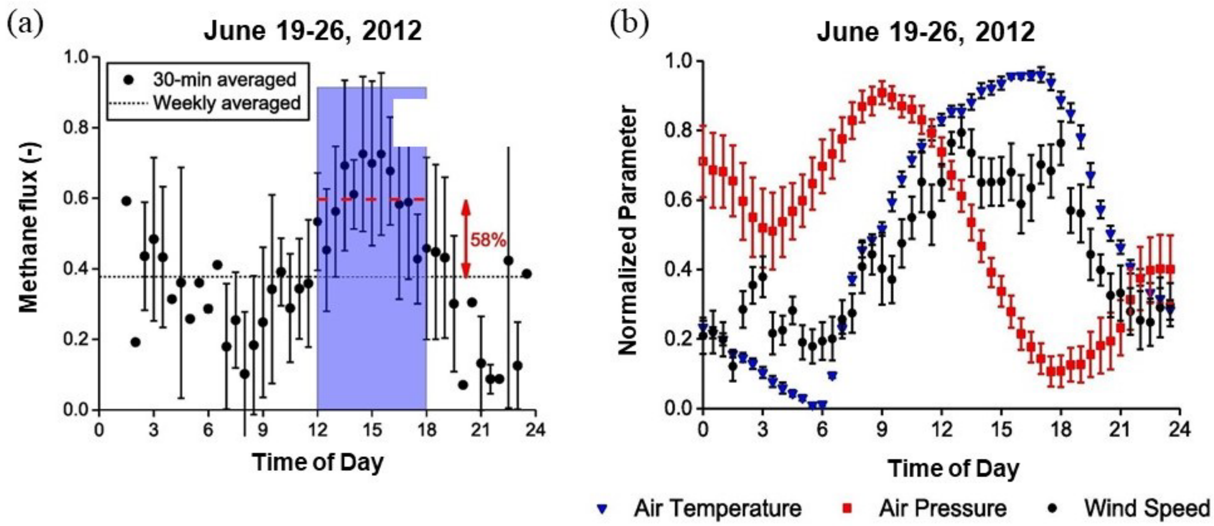


Figure 2. Diurnal variations of (a) landfill emissions as (b) atmospheric parameters change (adapted from Delkash et al., 2022).

A key finding of a study conducted by Aghdam et al. (2019) is the notable influence of barometric pressure on LFG recovery (Figure 3). Both the absolute levels and fluctuations of barometric pressure were found to be strongly correlated with the flow of recovered LFG and its methane content. The relationship between barometric pressure and the methane concentration and methane flow in recovered LFG was negative. This finding suggests that an increase in barometric pressure could potentially decrease the concentration and flow of methane in the recovered LFG by increasing air intrusion into the waste and diluting methane. On the other hand, a positive correlation with LFG flow indicates that higher barometric pressure might enhance the overall flow of LFG from the landfill. The study also underscores that fluctuations in barometric pressure have a more pronounced correlation with LFG recovery than the absolute pressure values, highlighting the importance of changes in barometric pressure in determining LFG recovery efficiency. Based on these insights, Aghdam et al. (2019) advise landfill operators to pay close attention to barometric pressure and wind speed to optimize LFG recovery systems.

