7.0 BEST MANAGEMENT OPERATIONAL PRACTICES

The design of LFG management systems has been discussed in this Guideline, and a number of standards and practices at the design level can be utilized to yield high performance systems. However, it should be specifically noted that operations are a critical parameter as it relates to the success of a system, and even a well-designed system can underperform if operations are not undertaken with specific objectives in mind. Lack of attention to the operational aspects of LFG management can lead to the following:

- Inadequate LFG supply to a utilization system and the associated effects on utilization system economics
- Diminished revenues from GHG emission reductions against forecasted yields
- Regulatory issues related to underperformance against stated performance standards
- Potential health and safety hazards to site employees and/or contractors
- Potential damage to the landfill and landfill systems including fires

The following subsections provide guidance and performance standards for LFG management system operations in the collection field and at the extraction control plant. It is recognized that operations are often a function of the skill, experience, and availability/time of the operator, and that education and training are key components of any management approach related to LFG and other landfill systems.

7.1 LFG COLLECTION FIELD

The first and most important component of successful operations is the management of the LFG collection field. This is an area that sometimes receives less attention than is required, often resulting in maintenance and performance issues.

7.1.1 COLLECTION FIELD MONITORING AND ADJUSTMENTS

Routine and scheduled monitoring and adjustment of the LFG collection field is required to optimize the effectiveness of the collection system in response to varying LFG generation rates; this activity is generally called well field balancing (Refer to Section 7.1.1.2). A well designed, constructed, and operated LFG recovery system can collect 75 percent or more of the LFG at a landfill site. It is important for a collection system to be operated to match the site's changing LFG generation potential without over or under-drawing on the collection field. In addition to the changing LFG generation rate over the life of the landfill, the effective LFG generation rate also varies somewhat over the short term as a function of factors such as meteorological conditions, differential settlement, equipment efficiencies, and cover system conditions.

The LFG collection field must be routinely monitored and adjusted to optimize the effectiveness of the collection system. The adjustment of valve settings to reduce or increase LFG flows from low or high generation areas of the landfill is required to maximize LFG collection without overdrawing from those areas of the site that may be susceptible to air intrusion. It should be noted that collection field adjustments must be made based upon a review of historic well or trench performance considered within the context of the overall field operation. Even relatively minor changes to a particular collection point will influence flow and vacuum at other locations within the collection system.

A certain amount of judgment gained from site-specific experience is required when making adjustments to the collection field. If combustible gas readings at a specific well or trench are found to be substantially below the plant gas concentration, then the flow from that well or trench should be reduced. Wholescale changes in the valve position (i.e., going from fully open to fully closed) are often counter-productive, as a given well may demonstrate high oxygen/low methane at full vacuum exertion, but reasonable gas quality at some reduced level; this reflects the purpose of well control valves. Smaller changes in valve position are more conducive to effective operations, and are most useful when the history of a well relative to LFG quality and valve position are recorded and utilized to guide future balancing activities.

7.1.1.1 AIR INTRUSION AND PRINCIPLES OF BALANCING

One principle that is often misunderstood or ignored, even by those working in the LFG industry, is that the operating basis for an individual well or trench must be based solely on LFG quality at that individual well or trench. Operating a well or trench on the basis of target recovery rates or expected performance yields is counter-productive; usually, oxygen content is the dominant parameter when assessing well performance and the need for valve adjustments.

Air intrusion into the landfill must be minimized since it has a negative impact on the natural decomposition of waste and can lead to landfill fires. Introduction of ambient air into the waste mass, with its 21 percent oxygen content, can have a counterproductive effect on the natural decomposition process. At the advanced stages of methanogenic decomposition, the microbes that carry out this process survive and thrive in an oxygen-free (anaerobic) environment. Introduction of oxygen into this process will kill the anaerobic microbes, forcing the process to become aerobic. This may result in a reduction in methane generation with an associated decline in potential energy recovery, greatly increased rates of differential settlement, high subsurface temperatures, and increased odour problems. In some cases, this can lead to landfill fires.

Excess vacuum that promotes air intrusion can lead to the aforementioned conditions; high vacuum that does not promote air intrusion may be appropriate in some situations. Intrusion generally manifests itself as oxygen at the wells, although it should be noted that oxygen may also be the result of leaks in the wellhead infrastructure; while this is a negative condition that must be corrected, there is no potential for waste-related impact that results from leaks in surface equipment. Earlier in this Guideline, it was recommended that two monitoring ports be attached to every well, as far apart as practically possible. This arrangement allows for an assessment of the upstream and downstream LFG quality; if the downstream gas quality shows significant deterioration (higher oxygen, lower methane) compared to the upstream point, the wellhead equipment almost certainly has a leak. Generally, this condition is easily repaired. If both monitoring ports exhibit the same poor gas quality, the leak may be in the subsurface and more difficult to address.

When excess vacuum is applied on wells such that intrusion occurs, the effective radius of influence around wells diminishes as the high vacuum is addressed by short-circuiting air from the atmosphere rather than drawing from the waste mass. This will lead to potential inefficiencies in the system extraction performance via reduced LFG draw to the extraction control plant. Where the response to this condition is to increase the vacuum on the collection field, intrusion may increase yet further, LFG flows and methane composition may decrease, and oxygen content may increase such that at some point, continued operation of the LFG management system may be impaired and damage may have been done to the waste and/or collection system.

