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An Introduction to Operation and Maintenance of Landfill Gas Systems

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1. INTRODUCTION. An operation and maintenance (O&M) plan for a landfill gas collection system should be prepared that addresses the following:

- Extraction wells;
- LFG monitoring probes;
- Condensate collection and treatment; and
- Flare station.

A site-specific monitoring program should be established that is flexible and performance based. LFG needs to be monitored on a regular basis to enable adjustments to be made to the wells to maximize extraction, prevent migration, and minimize drawing oxygen into the landfill. The procedures need to be regularly evaluated as changing climatic and operational conditions can have an effect on the results obtained. More detailed information on the O&M of LFG collection systems can be found in the reference entitled “Landfill Gas Operation and Maintenance Manual of Practice (SWAMA, 1998)”.

2. EXTRACTION WELLS.

2.1. COMPOSITION OF AIR. Knowledge of the composition of air can be used as an aid in monitoring and adjusting the flows from LFG extraction wells. The following provides a typical composition of air:

- Nitrogen (N2) 78.084%
- Oxygen (O2) 20.947%
- Argon (Ar) 0.934%
- Carbon dioxide (CO2) 0.033%
- Neon (Ne) 18.2 parts per million (ppm)
- Helium (He) 5.2 ppm
- Krypton (Kr) 1.1 ppm
- Sulfur dioxide (SO2) 1.0 ppm
- Methane (CH4) 2.0 ppm
- Hydrogen (H2) 0.5 ppm
- Nitrous oxide (N2O) 0.5 ppm
- Xenon (Xe) 0.09 ppm
- Ozone (O3) 0.07 ppm
- Nitrogen dioxide (NO2) 0.02 ppm
- Iodine (I2) 0.01 ppm
- Carbon monoxide (CO) trace
- Ammonia (NH3) trace

As can be seen above, nitrogen, oxygen, argon, and carbon dioxide are the predominant components (99.998%) of air. The ratio of nitrogen to oxygen is 3.8:1. The ratio of total air to oxygen is 4.8:1. This knowledge can be used to estimate the amount of air intrusion through the cover or to check for leakage into the collection piping.

2.2. MONITORING. Balancing a LFG extraction well system is best accomplished by monitoring the well field regularly. Each well should be monitored at least monthly for LFG composition, vacuum, flow, and temperature. The monitoring should be more frequent if the LFG is used as fuel in an energy recovery project. LFG composition measurements may include percentages of methane, carbon dioxide, oxygen, nitrogen, and other constituent gases. If excessive vacuum is applied to a LFG well, ambient air intrusion through the cap or well seals will occur. This phenomenon is called over-pull. Over-pull kills anaerobic bacteria and may increase the chance for an underground fire. The best way to monitor for ambient air intrusion at extraction wells is to check the concentration of nitrogen. Any amount of nitrogen in a well is a sign of ambient air intrusion. Unfortunately, monitoring for nitrogen requires analysis by a gas chromatograph, which is time consuming and expensive. The presence of oxygen is also an indicator of ambient air intrusion; however, oxygen is stripped away as it travels through the refuse by bacteria. Therefore, the concentration of oxygen measured at the wellhead is typically reduced, and is not an exact measure of ambient air intrusion.

2.3. BALANCING TECHNIQUES. Techniques for balancing LFG flow rate for a group of extraction wells include the following:

2.3.1. VALVE POSITION. Valve position gives a very rough indication of flow rate assuming similar air permeabilities throughout the landfill (or a correlation of valve position versus flow rate for individual wells has been developed).

2.3.2. WELLHEAD VACUUM. Wellhead vacuum can provide a very rough estimate of radius of influence and flow rate if a pilot study or historical data has provided a correlation between wellhead vacuum and flow/radius of influence.

2.3.3. LFG FLOW RATE. LFG flow rate is often measured using a fixed device such as a pitot tube, orifice plate, or by some portable measurement device such as an anemometer. The required flow rate at each well and for the system as a whole is generally determined empirically based on LFG composition readings.

2.3.4. LFG COMPOSITION. Methane, nitrogen, and oxygen are the key parameters measured. Carbon dioxide is often measured in order to indirectly determine nitrogen content, since nitrogen is difficult to measure. Carbon monoxide can be monitored as an indicator of a landfill fire (carbon monoxide is generated if the LFG temperature begins to rise).