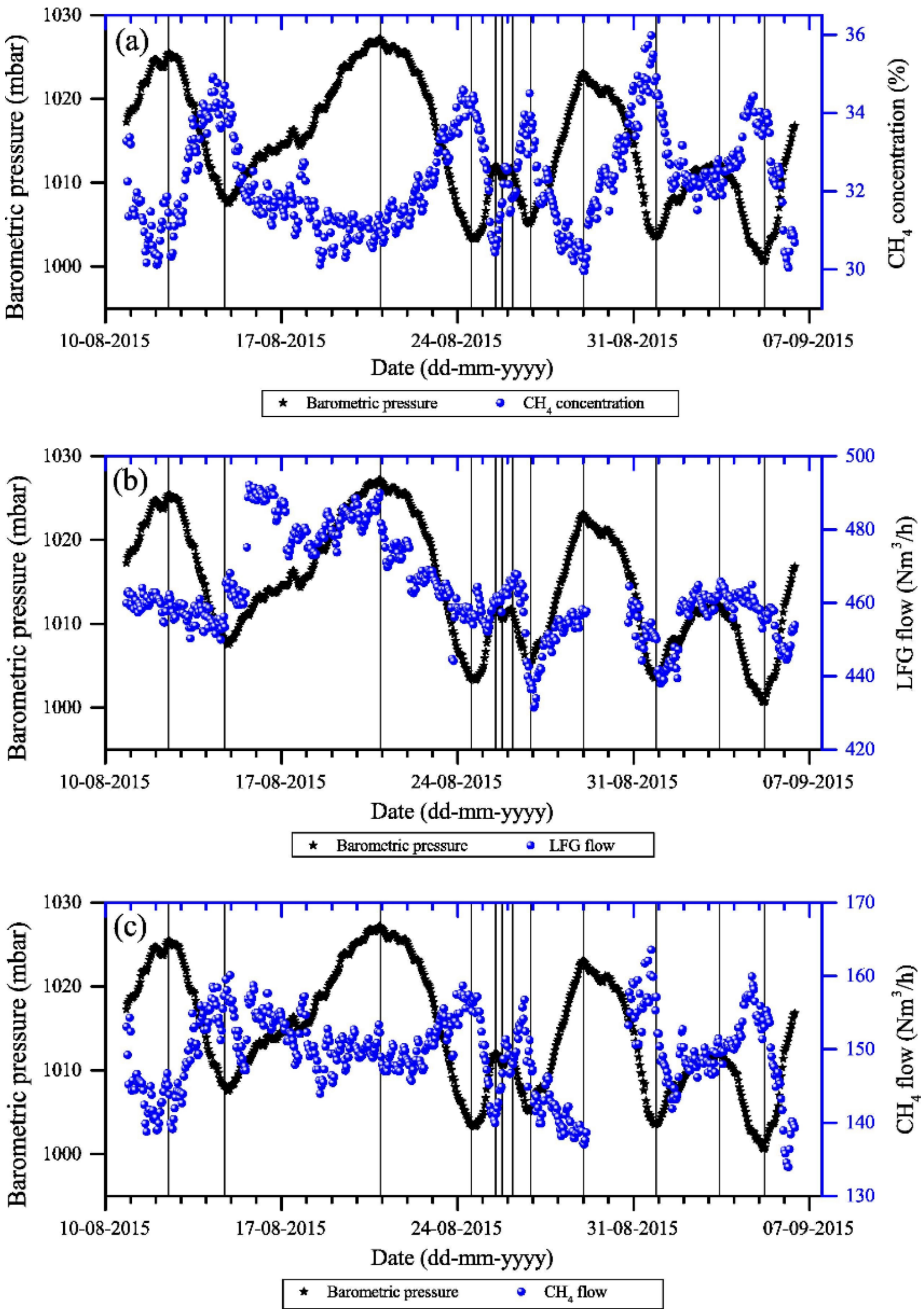


Figure 3. Barometric pressure compared to LFG CH_4 concentration, LFG flow, and CH_4 flow (Aghdam et al., 2019).

Review of Mitigating Gas Emissions by Handling Liquid More Effectively

Research literature (Zhang et al., 2019; Zhan et al., 2015) and landfill operators have suggested that gas collection efficiency at landfills with high leachate levels is significantly lower than at landfills with lower levels of leachate. This observation is largely attributed to the fact that leachate can accumulate and hamper LFG flow, thus lowering collection efficiency. Zhan et al. (2015) recommended that the leachate level be maintained at less than 30 percent of the total waste thickness to maximize LFG collection efficiency. Practical application at a landfill in China showed that retrofitting measures, such as installing deep vertical wells and horizontal drainage trenches, effectively reduced high leachate levels. As a result, the decrease in leachate levels led to an improvement in LFG collection efficiency from 10–20 percent to 60–90 percent.