Conversely, inadequate vacuum application on wells can also lead to system inefficiencies. Each well has a specific LFG flow-vacuum relationship, and underexploiting this relationship can reduce overall LFG capture volumes. Generally, an extraction point should be balanced on oxygen. If higher vacuum can be exerted on the well while keeping oxygen content below critical parameters, the overall recovery efficiency will be optimized.

Best management practices will set the vacuum applied at wells between 15 and 25 in WC; this refers to the vacuum on the well-side of the control valve. In some situations, applied vacuum may fall above or below these levels depending on local conditions and objectives, and actual applied vacuum may be higher or lower depending on gas composition. Note that these levels refer to the actual vacuum exerted on the waste through the extraction point. In some cases, orifice plates (typically used for flow measurement in wells) are utilized. If the monitoring port is downstream of an orifice plate, the actual vacuum exerted on the waste may be lower than indicated, especially if the orifice plate presents a significant flow constriction. This condition is counterproductive to optimizing LFG yields, and certainly is not warranted by the relatively-limited information that is gained by obtaining flow measurements using orifice plates.

Performance Standard 1

Oxygen content should not exceed 2.5 percent by volume and nitrogen should not exceed 15 percent by volume at a LFG extraction well.

If oxygen and/or nitrogen exceed this level, the well should be balanced to achieve LFG quality within the prescribed range.

Of note, a limit for nitrogen has been given because there are situations where low oxygen and high balance may exist in a well, with associated reductions in methane and carbon dioxide content. This condition also infers some amount of atmospheric air intrusion, but the intrusion pathway may be sufficiently lengthy through the waste mass that the oxygen content in the intruding air is consumed during transit. Nitrogen will then manifest itself at the well. This condition, if it remains unchecked, can produce the same negative impacts associated with air intrusion as described above.

Other parameters may also become the dominant criteria for well field balancing and adjustment. In some cases, loose wellhead components can lead to oscillating methane composition at the extraction control plant. While flares are sufficiently robust as to accommodate some amount of fluctuation in methane content, utilization facilities may demonstrate reduced performance in such situations, and require additional balancing activities to identify and correct the source of any instability.

7.1.1.2 FIELD MONITORING

In order to achieve the target of high collection efficiency, the following performance standard has been set:

Performance Standard 2

Methane content, oxygen content, carbon dioxide content, nitrogen content, and vacuum and valve position must be measured at all monitoring ports at all wells at least on a monthly basis.

Monitoring of main collection points, such as at subheader control valves, must also occur at least on a monthly basis. LFG collection system operational issues may indicate that more frequent monitoring of the main collection points is required.

Monitoring events should be paired with balancing activities to optimize LFG composition at individual wells and at subheaders as relevant.

Note that velocity measurements can be obtained at extraction wells and other monitoring points, but is generally not required as a matter of course. The provision for flow measurement should be made available at individual wells as long as it does not impact the operation of the wells, as orifice plates or other flow obstructions may. Provision for the insertion of a hot-wire anemometer is likely sufficient to yield velocity data if required. Generally, this information is used in field diagnostics if the conventional well field data is not able to identify the cause of an issue.

LFG temperature may also be obtained and recorded, but the importance of this parameter is somewhat less. If a LFG management system is correctly balanced, LFG temperatures are likely to be within acceptable ranges.

Water/leachate levels in vertical gas extraction wells may also be obtained and can be important where there is a known or suspected perched leachate or leachate mound condition. Interpretation of LFG data must be undertaken with caution where water level readings indicate that the well screen is flooded, as this suggests that none of the vacuum exerted on the well is being transmitted into the waste to draw LFG (i.e., no variance in pressure on either side of the control valve). This condition is often difficult to correct, as it requires evaluation of the leachate and surface water control systems. In some cases, inserting pumps into LFG extraction wells can reduce liquid levels, but if liquid is associated with a leachate mound, it is unlikely that single pumps will influence the liquid profile. Also, some cost implications are associated with the pumps, controls, discharge of liquid, electrical requirements, pneumatic air lines, etc. required with this approach.

Oxygen measurements, according to the performance standards set in this Guideline, will occur at the LFG extraction control plant on a continuous basis. An additional performance standard has been applied for oxygen:

Performance Standard 3

If the LFG analyzer detects high oxygen concentrations (greater than 2 percent by volume), a round of field monitoring and balancing must be initiated as soon as practically possible.

If there is rapid increase in oxygen content, this implies that there is a potential break in the subsurface piping system or an issue at a wellhead, and this should be responded to immediately.

The above performance standard is not meant to be restrictive. In some cases, especially where a utilization system is in place, it may be necessary to monitor and balance on a much more frequent basis, particularly if the LFG management system is large. Daily monitoring and balancing is not uncommon at large landfills. Additionally, LFG quality and flow can be subject to a number of meteorological conditions, one of which is atmospheric pressure. It has been observed that rapid changes in atmospheric pressure can affect LFG composition and flow. Typically, flaring systems can respond to this through modifying blower speed. For utilization systems, however, monitoring and balancing may need to respond to changes in atmospheric pressure, or even anticipate such changes by providing adjustments to well field valve settings before the pressure front arrives. There are a number of additional reasons for monitoring and balancing on a more frequent basis, and thus the performance standard for monitoring frequency should be seen as a minimum requirement.

Monitoring at each collection point should begin with the measurement of vacuum pressure. A portable gas meter is then used to measure methane, carbon dioxide, oxygen, and nitrogen composition. As good monitoring practice, combustible gas readings should not be taken until after the pressure measurements, due to the possibility of interference with pressures by the action of extracting the gas sample. If required, water/leachate levels should be taken after all gas measurements are completed, as this monitoring may require opening the LFG extraction well cap.