2.3.5. SUMMARY. The best way to balance a LFG extraction system is by monitoring some or all of the parameters listed above at each individual well, plotting trends over several monitoring events, and reviewing the trends to pick the individual well settings that meets the goals of the extraction system.

2.4. PRIMARY WELL FIELD MONITORING. Primary wells are those wells located within the landfill boundaries. The frequency of LFG well field monitoring will vary depending upon field requirements and conditions. Normal monitoring frequency for a complete field monitoring session will vary from once a week to once a month. Well field monitoring should not normally need to be extended beyond once a month for active systems.

2.5. PERIMETER LFG MIGRATION CONTROL. Perimeter collection wells are located at the edge of the landfill to prevent the off-site migration of LFG. Perimeter systems extract poor quality LFG that is often high in oxygen due to ambient air intrusion at the interface of the landfill and native soil. Operating objectives for the perimeter system are different than the primary wells of a LFG extraction system. The perimeter system provides a final opportunity to capture LFG before it migrates beyond the boundaries of the landfill. The frequency of monitoring is based on the perceived threat to the public from the off-site migration of LFG. Some perimeter migration systems are monitored daily if perimeter LFG monitoring probe readings are above established limits. In other cases, the perimeter system is monitored at the same frequency as the rest of the extraction system. Exceedences of compliance levels for % methane or % lower explosive limit (LEL) at the monitoring probes would likely dictate the need to increase extraction flow rates around the areas of the measured exceedences. Chronic exceedences after increasing extraction flow rates may dictate the need to re-evaluate the well design layout and possibly install additional extraction wells at closer spacings.

2.6. BAROMETRIC PRESSURE. The amount of LFG migrating beyond the boundaries of a landfill changes as atmospheric pressure varies, even when the LFG production rate is constant. Methane concentrations and LFG pressure measurements in a monitoring probe may be influenced by changes in barometric pressure. There may be a delay of several hours before equilibrium occurs, and this should be taken into consideration when assessing the collected data.

2.7. LEACHATE BLOCKAGE OF EXTRACTION WELLS. Leachate blockage of LFG extraction wells is occasionally a problem. Leachate in the well is either the result of a high water table or perched liquid that is migrating along a low permeable daily cover soil or a low permeability waste and draining into the well. Once liquid is in the well, it usually drains out slower than it drains in, creating a high leachate level in the well. The following procedure for clearing wells blocked with leachate is suggested:

- Discontinue LFG extraction.
- Remove the leachate using a temporary down-hole pump or a vacuum truck for wells that are less than 6.096 m (20 feet) deep.
- If leachate continues to flow into the well, or it takes more than five days to remove the liquid, then a permanent method of leachate collection is probably required.

Permanent dual LFG/leachate extraction systems typically include the following:

- One well casing for LFG extraction and leachate extraction;

- LFG extraction wellhead installed at the top of the well casing;
- Pneumatic or electric pump installed in the well casing (pneumatic pumps are most common due to the explosive environment); and
- Discharge piping headers.

Discharge of the LFG and leachate from the well is typically combined into one header. However, if the LFG and leachate are combined in one header, typically the header is a larger diameter than if it were simply transporting LFG. In addition, condensate dropouts or low points in a combined header system must be enlarged to allow for the added liquids.

2.8. LANDFILL FIRES. Spontaneous combustion is the process by which the temperature of a material is increased without drawing heat from an outside source. In landfills, the process occurs when the waste is heated by chemical oxidation via aerobic biological decomposition to the point of ignition. Landfill fires are most easily controlled by limiting ambient air intrusion into the landfill, which will serve to minimize aerobic biological activity that generates heat and elevates the landfill temperature. Atmospheric air is 21% oxygen and 79% nitrogen. LFG composition typically is measured with a portable LFG analyzer. Instrument readings include percent methane, carbon dioxide, and oxygen. The balance is assumed to be nitrogen. The nitrogen-to-oxygen ratio for atmospheric air is 79/21, which equates to a ratio of 3.76. LFG extraction wells are monitored in order to evaluate system performance. If the oxygen content reaches 3.2% or the nitrogen content is 12% ($3.2 \times 3.76 = 12$ %), ambient air intrusion may be occurring that can create conditions conducive to initiating a landfill fire. If the following is noted during the monitoring of extraction wells, it should be a signal to technicians that conditions are potentially favorable for a landfill fire to occur and increased monitoring or corrective action should be taken:

- Oxygen content is increasing and exceeds 3.2 percent by volume.
- Nitrogen content is increasing and exceeds 12 percent.
- LFG temperature is increasing and exceeds $60^{o}C$ ($140^{o}F$).