Figure 4 illustrates various forms of leachate mound distribution in landfills with elevated leachate levels, identifying three primary forms: The upper perched leachate mound above deep waste layers, the perched mound above intermediate cover, and the bottom mound within the leachate drainage layer. The prevalence of significant leachate mounds in landfills is primarily due to four factors:

- High leachate production is driven by the substantial volume of liquid from waste decomposition and heavy rainfall, especially in humid regions.
- The hydraulic conductivity of MSW decreases markedly with depth, leading to very low permeability in deep waste layers, which hinders leachate flow toward the leachate collection system.
- The use of fine soils for daily and intermediate landfill covers introduces low-permeability layers within the landfill structure.
- The leachate drainage systems often become clogged and lose functionality after several years, exacerbating leachate accumulation.

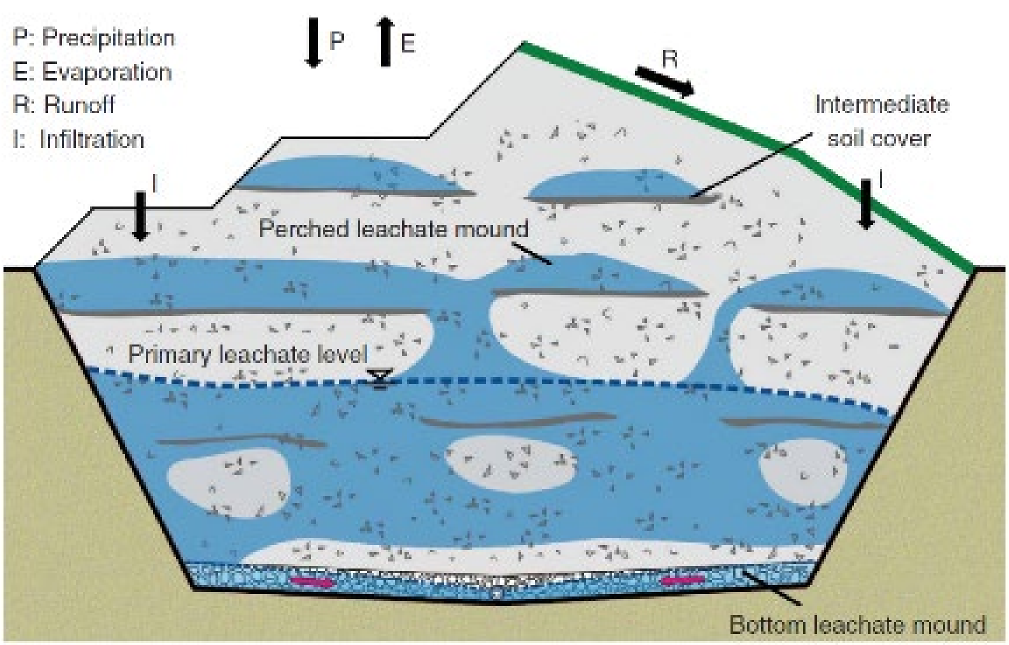


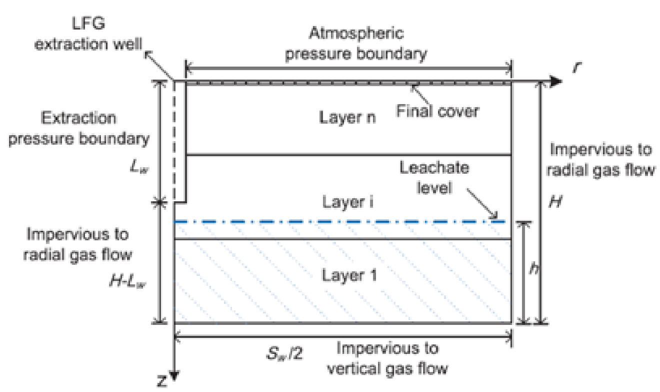
Figure 4. Forms of leachate distribution in landfills with high leachate levels (Zhan et al., 2015).

The formation of the upper perched leachate mound is primarily due to high leachate production and reduced hydraulic conductivity at depth. This leachate presence within the gas collection wells can obstruct the gas collection process. The perched mound over intermediate cover arises from excessive leachate production and the use of fine soils in covers. When the drainage layer within the landfill functions effectively, these mounds may remain distinct. However, if the drainage system becomes clogged, the bottom mound within the drainage layer can merge with the upper mound, further exacerbating the leachate presence in gas collection wells and preventing efficient gas collection.