Table 7.1 presents a simple diagnosis tool to highlight some common problems in the operation of the LFG collection and utilization facilities and their probable solutions.

Table 7.1: Common LFG Collection System and Fuel Recovery Issues

Diagnosis	*Potential Results*	*Recommended Solution*
O_2 > 2.5 % v/v or CH_4 < 45 % v/v	• Diluting LFG fuel therefore reducing energy recovery • Increased rates of differential settlement • High subsurface temperatures • Odour problems • Landfill fires	• Adjust valves and rebalance based on gas quality • Check well head for indications of differential settlement stresses • Assess gas composition at both well monitoring ports to identify potential wellhead leaks
CH_4 > 55 % v/v	• Increased energy content per unit LFG recovered • Odour problems • Vegetation stress • Increased emissions and migration	• Adjust valves to apply additional vacuum and rebalance based on gas quality • If gas quality and quantity are indicative of additional gas in area, add wells to system
O_2 <2.5 % and Nitrogen > 15 % v/v	• Diluting LFG fuel therefore reducing energy recovery • Increased rates of differential settlement • High subsurface temperatures • Odour problems • Landfill fires	• Adjust valves and rebalance based on gas quality • Check well head for indications of differential settlement stresses • Investigate other potential intrusion pathways including well seals, cracks and fissures in landfill cover, and intrusion points at other landfill systems such as the leachate collection system
Vacuum > 25 " WC with high relative flow rates	• Potential air intrusion • Increased rates of differential settlement • Landfill fires • Odour problems	• Adjust valves and rebalance based on gas quality, as required • If gas quality and quantity are indicative of additional gas in area, add wells to system; potential issue of blocked pipes, flooded wells, and/or extraction points
Vacuum < 10 " WC at extraction points with low relative flow rates	• Blockage/breakage of extraction piping • Condensate issues • Odour problems • Vegetation stress • Increased emissions migration	• Check well head for indications of differential settlement stresses • Identify and address blocked piping and potential piping sags that have accumulated condensate
Unstable vacuum readings	• Composition oscillations that may affect a utilization facility (i.e., surging)	• Investigate system for potential water bellies associated with piping sags

Note:

% v/v   percent by volume

7.1.2 COLLECTION FIELD MONITORING EQUIPMENT

A number of pieces of analytical equipment are required to carry out monitoring of the LFG collection field, including the following items:

- Digital manometer
- Portable LFG analyzer
- Ancillary equipment
- Portable health and safety air monitor (i.e., 4-gas meter)

The following briefly outlines the functions of the analytical and safety equipment listed above. Of the listed items, the digital manometer and portable LFG analyzer are the most important items.

7.1.2.1 DIGITAL MANOMETER

The digital manometer is used to measure both static and differential pressures of the system at the extraction points. The manometer should measure pressure/vacuum in the range of from 0.0 to 40.0 in WC pressure or vacuum with a measurement accuracy of ±0.1. For finer adjustments to the LFG collection system, a manometer with a range of 20.0 in WC may be required. Static pressure is measured relative to atmospheric pressure by connecting the positive (+) tubing lead from the manometer to the monitoring port being sampled. The pressure should only be recorded once the monitoring port ball valve is opened and pressure equilibrium is attained. Any fluctuating/pulsating pressures should also be noted, as this could indicate water accumulation in the well/trench, lateral, or subheader system.

The digital manometer should be the first piece of equipment used at any monitoring port.

7.1.2.2 PORTABLE LFG ANALYZER

The portable LFG analyzer permits field measurement of combustible gas (methane), carbon dioxide, oxygen, and nitrogen concentrations in the LFG, where the first three gases are measured and the last is calculated. The standard equipment used in the field incorporates an infrared detector for methane measurement, which has proven accurate and reliable; however, even this robust measurement technique can be prone to variations according to environmental conditions such as barometric pressure, temperature, and moisture. The oxygen sensor, if based on electrochemical principles, is generally the slowest to stabilize.

The portable LFG analyzer is operated by connecting the meter's tubing to the monitoring port being sampled and opening the monitoring port valve. Sampling is continued until sufficient volume has been purged through the sample lines to ensure that a representative sample has been evacuated through the instrument. A reading may be taken when a stable concentration is indicated on the display. The tubing should be observed for any water as this will damage the analyzer.

Filters are provided to prevent exposure of the internal instrument parts to water, which can severely damage the instrument. Spare filters and tubing should always be present when undertaking monitoring. While some portable LFG analyzers are able to determine vacuum/pressure, the use of digital manometers is still encouraged.

Shop and field calibration are crucial elements to the use of this equipment. Quality control/quality assurance plans for the equipment maintenance and calibration should be recorded and applied as required. Generally, shop calibration is required for units of this nature on a schedule prescribed by the manufacturer, but which is generally at least once per year.

The portable LFG analyzer should be used after the vacuum/pressure readings have been obtained.

Note that it is not appropriate to utilize portable health and safety gas meters for the measurement of LFG concentrations as it pertains to monitoring; portable safety meters often provide readouts outside of the typical methane concentrations observed in LFG, and are not intended for long-term exposure to high concentrations. Also note that photoionization detectors (PIDs) are not appropriate for monitoring of LFG, as methane is not within the ionization frequency of these detectors; additionally, PIDs are highly sensitive to moisture, which is present in substantial quantity in LFG.