The following parameters are evidence of a fire within the landfill interior:

- LFG temperature exceeds 75^{o}C (167^{o}F).
- Rapid settlement of the cover system.
- Carbon monoxide levels are greater than 1,000 ppm.
- Combustion residue is present in the LFG piping runs.

Landfill fires can be prevented by:

- Decreasing the extraction rate at individual wells, which will in turn decrease ambient air intrusion.
- Preventing ambient air intrusion by decreasing the air permeability of the
- landfill cover.
- Increasing the monitoring frequency of the extraction wells and probes.

If an interior landfill fire occurs, fire control may be accomplished through the injection of nitrogen or carbon dioxide into the landfill subsurface to suffocate the fire. Extraction of LFG should also be discontinued to prevent oxygen from being drawn into the landfill (Israel, 2000).

2.9. VERTICAL PROFILING. A perimeter LFG extraction well will typically penetrate several geologic layers, with each layer exhibiting different properties. LFG will flow to the well through the path of least resistance (usually through the coarser soils). Vertical profiling within the extraction well can be used to determine what geologic strata methane or other gases are traveling through. The profiling involves using a probe to take continuous LFG samples and measuring its velocity at all levels throughout the length of the well. The results may help provide a better picture of where additional extraction wells should be screened to minimize off-site migration of LFG.

2.10. INSPECTION AND MAINTENANCE. Inspection and maintenance should be performed during each sampling event. Each LFG extraction well and monitoring probe should be inspected for damage. Any damage should be noted on the field sampling record and repaired. Piping and associated equipment should be inspected for damage and settlement. Piping runs may develop low spots due to differential settlement. Additional drains or drip legs will need to be installed at these low spots if settlement occurs. Piping needs to be checked for leaks and degradation due to UV exposure. Plastic pipes manufactured without UV resistance may need periodic painting/coating to prevent cracking due to UV degradation.

3. LFG MONITORING PROBES.

3.1. MONITORING PROCEDURES. The reference entitled “Landfill Gas Operation and Maintenance Manual of Practice (SWANA, 1998)” provides excellent information on sampling LFG perimeter monitoring probes and interpretation of the collected data. Monitoring probes are typically placed outside the waste mass at the property boundary or the point of regulatory compliance. LFG monitoring probes are typically tested for the following parameters:

3.1.1. PROBE LFG PRESSURE. The vacuum/pressure should be recorded by connecting the pressure gauge to the quick connect valve.

3.1.2. LFG CONCENTRATIONS. Purge the probe of two volumes of LFG and then collect vapor samples for measurements using the appropriate instrumentation and record the appropriate concentrations (methane, carbon dioxide, oxygen, nitrogen, hydrogen sulfide, etc.).

3.1.3. GROUNDWATER LEVEL. This should be recorded, if applicable.

3.1.4. SUMMARY. The technicians name, date, time, ambient temperature, weather conditions, barometric pressure, and probe number are also typically recorded in a field report form during a sampling event. As mentioned previously, LFG is a mixture of various potential vapor phase constituents, including non-methane organic compounds (NMOCs). Periodic monitoring of specific NMOCs may be required to verify no off-site migration.

3.2. IN-PROBE ACCEPTABLE LEVELS. In-probe methane levels should be monitored with an infrared LFG analyzer. A methane concentration greater than 5% by volume in a monitoring probe indicates the potential for explosive conditions. Adjustments to the LFG collection system operating procedures should be made if methane levels exceed some specified level (typically 0.5% to 5%) at the perimeter of the landfill or in structures such as vaults, manholes, sumps, or buildings.