Based on these leachate mound distribution forms, the distribution of LFG can be summarized as follows:

- Waste within the upper perched leachate mound may not be fully saturated, allowing for the presence of LFG in discrete bubbles or pockets under significant pressure.
- LFG beneath local perched mounds may also be pressurized, trapped by surrounding leachate.
- Shallow, unsaturated zones tend to have a continuous and abundant LFG presence.

The efficiency of gas extraction wells in landfills is influenced by the gas permeability of the waste material. In wet landfill environments, reducing the leachate level can enhance this permeability, thereby improving the efficiency of gas extraction. Zhan et al. (2015) analyzed the impact of liquid drawdown from gas collection wells. The scheme of a landfill that is partially drowned with leachate is shown in Figure 5 (left). The relationship between gas collection efficiency and ratio of leachate height to landfill height for large (H=41.5 meters) and medium (H=16.5 meters) size landfills is depicted in Figure 5 (right). This research clearly indicates that the presence of liquid in landfills can negatively affect gas collection efficiency.



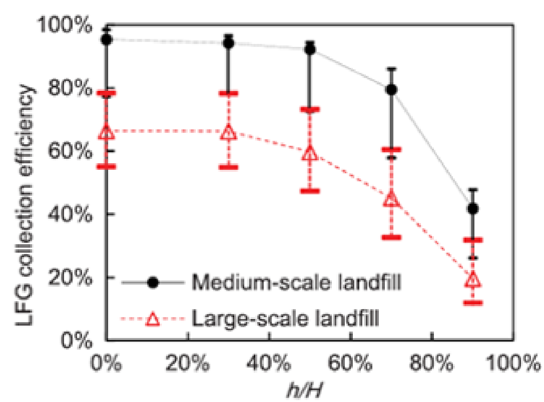


Figure 5. Left: Illustration depicting the setup of LFG collection using vertical wells in a landfill characterized by high leachate levels. **Right:** Graph showing the relationship between LFG collection efficiency and the relative leachate level (h/H), where 'h' represents the height of leachate and 'H' denotes the total height of the waste column (Zhan et al., 2015).

Figure 5 illustrates how the efficiency of LFG collection is influenced by the relative level of leachate within the landfill, expressed as the ratio of leachate height to total waste height (h/H). In the analysis, the LFG collection efficiency at a large-scale landfill was found to be lower than that at a medium-scale landfill. This finding is attributed to the larger well spacing employed in the large-scale landfill.

Furthermore, altering the intrinsic permeability of the waste gas by approximately ±100 percent led to a change of about ±10 percent in the calculated LFG collection efficiency. The numerical results conducted by Zhan et al. (2015) highlight a significant dependence of the collection efficiency on the ratio h/H for both medium- and large-scale landfills, particularly when the leachate level exceeds 30 percent of the total waste thickness (i.e., h/H ≥ 30 percent). An increase in the h/H ratio from 30 percent to 90 percent could lead to a reduction in LFG collection efficiency by 45–55 percent for both landfill sizes. These findings underscore the importance of maintaining the leachate level below 30 percent of the total waste thickness to ensure high efficiency in LFG collection.

Results

Mitigating Gas Emissions Using Wellhead Tuning Systems

Landfill GCCS tuning can pose significant challenges in optimizing gas capture due to the dynamic nature of emissions, which are influenced by changing atmospheric conditions such as fluctuations in barometric pressure and temperature. Under the existing federal regulations, landfill operators only need to check wellhead pressure, temperature, and oxygen content on a monthly basis. The fluctuation of these parameters can directly impact the emission rates of gases, particularly methane, from the landfill. Traditional monthly GCCS tuning often struggles to adjust to these more rapid temporal changes effectively, leading to inconsistencies in gas capture and potential environmental impacts.

By adapting gas recovery strategies in response to meteorological conditions, it may be possible to enhance the efficiency of LFG recovery and thus reduce methane emissions. Integrating barometric pressure and wind speed considerations into comprehensive collection system tuning for landfills to ensure more accurate and representative emissions data would allow for more effective methane capture.