7.1.2.3 ANCILLARY EQUIPMENT

As noted, velocity measurement is of secondary importance when monitoring and balancing a LFG well field. In-flow measurement devices include pitot tubes and orifice plates, but both are prone to degraded performance with time during continuous exposure to LFG flow. A hot wire anemometer device is relatively accurate and can measure both flow velocity and temperature as required, provided there are sufficient and accessible monitoring points at the wells and in the piping system.

A water level meter is a standard piece of equipment for measurement of liquid levels in vertical extraction wells. Interpretation of water levels is greatly facilitated if the construction details of the wells are available during the monitoring event to determine the available well screen.

Use of this type of equipment should only be undertaken after vacuum/pressure and LFG composition readings have been taken and logged.

7.1.2.4 PORTABLE AIR MONITOR

The portable air monitor (gas detector) is required to verify the safety of the atmosphere in any confined space prior to entry. Confined space entry is not and should not be normally required to complete a round of collection system monitoring; however, should any entry into a condensate trap or other confined space become necessary, confined space entry procedures must be followed.

It should be noted that the air monitor is a personal safety device and is not recommended for analytical purposes. Direct sampling of LFG may damage the monitor; however, its use during routine monitoring events is recommended for personal health and safety around extraction points and chambers.

7.1.3 COLLECTION FIELD REPORTING

A record of all monitoring data should be kept for maintaining a history of field performance for optimization and troubleshooting purposes. The LFG collection field monitoring records for each LFG monitoring point should include the following data:

- Time of sampling event
- Initial valve position
- Static vacuum pressure
- Methane concentration
- Carbon dioxide concentration
- Oxygen concentration
- Balance concentration
- Adjusted valve position
- LFG flow rate, as applicable
- Water level, as applicable

In addition, a subjective description of LFG collection field operations should be included in field reporting. This includes, as examples:

- Swings in vacuum or LFG composition that may indicate pipe blockages
- Evidence of water in collection field piping potentially resulting in reduced vacuum
- Localized settlement of the landfill indicating rapid settlement associated with increased waste temperatures
- Areas of compromised landfill cover that may result in atmospheric air intrusion
- Ponding of water on the landfill surface/cap/final cover system indicative of differential settlement
- Well heaving that may indicate compromised integrity of extraction piping
- Audible evidence of air leaks into wellhead systems at extraction points
- Distressed vegetation indicating short-circuit in collection field
- Need for additional vertical extraction wells
- Need for cap maintenance or repair
- Any other items that affect the operation of the LFG management system

Barometric pressure should also be noted once per day for each day of well field monitoring. Any changes in weather during the well field monitoring should also be noted as this typically indicates a change in barometric pressure, which may have an influence on the operation of the LFG management system. For dramatic changes in weather, the change in barometric pressure from the start of the monitoring round to the end of the round should be documented.

A proper record of all documentation is instrumental in trending field performance, identifying problematic system issues that may require repairs, and areas of the field that may benefit from additional wells. All data should be retained on-site with appropriate backup and should be available upon request.

7.1.4 COLLECTION FIELD MAINTENANCE

Any maintenance events should also be noted and logged. For a LFG collection field, this includes testing of valves, replacement of flex hose and monitoring ports, and additional landfill items such as repairs to the cover system. A maintenance program should be specified in the LFG management system's operations and maintenance (O&M) manual.

Monthly maintenance activities should include all weekly inspection activities as well as monitoring the LFG quality and pressure at each vertical extraction well and horizontal collection trench. The collection field should be adjusted as needed.

Of note, maintenance of the LFG collection field includes the replacement of defunct LFG extraction wells. As the landfill environment settles and shifts, there is generally some damage to wells, and in some cases this damage is not repairable. In such cases, replacement wells are generally needed.

7.1.5 LANDFILL FIRE MANAGEMENT

Management of landfill fires is another item that requires attention, especially when operating a LFG management system that can potentially be responsible for initiating and propagating/aggravating the magnitude and nature of fires. Fires can occur in a number of areas and for a number of reasons, including operations of a LFG management system, deposition of hot loads, and chemical reactions occurring within the landfill itself.

Effective fire management can be undertaken by understanding the causes of fires as part of a preventative strategy, and by means of addressing fires if they do occur. It is strongly recommended that any landfill have a fire management plan, and that the operation of the LFG management system be addressed specifically in this plan.

Landfill fires pose a health and safety risk to humans and the LFG management system itself due to the unsafe conditions they create. The burning waste can emit toxic gases. Due to settlement caused by the fire, sinkholes may be present, posing a hazard to site workers. If the fire comes in contact with the LFG management system equipment, any interaction with the equipment may be hazardous to site workers (i.e., hot equipment, malfunctions, etc.).

Landfill fires also pose a great risk to environmental conditions of the landfill and the surrounding area. As previously stated, fires can generate toxic air emissions; uncontrolled combustion of halogenated compounds often results in emission of dioxins and furans.

One of the risks of landfill fires is the potential damage to the LFG management system equipment. Fire damage may cause downtime in the LFG management system and require the replacement of expensive equipment or repair of landfill infrastructure. Note that, generally, one of the first response measures for a landfill that has a fire is the termination of operation of the LFG collection in that portion of the site that may be on fire or may be at risk of a fire. The use of the fuel (LFG) is one of the primary elements used in the proper approach to extinguish a landfill fire. While this approach may sound contradictory, it becomes clear that this is a valid response when conditions involved and the gas generation mechanisms within the site are taken into account. The fuel itself is one of the most important elements to create an environment that cannot support continued combustion.

