Challenges of Designing a Landfill Gas System for a Landfill over Compressible Soils

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EXECUTIVE SUMMARY

When landfilling over soft soils, the total waste thickness that can be placed over a particular area is usually limited by the strength of the underlying soil and, as a result, waste placement is distributed in thin lifts over large areas rather than confined within thicker lifts in a smaller active cell, as is the case at landfills with firmer foundations. Spreading the waste in thin lifts over a large area allows the foundation to consolidate and gain strength before the next lift of waste is placed. As a result of this waste placement practice, the area corresponding to the active landfill phase is usually large and flat. At landfills sited in geographic locations with significant precipitation (e.g., northeastern United States), this results in significant surface stormwater infiltration, which in turn leads to generation of large quantities of leachate and landfill gas (LFG). At such sites, a typical gas collection and control system (GCCS) consisting of vertical gas wells distributed throughout the landfill and connected to surface transmission pipes is unlikely to be a practical means of LFG management system, as it hinders efficient landfill operations. For such cases, a GCCS consisting of horizontal trenches provides a practical and cost-effective alternative for efficient LFG management.

This paper describes the main difficulties associated with the use of vertical LFG wells in large active areas and describes an alternative GCCS design that consists of horizontal trenches installed in several stages. This paper also discusses the overall design criteria and proposed approach for implementing the horizontal GCCS at the CIL, and the specific design challenges presented by each of the individual stages. Details of the design are also presented and discussed.
INTRODUCTION

Background and Site History
The Cherry Island Landfill (CIL), located at the confluence of the Delaware River and the Christina River in Wilmington, Delaware, in the northeastern coastal region of the United States, is owned and operated by the Delaware Solid Waste Authority (DSWA). This municipal solid waste (MSW) landfill is the largest landfill in Delaware taking in about 2,000 tonnes per day. It was constructed over an area that was partly reclaimed from the Delaware River and used for many years as a dredge disposal site for the U.S Army Corps of Engineers (USACE). As a result, the subsurface characteristics at the CIL site consists of very soft and extremely compressible materials with undrained shear strength as low as 9.6 kPa. This layer of soft material is as thick as 30 m in places.

The CIL site was opened in 1985 with construction of Phase I. Thereafter, the capacity of the CIL has been continually expanded to include Phases II, III, IV, and V (constructed in 1987, 1989, 1992, and 1996, respectively). Although MSW is no longer disposed of in Phases I and II, these two phases serve as staging areas for compost and white goods as well as disposal of dry asbestos.

Figure 1 overleaf the location of the CIL and layout of each phase. The maximum permitted elevation is 52.5 meters above mean sea level (m-msl). Under the current filling plan, MSW is placed in relatively flat benches which results in an approximately 8H:1V overall slope. At current filling rates, DSWA projects that the CIL has less than ten years of capacity remaining and are therefore proactively seeking to expand the site. However, due to the horizontal space constraints at the sites (see Figure 1) it is proposed that a vertical expansion of the CIL be designed to increase the maximum elevation to 59.5 m-msl while only increasing the footprint by 12 ha. The vertical expansion will be supported by a mechanically stabilized earth (MSE) wall that will be constructed around the perimeter of Phases III to V. The vertical expansion will provide an additional 11.5 million m$^3$ of capacity at the site.

Existing Vertical Gas Collection and Control System (GCCS)
Because of the subsurface conditions at the CIL, MSW is placed over the entire 60 ha area comprising Phases III through V to allow for consolidation of the foundation soils and corresponding strength gain. The current GCCS at the landfill consists of 262 vertical gas wells installed throughout all five phases (see Figure 1). The number of wells installed at the CIL corresponds to the U.S. industry norm of between two and three wells per hectare.