Automated wellhead tuning has emerged as a solution to address these challenges by dynamically adjusting system parameters like vacuum pressure and flow rates in response to real-time data. By continuously monitoring atmospheric conditions and compensating for lower performing adjacent wells, automated systems can optimize gas collection, minimizing emissions and maintaining overall efficiency. New and advancing technology has the potential to actively monitor gas collection wells, notify operators as soon as issues occur, identify out-of-range parameters, and allow for automatic wellhead tuning.

Similarly, automated wellhead tuning can assist in remedying damages to the GCCS. Damage to the collection system can occur and remain unnoticed until monthly wellhead parameter checks. Depending on the issue, technicians may make manual tuning adjustments that reduce or stop collection at a well without addressing the root cause of the gas collection concern, such as a crack in gas collection piping causing high oxygen levels from air intrusion. Using better designs and materials for gas collection wells and pipes can avoid the occurrence of some issues while continuous monitoring and automated tuning can more quickly identify these sorts of operational concerns and result in faster and more targeted correction.

The implementation of automated tuning systems can enhance the efficiency and consistency of LFG collection. A key component of this improvement is the process of individual wellhead tuning, which involves adjusting gas extraction parameters at individual wellheads based on real-time monitoring. Wellhead sensors can continuously collect data on critical parameters, including gas composition, flow rates, temperature, and pressure; thus, allowing the system to respond swiftly to temporal variations in emissions caused by atmospheric changes.

The data-driven adjustments made by advanced software, which automatically optimize the performance of the system, lead to increases in gas collection efficiency. For instance, if adjacent wells are underperforming, the automated system increases vacuum pressure in active wells, thereby capturing more gas. Additionally, the automated system improves gas quality by optimizing the balance between oxygen and methane content, reducing air intrusion risks. Automated wellhead tuning not only improves the effectiveness of gas capture but also ensures that the system adapts to the ever-changing conditions within the landfill environment, reducing the risk of methane release and enhancing the sustainability of the landfill operations.

Mitigating Gas Emissions Using Durable Gas Collection Wells and High Frequency Well Monitoring

Different components of a GCCS, including pipes inside the waste and wells, can get damaged. Damage significantly affects GCCS performance and the temperature inside the waste might increase to 140^{o}C or more. Polyvinyl chloride (PVC) pipes might be compromised, but high-density polyethylene (HDPE) pipes can tolerate a higher temperature.

Gas collection wells can also fail due to waste settlement, equipment colliding with wells near working face areas, during landfill cell development, or when wells are extended (U.S. EPA, 2024).

Real-time well monitoring data could help continuously monitor performance and facilitate quick actions, if needed. Potential parameters for real-time well monitoring are applied vacuum, gas flow rate, and methane content.

Mitigating Gas Emissions by Handling Liquid More Effectively

It is crucial to understand the relationship between LFG collection efficiency and leachate levels, and to identify ways to enhance LFG collection in landfills with high leachate levels. Various factors contribute to the formation of significant leachate mounds within landfills, including high water release from waste decomposition, disposing sludge with low permeability, reduced hydraulic conductivity with increasing landfill depth, the use of fine soils for daily and intermediate covers, and clogging of leachate drainage systems.

Removing leachate from gas collection wells significantly enhances the efficiency of the GCCS. When leachate is present, it causes partial or complete blockages, leading to reduced vacuum pressure and a lower volume of gas being captured. Pumping leachate out restores the necessary vacuum conditions, allowing gas to flow freely into the collection system. Regular leachate pumping, combined with proper well maintenance, ensures that the GCCS operates at its optimal capacity, maximizing the capture of methane for flaring or energy recovery.

A dual-phase well in landfills is a type of well designed to extract both gas and liquids from the landfill simultaneously. These wells are designed with separate sections or pipes for liquid and gas extraction, allowing for efficient and simultaneous removal of both phases. The vacuum system controls the pressure in the well, ensuring the continuous collection of gas while preventing liquids from flooding the system. In addition to dual-phase wells, vertical or horizontal gas wells equipped with dedicated leachate pumps also improve gas collection efficiency. Vertical wells are particularly prone to leachate accumulation due to their depth, making it essential to integrate pumping systems. The integration of pumps into the GCCS, with consideration of well design and site management, ensures that both gas and leachate are effectively managed, leading to better overall system performance.