A fire will only occur if the following sources are present, in ideal conditions, within the landfill:

- Fuel, which is provided by waste and/or the methane component of LFG
- Oxygen, which can be drawn into waste through elevated vacuum levels associated with the LFG management system
- Heat/ignition, which can result from spontaneous combustion, friction from settlement of waste, fresh waste loads, hot loads, household chemicals, or equipment

Fires may occur entirely under the cover of the landfill and may not be visually present to site employees. A list of signs that landfill fire may be presently occurring or has occurred include:

- Active LFG collection areas that are overdrawn and may have too much available vacuum being applied to the well field
- Monitoring data shows high O_2, high CO (> 1,000 ppm), and high LFG temperature (> 60 degrees Celsius)
- Accelerated landfill settlement in localized areas
- Impacted infrastructure such as melted wellheads or piping
- Smoke, odour, or residue

A landfill fire may be officially confirmed through the use of field equipment monitoring and laboratory testing for incomplete combustion compounds such as carbon monoxide. Generally, CO monitors are not included as part of the standard monitoring package for a LFG management system, but samples of LFG can be directed to a laboratory for analysis of this compound.

Fire prevention measures may be implemented into active LFG collection systems by using:

- Flare stop and fail-safe valves
- Isolation valves
- Extraction well valves
- Collection trench valves
- Good well seals
- Well-developed site monitoring and balancing protocols
- Well-trained staff implementing the balancing program that are trained to recognize the signs of fires

Note that a LFG management system is in itself a fire prevention measure. Within the landfill, management systems safely collect methane and monitor gas and temperature levels, among other important parameters. A multifaceted approach to preventing and controlling landfill fires may contain the following:

- Supplemental soil cover material to cut off the supply of oxygen to a fire, returning the waste to anaerobic conditions
- Fire suppressant foams
- Fire breaks and containment berms
- Injection systems such as steam, carbon dioxide, or nitrogen

While an effectively-operated LFG management system can be a fire prevention system, inappropriate operations can pose a fire risk. For example, installation of new vertical wells in an area of ongoing LFG extraction may readily incur the intrusion of atmospheric air into fresh boreholes; typically, vacuum in the area of new wells should be reduced or eliminated to prevent excess air intrusion. Also, it should be noted that response to landfill fires may be counter-intuitive in some ways to typical fire management programs. For example, excavation of landfill cover in the vicinity of a suspected fire merely serves to introduce additional air (and thus oxygen) into the waste, thereby potentially propagating/feeding the fire. Given the explosive limits of methane, it may be advisable to pursue a strategy that allows methane levels to elevate such that the fire is no longer able to self-sustain; this may require temporary cessation of parts of the LFG management system to allow for methane levels in the waste to elevate. One method of elevating methane levels to allow for anaerobic conditions to return within the waste involves the addition of soil cover that reduces any air intrusion. Water should not be added to the waste on fire unless it is being used to hydrate low permeability material.

7.2 EXTRACTION PLANT

As previously mentioned, this document has been compiled in general accordance with CAN/CGA-B105-M93, the Canadian Gas Association's "Code for Digester Gas and Landfill Gas Installations." This standard and all other applicable standards should be consulted for specific information and requirements when engaging in the operation and maintenance of LFG management systems and the practitioners should seek to remain abreast of additional requirements as they emerge.

Proper operation and regular maintenance of the LFG collection plant (including condensate knockout(s), blower(s), flare, and associated equipment) enhances collection system efficiency and maximizes equipment life.

A weekly plant operation and maintenance inspection should be performed. This consists primarily of a plant inspection with recording of observations and readings of a number of items such as gas flow and composition (which will be monitored continuously), flare temperature, bearing temperatures, motor run times, etc. In addition to the detailed weekly plant inspection, it is advisable to perform a brief visual plant check on a daily basis. The daily check will include observation of any unusual conditions. Correction of irregularities or adjustments to the system operation should be carried out only by personnel familiar with the operation of the LFG collection system.

In addition to the LFG collection field inspection, the manual isolation valves at the LFG management facility and in the LFG collection system should be exercised monthly and inspected quarterly. Manual valves should be opened and closed to ensure they are operational. It should be confirmed that all valves close tightly and open fully. Each valve should be opened and then closed a minimum of three times to distribute the sealing compound evenly around the plug.

To ensure that any maintenance issues are addressed prior to developing into major cost items, it is recommended that a bi-annual shutdown and thorough inspection of the major system components be performed. This 6-month inspection and maintenance may include disassembly, inspection, cleaning, and servicing of equipment by qualified service technicians. The system shutdown should be scheduled for a one- to two-day period to allow completion of the work.

Note that if a LFG utilization system is installed at the site, the backup flare and appropriate equipment should also be periodically operated and maintained when in standby mode, with routine inspection, operation, exercising of the blower, valves, etc. to ensure adequate operation when required.

The following equipment associated with the LFG management facility should be inspected:

- Thermocouples (pilot and flare)
- Flame arrestor
- Thermal shutoff valve
- Flow meter
- Condensate knockout
- Blower inspection and lubrication
- Sample ports
- LFG analyzer
- LFG analyzer sample line
- Pipe flanges and bolt connections
- Propane automatic changeover valve, hoses, and valves

- Internal flare inspection
- Condensate trap

If the LFG analyzer at the extraction plant detects high oxygen concentrations (greater than 2 percent by volume), a round of field monitoring and balancing must be initiated as soon as practically possible (see Performance Standard 3, Section 7.1.1.2). The the LFG analyzer warning for high oxygen concentration alarms (greater than 2 percent by volume), a round of field monitoring and balancing should be initiated as soon as practically possible.