DIFFICULTIES WITH EXPANDING A VERTICAL GCCS

Although use of vertical wells has proved useful during placement of the initial waste lifts, as the thickness of waste increases it is clear that this type of GCCS will become increasingly impractical. Because the total waste thickness that can be placed over a particular area in the CIL is limited by the low strength of the underlying soil, waste placement must be distributed in thin lifts over large areas. Spreading the waste in this way allows the foundation to consolidate and gain strength before the next lift of waste is placed.
In addition to imposing significant restrictions on landfill operational activities, the necessarily restrictive waste placement practices at the CIL also results in a number of key issues that can hinder to efficient LFG management using a vertical GCCS, the most notable of which are listed below and illustrated schematically on Figures 2a and 2b.

- **Large Active Area:** The area corresponding to the active landfill phase is usually large and flat at landfill with soft foundation soils. In addition, because final grades have not been reached, these large flat areas can only be covered with intermediate soil cover and not low permeability final cover systems (see Figure 2a). At such landfills sited in geographic locations with significant precipitation (e.g., northeastern United States), this results in significant surface stormwater infiltration, which in turn leads to more rapid generation of large quantities of LFG, emission of which must be controlled.

- **Large Number of LFG Wells Required:** At landfills with firm foundation soils, MSW can be rapidly placed in thick lifts in relatively small active cells which are built up to final grade before installing a few vertical LFG wells through the entire depth of waste (see Figure 2b). At landfills with soft foundation soils, MSW must be placed in over a large flat area and short vertical LFG wells installed in each shallow lift (see Figure 2a).
- **Operational Difficulties**: At landfills with firm foundation soils, active landfill operations do not interfere with the GCCS (see Figure 2b). As clearly illustrated on Figure 2b, however, at landfills with soft foundation soils vertical LFG wells create landfill operational difficulties for vehicle maneuvering around the LFG well penetrations and lateral piping in and around the active area. Under past operations at the CIL with a vertical GCCS, the vertical LFG wells were protected by concrete manholes that surround the protruding vertical pipes, but this practice was stopped when it became apparent that these manholes were significant sources of excess LFG emissions. When left unprotected, however, these wells were easily damaged by landfill equipment, thereby creating operational difficulties as they needed continuous maintenance to remain functional. In addition, vertical wells in an active area must continually be disconnected and reconnected from their aboveground laterals to allow for waste placement, thus interrupting LFG collection in the active area. Surface GCCS transmission pipe connections between vertical wells also hinder the movement of vehicular traffic.

- **Periodic Upgrades**: In order to continuously extract LFG at landfills with soft foundation soils, vertical LFG wells require continuous vertical extension with solid pipe sections as landfilling progresses vertically in thin lifts (see Figure 2a). This practice results in an inefficient LFG management system as more vertical wells are required to provide the same coverage as a single vertical well that is installed when final grades are reached. This is clearly illustrated through comparison of the well network in Figures 2a and 2b. In addition, as the number of wells and length of associated lateral piping continues to increase, operational problems are further aggravated, making it even more difficult for vehicles to maneuver.

- **LFG Emission Source**: Vertical LFG wells often times become point sources for landfill gas emissions due to the difficulty associated with compacting waste around the wells without damaging them. This is especially true after vertical extension of LFG well piping through an active area. Maintaining the verticality of the extended vertical wells is also difficult. Finally, fugitive LFG emissions are best controlled through operation of an active GCCS in conjunction with a final cover system. As illustrated by comparison of Figures 2a and 2b, application of significant coverage of final cover is typically delayed at landfills with soft foundation soils.