3.3. MONITORING FREQUENCY. The frequency at which probes are monitored is typically once per week to once per quarter. However, when LFG concentrations exceed acceptable levels, probes should be monitored at an increased frequency (as frequently as once per day). If monitoring probe readings indicate LFG is migrating off-site, consideration should be given to monitoring off-site structures to ensure LFG is not building up in these structures. Examples of structures that should be monitored include basements, crawl spaces, wells, sumps, subsurface vaults, and any other enclosed location where LFG could potentially collect.

3.4. ENCLOSED STRUCTURE MONITORING. LFG monitoring must be conducted in any on-site enclosed structures located on top of or adjacent to the landfill. Enclosed areas that contain a potential sparking device (wiring, electrical motor, etc.) should also be monitored routinely. Buildings are typically monitored at least quarterly with a portable LFG instrument at the following locations:

- The base of each exterior wall;
- Underground utility lines leading into the building; and
- Ambient air in each room of the building.

A continuous monitoring device with alarm should be installed in structures that are frequently occupied. Remedial actions (e.g., venting or increasing LFG extraction rate) should be taken if methane concentrations exceed 25% of the LEL (i.e., 1.25% methane by volume).

3.5. SURFACE EMISSION MONITORING. Surface emission monitoring is typically performed at large municipal solid waste (MSW) landfills that do not have a geosynthetic barrier in the landfill cover. Surface emission monitoring is not commonly performed on projects, because the waste typically found in some landfills does not produce large amounts of LFG. A summary of surface emission testing procedures can be found in the reference entitled “Landfill LFG Operation and Maintenance Manual of Practice (SWANA, 1998)”.

4. LFG MONITORING EQUIPMENT. Common portable measuring instruments for pressure include micromanometers and magnehelic gauges. A combustible gas indicator (CGI) can be used in above-grade monitoring situations when there is sufficient oxygen for the instrument to operate correctly. Below-grade monitoring, as well as situations where oxygen has been displaced by LFG, require use of an infrared gas analyzer. Several specific instruments are common to LFG control systems that should be considered during design. These include:

- CGI;
- PID;
- Infrared gas analyzers;
- Colorimetric tubes; and
- Field GCs.

Portable field GCs can be used for on-site monitoring. However, this is an expensive option, because laboratory facilities and trained chemists are required for monitoring operations. CGIs operate on two different principles, catalytic oxidation and thermal conductivity. Some CGIs operate by both methods; however, surface emission sampling will focus on the catalytic oxidation method, as the thermal conductivity detection method is used primarily for LFG measurements in migration probes. The catalytic oxidation type of CGI measures the concentration of a combustible gas in air, indicating the results in parts ppm or in % LEL. These readings are often taken in conjunction with oxygen readings. These instruments operate by the detection method of a platinum filament being heated by the combustion of the LFG being sampled. The increase in heat changes the resistance of the filament that results in an imbalance of the resistor circuit called the "Wheatstone Bridge". This imbalance is measured via the analog or digital scale of
the unit. Some CGIs have two scales, one measuring in ppm and the other in % LEL. Limitations to this equipment are as follows:

- The reaction is temperature dependent and is, therefore, only as accurate as the incremental difference between calibration and ambient sampling temperatures.
- Sensitivity is a function of the physical and chemical properties of the calibration LFG; therefore, methane should be used as the calibration standard.
- The unit will not work in oxygen deficient or oxygen enriched atmospheres.
- Certain compounds such as lead, halogens, and sulfur compounds can damage the filament. Silicone will destroy the platinum filament. Since LFG contains some halogenated (chlorinated) hydrocarbons, the meter should be calibrated often to methane and serviced annually if it used on a routine basis to monitor methane surface emissions. In addition, if the meter contains an oxygen cell, this cell can be fouled by the carbon dioxide found in LFG, and replacement of the cell may be required frequently.

Advantages are that CGIs are small and portable, self-contained for field use, have an internal battery, are easy to use, and typically are intrinsically safe.