Routine cleaning of the propane pilot assembly should be performed according to the manufacturer's recommendations. The thermocouples should be visually inspected for signs of damage. The thermal shutoff valve should be inspected in accordance with the manufacturers' recommendations, and the flame arrestor should be disassembled and cleaned according to the manufacturers' instructions.

Minor maintenance procedures, such as greasing bearings, changing belts, and calibrating detectors shall be carried out in accordance with manufacturer's instructions. All maintenance schedules should be specified in an operations and maintenance manual for the LFG management system.

A major system shutdown and equipment overhaul should be carried out on an annual basis. This should include the following activities as a minimum:

- Shutting down and inspecting the flare
- Making repairs and adjustments as necessary
- Overhauling blowers by cleaning and repacking bearings, replacing belts, carrying out performance tests, and making repairs and adjustments as necessary
- Removing, cleaning, and overhauling pumps

Per the above, a detailed operation and maintenance manual for the LFG management system should include maintenance schedules for all critical system components. (Refer to Section 7.3 below.)

7.3 OPERATION AND MAINTENANCE MANUAL

A detailed operation and maintenance manual shall be prepared for each LFG management system and shall be kept on-site throughout the duration of the operational life of the LFG management system. This manual shall be kept up to date and shall be available for inspection by the MOE as required.

Design Standard 9

Landfill owners and operators must develop an Operations and Maintenance Manual for the LFG management systems.

A detailed description of the following items should be included as part of a typical LFG management system Operations and Maintenance Manual:

- Site description
- LFG overview (composition and potential impacts)
- LFG collection and flaring system component overview (LFG collection field, LFG control facility, condensate management system)
- LFG collection field description, operation and control (i.e. well details, troubleshooting)
- LFG control facility description, operation, and control (i.e. alarm summary, troubleshooting)
- Condensate management system description, operation, and control
- System maintenance, monitoring, and reporting (i.e. inspections, calibration, maintenance and reporting requirements)
- Health and safety (i.e. general system and LFG safety, system safety features, confined space entry)
- Landfill fires (prevention and control)
- Drawing set of LFG management facility
- Approvals to operate
- Equipment supplier and manufacturer contact information

It is expected that the implementation of efficient, well-operated LFG management systems will in many cases address concerns regarding LFG migration through subsurface soils. Nevertheless, it is important to evaluate potential for migration through completion of a migration assessment, then provide adequate controls if the LFG management system is not sufficiently protective of on- or off-site migration issues.

8.0 LANDFILL GAS MIGRATION ASSESSMENT AND CONTROL

It is expected that the implementation of efficient, well-operated LFG management systems will in many cases address concerns regarding LFG migration through subsurface soils. Nevertheless, it is important to evaluate potential for migration though completion of a migration assessment and then to provide adequate controls if the LFG management system is not sufficiently protective of on or off-site migration issues.

8.1 MIGRATION ASSESSMENT

Field activities for migration assessments typically include the installation of gas probes along the perimeter of the landfill. Perimeter gas probes are used to monitor LFG migration beyond the waste discharge area typically at or near the property line or nearby structures. These perimeter probes are usually permanent installations for ongoing monitoring. A LFG migration assessment should be completed by a Qualified Professional to identify potential risk and pathways of the LFG prior to installation of any monitoring probes. The perimeter gas probes should be monitored for combustible gas content and probe gauge pressure on a regular basis. Water levels within probes installed near the water table or in areas of perched water tables should be monitored to determine seasonal fluctuations in the water table at each location. It is expected that correctly installed gas probes should generally remain dry, but a varying water table surrounding the site may cause periodic flooding of some probes. Interpretation of soil gas data from flooded probes must be undertaken with great care, as LFG composition data is generally meaningless if the soil probe screen does not have access to soil gas.

Immediately following each monitoring event, the data collected should be reviewed. The objectives of the review are:

- Verify unusual and/or erroneous readings
- Identify problems and, if necessary, initiate remedial action (i.e., repair damaged probes, calibrate or repair equipment, etc.)
- Bring to the attention of the individuals responsible for detailed assessment and contingency plans, those readings that may indicate gas presence
- Identify the occurrence of LFG migration
- Develop any remedial actions that are warranted
- Assess the effectiveness of any actions that may have been taken

A more detailed evaluation of the data should be performed on an annual basis and should include an analysis of all prior readings for trends. This analysis is an important tool in anticipating the occurrence of migration and assessing the effectiveness of any remedial measures taken. Where an active LFG management system is present in the landfill, the performance of this system should be evaluated against monitoring data related to probe data. Optimization of the LFG management system may be required to address ongoing migration concerns.

Note that analysis of monitoring data from perimeter probes is complex and must consider not only the monitoring results but also must take into account the following:

- Barometric pressure (may be incorporated into routine LFG collection field monitoring and/or tracked daily)
- Frost conditions
- Soil stratigraphy
- Hydrogeology
- Status of LFG controls (if applicable)

The detection of combustible gas in the soil constitutes evidence of migration; the confluence of combustible gas with high pressure readings indicates a situation where this combustible gas is migrating with a driving force beyond that of simple diffusion. Gauge pressures that are consistently positive in probes where combustible gas is detected give an indication of the magnitude of the force behind the migration. Gradients of combustible gas concentrations may be helpful in indicating the extent, range, and direction of migration. However, interpretation of concentration gradients may be complicated by physical and/or chemical processes acting upon the gases as they move through the soil. As indicated previously in this Guideline, such processes may have a preferential effect on some LFG constituents over others; specifically, the carbon dioxide component of LFG may be stripped into soil water over extended migration lengths, resulting in a proportionately-higher concentration of methane per unit volume.