Regulation Changes

Several potential regulation changes could be applied in the upcoming NSPS/EG rulemaking to improve the performance of GCCS. One potential regulation change is the encouragement of using more durable materials and design for wells to resist damage during waste settlement, cell development, and high waste temperatures. Moreover, a more robust well decommissioning procedure could be proposed to consider methane flow rate (LFG flow rate multiplied by methane content) in wells and also include surface emissions monitoring to confirm wells can be decommissioned without significant methane emissions.

Innovations in well technology also show potential for enhancing the operation of the GCCS. For example, well technology can account for atmospheric conditions or fluctuations in well performance, thus reducing impact on emissions. Such performance improvements could be integrated into the upcoming NSPS/EG rulemaking, potentially leading to more efficient and effective LFG management and emission control measures.

To address the challenges of managing liquids without hindering gas collection, implementing dual-phase collection systems equipped with both gas and liquid pumps could be a potential solution in the upcoming NSPS/EG rulemaking. This could streamline the simultaneous management of leachate and LFG, improving overall efficiency. Potential regulation changes could include requirements to include leachate pumps to keep the liquid levels in wells low or to include more frequent gas collection well monitoring to ensure gas is being collected continuously.

A practical and effective method to improve GCCS performance in the upcoming NSPS/EG rulemaking could involve the installation of wellhead tuning systems that automatically adjust vacuum levels based on the methane concentration in the LFG and other parameters that affect LFG flow and quality. This adaptive approach could optimize gas collection efficiency and reduce emissions, aligning with environmental goals while offering operational benefits to landfill operators.

Implementation

LFG collection wells must have durable materials and designs to better resist any cause of failure, including high waste temperatures, equipment near working face areas, and well extension during cell developments. Using HDPE piping inside the waste could be required to avoid any pipe failure due to high temperatures. EPA is evaluating suggestions of less vulnerable well designs (e.g., Caisson wells) to decrease the number of well failures (U.S. EPA, 2024).

While managing liquids and gases simultaneously many landfills have encountered issues with water accumulation in gas collection wells, but have successfully implemented liquid pumps in dual-phase collection systems. This dual-phase collection technology has proven to be feasible. A potential regulation change in the upcoming NSPS/EG rulemaking could be to either encourage or mandate landfill operators to adopt dual-phase collection systems. Another way to help optimize gas collection efficiency in the upcoming NSPS/EG rulemaking could be to encourage or mandate that wastewater sludge should be dried prior to being placed in landfills to avoid low-permeable wet patches in landfills and reduce clogging of leachate drainage systems.

Regarding the issue of increased methane emissions due to atmospheric conditions, several companies already offer wellhead tuning technologies that are commercially available. EPA contends that by promoting this approach, more advanced and widespread wellhead tuning solutions could be developed, potentially covering all U.S. landfills with a GCCS. Furthermore, EPA could require more frequent well monitoring in order to facilitate more rapid reaction to any low methane collection incidents or other operational issues. EPA is assessing the use of distributed gas header sensor monitoring and the possibility of reporting higher time resolution speciated aggregate gas monitoring in a separate paper.

Next Steps

As a next step, EPA intends to solicit more experience-based feedback from landfill operators regarding the efficacy of various solutions to improve LFG collection efficiency. For example, it would be valuable to develop a comprehensive understanding of the costs and benefits associated with automated GCCS tuning with higher time resolution reporting to inform gas collection performance. Additionally, identifying strategies to prevent waste from becoming waterlogged is crucial. The role of dual-phase collection systems in supporting leachate recirculation and maintaining landfill sustainability warrants further practical investigation.

Furthermore, the potential challenges associated with wellhead tuning, such as the possibility of interference or competition between adjacent tuning wells, need to be thoroughly examined. It is essential to explore and recommend the most effective configuration of tuning wells in conjunction with conventional wells to optimize LFG collection efficiency while mitigating any negative interactions. Lastly, for understanding seasonal emission fluctuations, data from multiple landfills would be valuable to assess how LFG flow rates vary over time for sites where fugitive emissions are being minimized.

Consultations with landfill owners and operators could help ensure that potential regulation changes are not only theoretically sound, but also practically feasible and effective in enhancing landfill operations.

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