4.1. COMBUSTIBLE GAS INDICATOR/THERMAL CONDUCTIVITY METHOD.

4.1.1. HIGH CONCENTRATIONS OF METHANE (greater than 100% of the LEL or 5% methane by volume) are measured with a CGI using a thermal conductivity (TC) sensor. This type of sensor is often used with a catalytic oxidation sensor in the same instrument. The catalytic sensor is used to detect concentrations less than 100% of the LEL. At higher concentrations, the TC sensor is used to measure up to 100% methane by volume. The TC sensor is composed of two separate filaments heated to the same temperature. Combustible gases enter only the TC side of the filament; the other filament (compensating) maintains a steady heated temperature. Incoming gases cool the TC filament, and as the filament temperature decreases, the resistance across the Wheatstone Bridge also decreases, resulting in a meter reading. Instruments using a TC sensor do not require oxygen for a valid reading, as burning of the LFG is not involved.

4.1.2. COMBUSTIBLE GASES VARY in their ability to cool the TC filament. Methane absorbs heat well and efficiently cools the filament, and is the calibration gas of choice when using the instrument to measure methane in LFG. However, since LFG is comprised of a combination of different constituents, readings on the meter will vary depending on the concentration of the various constituents in the sample. Gases which cool the filament more effectively than methane (as the calibration gas) will display a higher percent gas reading than is actually present.

4.1.3. THE CONVERSE IS ALSO TRUE, that gases which are less effective in cooling the filament will display a lower percent gas reading than is actually present. It is important to realize that certain gases can cool the filament and not be combustible. Carbon dioxide absorbs heat readily and can produce a false positive reading. Meter sensitivity to carbon dioxide varies from manufacturer to manufacturer, so one should be very familiar with the technical information supplied with the equipment. With some meters, calibration with a methane/carbon dioxide mixture can help alleviate the interference of carbon dioxide.

4.1.4. THERE MUST BE SUFFICIENT oxygen present in the atmosphere being analyzed for a CGI to work correctly. Therefore, the CGI is a poor instrument selection for monitoring explosive conditions (methane concentrations) directly, since oxygen levels can be very low.

4.2. FLAME IONIZATION DETECTOR (FID)/ORGANIC VAPOR ANALYZER (OVA).

4.2.1. FIDS MEASURE MANY ORGANIC gases and vapors, and unlike PIDs will detect methane. Some FIDs are commonly referred to as OVAs. FIDs operate by a sample being ionized in a detection chamber by a hydrogen flame. A current is produced in proportion to the number of carbon atoms present. There are two modes of operation, the survey mode and the GC mode. For methane surface emissions, the survey mode is used if both are available on the instrument. Since the sensitivity of the instrument depends on the compound, methane should be used as the calibration standard. These instruments are less rugged in the field than the CGIs and require hydrogen gas cylinders for use.

4.2.2. THE ADVANTAGES TO THE FIDS ARE fast response in the survey mode, wide sensitivity (1 to 100,000 ppm), and some models offer a telescopic probe with cup intake that minimizes operator exposure to LFG and minimizes the effects of windy conditions at the site. The "cup" probe design can also serve to reduce the near surface dilution effects of the wind by providing a small sampling chamber when the probe is held normal to the surface. The zero on the FID should be checked daily, since it often drifts upward during use.

4.3. INFRA-RED (IR) ANALYZER.

4.3.1. INFRARED IS A RANGE OF FREQUENCIES WITHIN THE ELECTROMAGNETIC SPECTRUM. The infrared frequencies act to set the molecules of chemicals into vibration. Chemicals have a vibration energy that is specific to that chemical. When the gas interacts with IR radiation, it absorbs a portion of the IR energy. The absorption spectrum for that gas is the pattern of vibrations from the atoms/functional groups, along with the overall molecular configuration. Specific gases will demonstrate optimal absorption within a small IR range. Since absorption ranges have been classified for different gases, it is possible to filter out all but a small part of the spectrum and measure the vapor constituent known to be present. The advantage of IR analyzers is that the high carbon dioxide levels found in landfills will not affect methane readings.

4.3.2. MOST IR ANALYZERS ARE SINGLE BEAM SPECTROPHOTOMETERS. Portable IR meters available for the field are capable of measuring up to 100% by volume methane and carbon dioxide. The concentrations of these gases are detected by infrared absorption. Oxygen concentration is measured by an electrochemical cell. These meters are designed to measure large concentrations of methane and carbon dioxide and are not sensitive at concentrations less than 0.5%. A field calibration gas should be used to verify the accuracy of the monitoring results. A combination gas of 15% methane and 15% carbon dioxide is a common mixture when using the equipment to test migration probes. Higher concentrations of calibration gases should be used if monitoring levels in LFG extraction wells.