Soil gas concentrations at the property boundary should not exceed the lower explosive limit of methane (5 percent by volume). If greater than 5 percent by volume of methane is measured at the property boundary, an additional assessment must be conducted as soon as possible to assess the potential issues that may arise from LFG migration. Additional monitoring of the probes may be warranted, as well as residential monitoring if LFG migration is suspected in residential areas around the landfill.

Modifications to the active LFG collection system may be warranted and/or a passive LFG system may be installed to intercept the migrating LFG.

It has been shown that barometric pressure has a strong influence on subsurface pressures, and that changes in subsurface pressures lag behind changes in barometric pressure. This time lag is dependent on many factors, including the depth of the probe, permeability of soil or waste, daily cover, final cover, degree of saturation, presence of frost or frozen ground cover, and rate of change in barometric pressure. Due to the many factors that influence the time lag, it is difficult to determine absolute subsurface gas pressures (i.e., subsurface gauge pressure with the barometric pressure influence removed). Reduction of probe pressures to absolute values may be misleading. Barometric pressure should be considered when analyzing data, as large fluctuations before monitoring can lead to an erroneous interpretation of the data.

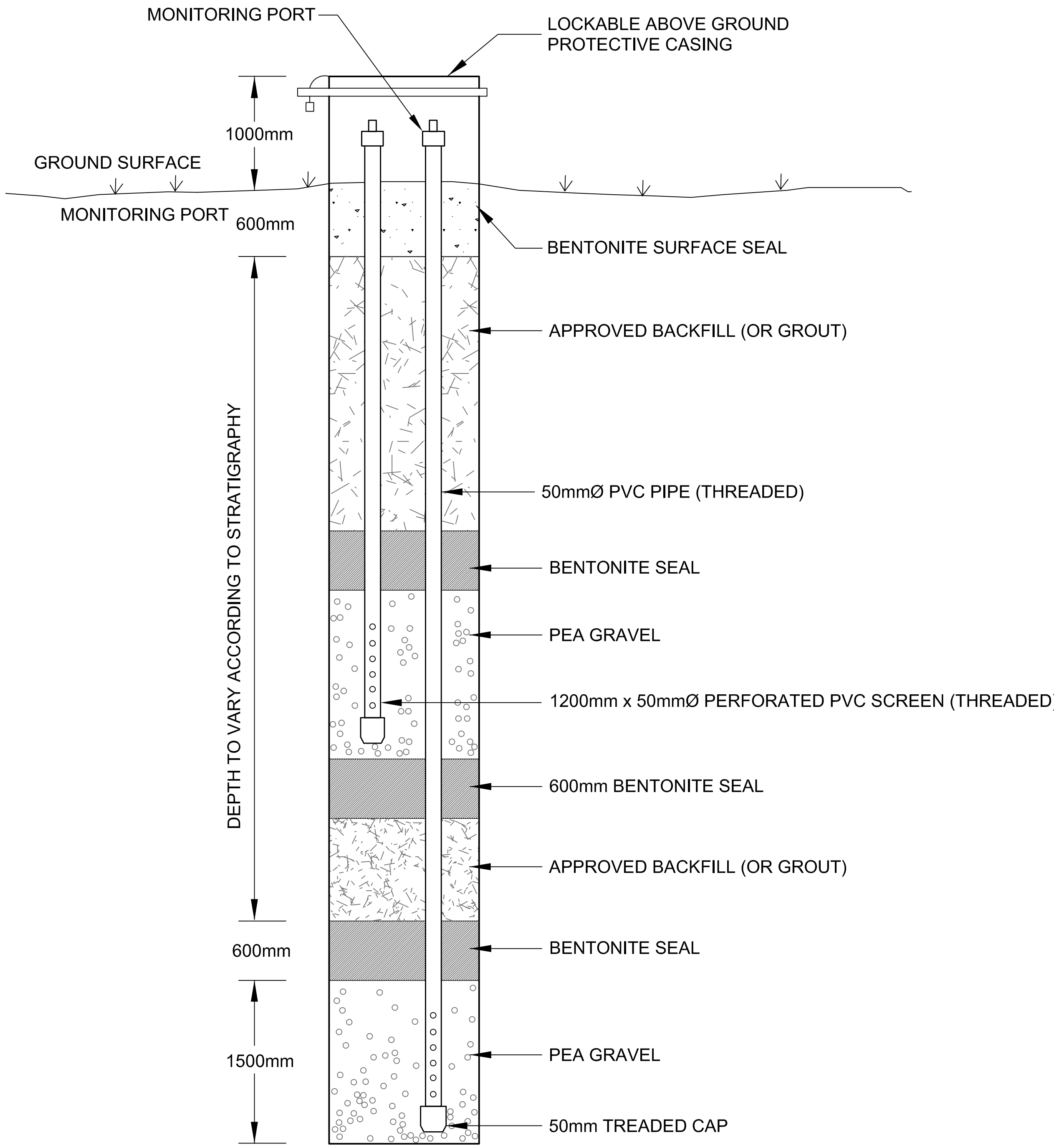
Probe pressures provide data that is useful for analyzing long-term trends. Due to the numerous factors affecting subsurface pressures, trend analysis of subsurface pressures should be based on review of annual average gauge pressures at each probe. This will help eliminate the daily and seasonal barometric fluctuations that will be most evident in individual readings.