- **Shallow LFG Wells**: Figure 2a shows that active LFG extraction at landfills with soft foundation soils would be conducted at recently filled locations using shallow wells in areas with only intermediate soil cover. This is unlikely to be efficient and may potentially lead to ingress of air and problems with MSW combustion.
Figure 2a: Sequence of Cell Construction and Installation of Vertical Landfill Gas Wells at a Landfill with Soft Foundation Soils
Figure 2b: Sequence of Cell Construction and Installation of Vertical Landfill Gas Wells at a Landfill with Firm Foundation Soils
DESIGN AND CONSTRUCTION OF HORIZONTAL GCCS

Overview
To overcome the problems described above, a GCCS comprising horizontal LFG collection trenches was designed for the CIL expansion (GeoSyntec Consultants, 2003). The use of horizontal collectors allows LFG extraction to proceed during the majority of the operational life of the facility with minimal disruption of operational activities. Installation of horizontal collectors eliminates the disruption typically associated with continually needing to extend vertical wells as each additional waste lift is placed. It allows collection of the estimated 10x10^7 cubic meters of landfill gas generated each year. This number will continue to grow with the landfill.

In addition, the need to continually move and reconnect exposed LFG transmission piping on the landfill surface, along with the disruptions to and limitations placed on site traffic routing associated with vertical LFG systems is minimized.

For extraction of LFG from the final top lifts of waste, a conventional system of shallow vertical LFG well system that extends from the surface of final cover to the top of the last level of horizontal collectors was designed. Switching to vertical wells for extraction of LFG from these final lifts of waste is more practical as horizontal collectors would need to be buried at least 12 m below the surface before maximum design vacuum could be applied. Because installation of these shallow vertical wells and associated transmission piping will be carried out after cessation of landfill operations and application of the final cover system, and therefore none of these wells will require extension, they will not cause any operational problems. Figure 3a and 3b, respectively, show a plan view and a schematic cross-section of the horizontal GCCS designed at CIL.

Design Challenges
Although horizontal LFG management systems provide a valid alternative for managing LFG at landfill facilities with large active cell areas, there are several issues that need to be considered to attain a successful design of these systems.

- **Limited Vertical Mobility of LFG**: Waste mass is a highly permeable medium with a hydraulic conductivity on the order of 1x10^{-3} cm/s. Waste placement practices usually result in layers of waste interbedded between horizontal soil layers with lower permeability. These horizontal soil layers can restrict the vertical flow of LFG as well as liquids. Vertical flow of LFG is important for a landfill with a horizontal gas collection system because LFG produced between levels of collectors must travel vertically in order to reach a collector. Restrictions on vertical flow of LFG were minimized in the design by installing vertical gravel-filled conduits spaced every 60 m along a horizontal collector. For the lowest horizontal collectors in Level 1, existing vertical LFG wells will be decommissioned and converted to conduits.

- **Clogging Potential**: The flow of LFG through a horizontal collector may be interrupted if a portion of the trench becomes inundated with perched liquids and clogs. To avoid this potential problem, the trenches were designed to be installed 1 m below a layer of intermediate/daily cover soil to provide a buffer between the horizontal collector and possible perched liquid on top of the
cover soils. In addition, the vertical conduits will also serve to drain any perched liquids within a trench.

**Figure 3:** (a) Plan and (b) Cross-Section of Proposed Horizontal GCCS

- **Vacuum Loss:** In general, vacuum is applied at one end of a pipe in a collection well or trench to withdraw LFG from surrounding waste within the effective radius of influence of the collector. Vacuum loss occurs along the length of the collector pipe due to friction along the pipe walls. Thus, the
longer the collector pipe, the larger the vacuum loss. Depending upon the size of an active cell, the length of perforated pipes in a horizontal collector can be several hundred meters. Because LFG collection systems are designed assuming that the internal gas pressure in the landfill is approximately equal to atmospheric pressure, typical design models may incorrectly conclude that there is insufficient vacuum available at the end of a long horizontal pipe to withdraw LFG from surrounding waste. However, the internal gas pressure in a landfill is typically higher than atmospheric pressure because LFG is actively being generated. This can provide enough differential pressure to allow satisfactory flow of LFG from the end of a long perforated pipe to the free end at which a vacuum is being applied.