4.4. COLORIMETRIC INDICATOR TUBES. If necessary for regulatory or health and safety purposes, specific NMOCs can be measured in the field using colorimetric tubes that are calibrated for specific chemicals or family of chemicals. Alternatively, samples can be collected for laboratory analysis using Summa canisters for off-site laboratory analysis of specific organic constituents. Colorimetric tubes are typically used as a screening tool only for measuring ambient air concentrations for health and safety or other purposes, since the accuracy of their concentration readings can have an error rate as great as 25% and are subject to various interferences. Colorimetric tubes are capable of measuring air concentrations within a specified range, so some knowledge of the anticipated constituent concentration is needed to select an appropriate tube for use. Previous measurements using field screening instrumentation (e.g., PID) can sometimes be used to estimate the expected concentration. If unknown, then colorimetric tubes representing different concentration ranges should be used for the initial measurements.

4.4.1. VARIOUS MANUFACTURERS EXIST FOR COLORIMETRIC TUBES that offer different chemical and concentration range capabilities. Each manufacturer has its own hand sampling pump that must be used with its brand of colorimetric tubes. It is beneficial to review each manufacturer’s line of colorimetric tubes to identify the one(s) that best fit the measurement needs (i.e., chemical specificity and concentration range). Sampling pumps that match the selected colorimetric tube can either be rented or purchased, depending on the frequency of need. The instructions for each colorimetric tube should be carefully reviewed before use to identify the proper number of sample pulls, calibration of tube reading to actual concentrations, other chemicals that can interfere with or skew the measurements, and other use requirements.

4.4.2. TO PERFORM A MEASUREMENT USING COLORIMETRIC TUBES, an LFG sample from the piping line must first be collected (if consistent measurements cannot be obtained directly from the line). The easiest method for collecting a LFG sample is to use a portable vacuum pump to draw a LFG sample from the piping line into a Teflar bag. The vacuum capacity of the sample pump must be greater than the line vacuum to pull a sample that is not diluted by ambient air (all connections must also be tightly sealed). A short tubing connection can then be used between the Teflar bag and colorimetric tube to make a tight seal that will allow the hand drawn sample to be drawn through the tube. The change in indicator color allows the measurement to be read off the tube and then converted to the actual concentration measurement in accordance with the instructions.

5. CONDENSATE COLLECTION AND TREATMENT. Disposal of LFG condensate is an issue common to most landfill sites in humid climates. Methods of disposal for LFG condensate include the following.

5.5.1. TREATMENT. LFG condensate can be collected from the various condensate collection points and treated prior to release. When a liner system is present, condensate is commonly combined with landfill leachate and disposed of in the same manner as the leachate.

5.5.2. INJECTION/RECIRCULATION. Federal solid waste regulations allow leachate and condensate recirculation if the landfill has a composite liner system. Recirculation employs the absorptive properties of the MSW to hold the condensate within the material. However, once the MSW reaches field capacity or decomposes, condensate recirculation in that portion of the site is no longer effective and will short-circuit directly into the leachate collection system. Condensate injection/recirculation is being practiced at numerous sites, and is accomplished primarily through drainage into the collection well field at moisture traps.

5.5.3. ASPIRATION INTO THE LFG FLARE. This method of condensate disposal consists of spraying it directly into a LFG enclosed flare. This technology can typically destroy up to one gallon per minute of condensate. The popularity of this method of disposal is increasing. Aspiration of condensate into LFG flares has been accomplished on several sites and appears to be an efficient and effective method of condensate disposal, provided the condensate is non-hazardous. Flare destruction efficiency is dependent on the following: flare temperature, flare residence time, and turbulence. Tests must be conducted to ensure that condensate aspiration will not cause an unsatisfactory drop in operating temperature of the flare. Analysis of LFG condensate quality, pre-aspiration flare emissions quality, and emission quality during aspiration are typically required. Condensate is transferred from a liquid state to vapor upon aspiration into the flare. This requires approximately 12,000 BTUs of energy per gallon of condensate. With the aspiration of condensate into the flare unit, draft velocities are created during condensate evaporation that could significantly change the retention time on which the original flare design was based. Recent applications of condensate aspiration, however, have not caused a decrease in destruction efficiencies. Only enclosed flame flares provide adequate residence time for condensate aspiration. Collected condensate is typically collected either for on-site treatment or off-site disposal at a POTW or commercial disposal facility.