An analysis of the data should include consideration of the site stratigraphy and hydrogeology, as these characteristics impact gas migration. Low permeability soils inhibit migration more than high permeability soils. Stratified layers of high permeability soils overlain by low permeability soils will tend to increase migration distance by confining the gas and limiting venting to the atmosphere. This is similar to the effect that frost or frozen soil has on migration. This may indicate the need for nested soil gas monitoring probes around the perimeter of the waste installed at varying depths to monitor the soil gas within the different high permeable soils. Nearby underground utility corridors with granular bedding can also provide a preferential pathway or conduit for gas migration.

Note the importance of a small probe diameter to reduce the volume of gas that must be purged from the probe during monitoring; this should be balanced against the diameter required to obtain water level readings. Typically, a 50 mm (2-inch) diameter gas probe is suitable. Purging of probes is essential in order to obtain a sample that is representative of the soil gas present at the well screen level.

Probes are generally constructed from PVC pipe. Glued joints should be avoided for probes that may be sampled for trace gas analyses, as solvent cements contain VOCs that will then appear in the analytical results.

Figure 8.1 shows a typical detail for a two-level nested soil gas probe. It should be recognized that installation of multilevel gas probes requires supervision by an experienced drilling technician. To function properly, the perforated portion of the probe must be located in the more permeable strata. The integrity of the borehole seals between the probe levels is critical to the proper functioning of the probe. As an alternative to multilevel probe nests, probes may be installed at the desired levels in individual, adjacent boreholes.



NOTE:

1. GAS PROBE DEPTHS AND SCREEN LOCATIONS TO BE VERIFIED IN THE FIELD, BASED ON LOCAL SOIL CONDITIONS.
2. CONNECTIONS AND ADAPTORS SHOULD NOT BE GLUED.
3. A FLUSHMOUNT CASING IS A SUITABLE ALTERNATIVE.
4. APPROPRIATE FOR SINGLE LEVEL GAS PROBE

figure 8.1

MULTILEVEL GAS PROBE DETAIL (TYPICAL)

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The length of perforated screen, generally on the order of 1 m, is designed to allow differentiation of vertical gas measurement zones. Some probe designs include larger perforated sections, but it should be recognized that the larger the perforated section, the less certainty there is regarding the vertical extent of migration. Probes that are screened for most of their depth (if depth >3 to 4 m [>10 to 13 ft]) can act only as general indicators of migration.

To prevent interference by atmospheric conditions, probe perforations should generally be located more than 1.5 m (5 ft) below ground surface and equipped with seals. Although the potential for air intrusion into gas probes is much lower than in gas extraction wells where an active vacuum is applied, portable LFG analyzers generally exert vacuum to draw sample, and thus may induce intrusion.

Gas probe locations will be selected primarily to provide a good geographical distribution across the site, given the site conditions anticipated, and to match the site's specific characteristics (i.e., traffic patterns, drainage patterns, etc.). Any known sensitive areas such as buildings on or near the site, previously identified permeable soil zones, and underground service alignments should be targeted for probe installation.

8.2 MIGRATION CONTROL

Control of lateral migration of LFG in the soil may be required to prevent potentially hazardous conditions from developing in structures on or near the landfill site and to prevent off-site migration of LFG. Where natural barriers to LFG migration exist, gas migration controls may not be required. Such natural barriers may include a high water table or steep embankment such as a ravine. The purpose of the LFG migration assessment is to identify potential migration pathways and provide a strategy for control systems as required. As indicated, an effective LFG management system comprising an active collection component is generally sufficient to address any migration-related issues, but the assessment must be conducted on a site-specific basis as there are conditions that may warrant additional controls. Table 8.1 outlines the typical spacing distances for off-site soil gas monitoring probes.

Table 8.1: Guidance on Typical Off-Site Monitoring Gas Probe Spacing

Site Description	*Recommended Monitoring Gas Probe Spacing (m)*	
	Minimum	*Maximum*
Uniform low permeability strata (e.g., clay); no development within 250 m	50	150
Uniform low permeability strata (e.g., clay); development within 250 m	20	50
Uniform low permeability strata (e.g., clay); development within 150 m	10	50
Uniform matrix dominated permeable strata (e.g., porous sandstone); no development within 250 m	20	50
Uniform matrix dominated permeability strata (e.g., porous sandstone); development within 250 m	10	50
Uniform matrix dominated permeability strata (e.g., porous sandstone); development within 150 m	10	20
Fissure or fracture flow dominated permeable strata (e.g., blocky sandstone or igneous rock); no development within 250 m	20	50
Fissure or fracture flow dominated permeable strata (e.g., blocky sandstone or igneous rock); development within 250 m	10	50
Fissure or fracture flow dominated permeable strata (e.g., blocky sandstone or igneous rock); development within 150 m	5	20

Source: SEPA, 2004

It is recommended that migration control systems be designed to cover the entire migration "window" surrounding the site. The migration window is defined as the zone in the soil surrounding the landfill extending from the ground surface down to a natural migration boundary (i.e., water table or low permeable soil).

A number of LFG migration control technologies are available. These include passive venting systems, barrier systems, and active LFG extraction systems, as described in Section 4.2.