- **Operation under Design Vacuum:** To avoid ingress of air, a minimum thickness of 3 m of waste must be in place above a collector prior to its initial activation under partial design vacuum. It is recognized that performance of the horizontal collectors will be somewhat limited during the period it takes to place this lift of overlying waste, although the waste filling plan will be developed to minimize this waiting period. In addition, because the vertical radius of influence of a collector under full design vacuum is 12 m, this vacuum can only be exerted on a collector once the full 12 m of waste is in place vertically above a collector (i.e., an additional 9 m of waste is required between initial application of some vacuum and application of the full design vacuum). Carefully controlled incremental increases in the rate of LFG extraction from these collectors as the depth of waste above a collector increases will be required to ensure that air is not drawn into the landfill. However, as landfilling progresses, the deeper collectors in Levels 1 and 2 (see Figure 3a) will be under continual operation at full capacity.

**Design of Horizontal GCCS**

The majority of LFG extraction devices at the CIL facility will comprise horizontal collectors consisting of loosely connected pipe sections situated in trenches backfilled with inert granular material (e.g., pea gravel, glass shards, tire chips, etc.). The maximum total length of an individual horizontal collector is anticipated to be approximately 450 m. The horizontal collector design is based on the horizontal GCCS installed at the Puente Hills Landfill in the greater Los Angeles metropolitan area in California (Tchobanoglous et al., 1993). In the Puente Hills design, 15 cm diameter pipe sections were loosely connected at 6 m intervals along the centerline of a trench. The total length of some trenches at the site exceeds 900 m. Trenches are evenly spaced at intervals of 60 m (horizontally) and 25 m (vertically).

Horizontal collectors will be installed in Phases III through V of the facility in three levels during the main active filling stages (see Figure 3b). These levels will be sequentially installed at a vertical spacing of 12 m when the top elevation of the waste reaches the following nominal elevations:

- **Level 1:** Elevation 21 to 24 m-msl (depending on existing elevations at the time of construction).

- **Level 2:** Elevation 29 m-msl.
• **Level 3**: Elevation 41 m-msl.

Each horizontal collector will be installed in a 60 cm wide by 90 cm deep trench which will be evenly spaced horizontally on-center at intervals of 60 m with each level staggered 30 m horizontally (i.e., Levels 1 and 3 collectors are aligned in plan view while Level 2 collectors are offset by 30 m). To minimize the total length of trenches, and thus the potential loss of vacuum at the end of long trenches, horizontal collectors are installed in four quadrants protruding radially into the center of the landfill in Phases III through V (see Figure 3b). Trenches will end a minimum of 6 m from the landfill side slopes and trench ends will be sealed with bentonite plugs. Solid pipe sections will be used to connect the perforated pipes in the trenches to the GCCS main header pipe. Vertical gas conduits (50 cm diameter boranings backfilled with aggregate) will be installed at nominal 60 m intervals along the length of each trench. 6 m diameter geomembrane boots will be fitted to each solid pipe protrusion to minimize the potential for air to be drawn into the landfill and/or for pipe trenches to act as conduits for leachate seeps.

**Construction of Horizontal GCCS**

Initial installation of horizontal collectors in Level 1 began during the summer of 2005. To date, four horizontal collectors have been installed at the CIL as shown on Figure 1.

**CONCLUSION**

The soft foundation conditions at the CIL facility imposes several challenges to the design of a vertical expansion and GCCS from which it was concluded that, although use of a vertical GCCS has proved useful during placement of the initial waste lifts, this type of GCCS will become increasingly impractical at the site. An alternative design approach was taken in which a horizontal GCCS was devised to address site-specific requirements. The use of horizontal collectors allows LFG extraction to proceed during the majority of the operational life of the facility with minimal disruption of operational activities. Installation of horizontal collectors eliminates the disruption typically associated with continually needing to extend vertical wells as each additional waste lift is placed. In addition, the need to continually move and reconnect exposed LFG transmission piping on the landfill surface, along with the disruptions to and limitations placed on site traffic routing associated with vertical LFG systems is minimized.

**REFERENCES**