5.5.4. SUMMARY.

5.5.4.1. DATA THAT HAVE BEEN PUBLISHED shows that the aqueous phase concentrations of LFG condensate are generally below the Resource Conservation and Recovery Act (RCRA) Toxic Compound Leachate Procedure (TCLP) criteria, which should allow for disposal as a non-hazardous waste. If a non-aqueous phase liquid is present in the condensate, this fraction has been found to typically exceed the RCRA characteristic ignitability criteria, which would require disposal as a hazardous waste. Landfills that have been operating principally as MSW landfills are rarely found to have a significant non-aqueous phase fraction in its condensate.

5.5.4.2. IN PREPARING THE PROPER MANAGEMENT PLAN for condensate, it should first be determined if the condensate contains two phases. If the condensate does have a non-aqueous phase, management plans should include a phase-separation process to separate the non-aqueous phase liquids from the aqueous phase fraction.

5.6. FLARE STATION. Maintenance and inspection of a blower/flare station is commonly performed on a weekly basis. Activities include LFG flow rate alteration, mechanical repair, lubrication, pilot/auxiliary fuel refill, and equipment cleaning. The total blower LFG flow rate at the station may need to be adjusted due to changes in the flow rate or to eliminate off-site migration. Partially opening or closing the valve on the blower inlet side usually accomplishes flow rate adjustments. The following paragraphs describe additional monitoring requirements associated with various components of a blower/flare system.

5.6.1. BLOWER.

5.6.1.1. MONITORING REQUIREMENTS. Inspection of this unit should include recording the flow rate and pressure of the system for comparison against the manufacturer's blower curve. The pressure drop across the blower should also be monitored using permanent gauges or portable magnehelic gages at entrance and exit ports on the blower.

5.6.1.2. FREQUENCY. Monthly inspections should be made, unless recommended otherwise by the manufacturer, to ensure that operating parameters are within expected ranges. After the first year and every second year thereafter (at a minimum), comprehensive inspections by a representative of the manufacturer should be made to determine if parts are wearing at an excessive rate. Should the equipment warranties recommend more frequent inspection, this frequency should be upgraded to the recommended levels.

5.6.2. FLAME ARRESTOR.

5.6.2.1. MONITORING REQUIREMENTS. Monitoring of the flame arrestor consists of measuring the head loss across the flame arrestor to ensure that operating head losses are not significantly above or below the losses expected for the unit. In general, flame arrestors require little maintenance (cleaning) and are rarely replaced in operating systems.

5.6.2.2. FREQUENCY. INSPECTION OF the flame arrestor can be infrequent since it does not have any moving parts. Monthly inspections conducted with several other portions of the LFG collection and flaring system will be adequate.

5.6.3. FLARE.

5.6.3.1. MONITORING REQUIREMENTS. The flare unit should be capable of operating at >98 percent destruction requirement efficiency (DRE) for methane. In addition to DRE monitoring, the flare inlet should be inspected for:

- LFG flow rates;
- LFG supply pressure;
- Minimum operating temperatures; and
- Influent LFG parameters (including methane, carbon dioxide, oxygen, and regulated NMOCs).

5.6.3.1.1. MANUFACTURER'S RECOMMENDATIONS for minimum and maximum values for these parameters should be determined for the specific flare unit. Manufacturers typically specify a minimum supply pressure for a given flow rate. Inspection should include referencing operating parameters of flow rate and pressure drop against the design curve established for the flare. Inspection should verify that a sufficient delivery pressure is being supplied for the observed flow rate.

5.6.3.1.2. THE TEMPERATURE OF THE FLARE UNIT should be monitored to ensure that this parameter is being maintained. The methane content and flow rate of the influent LFG should be inspected as described below. Excessive operating temperatures should not occur, since the flare unit should be designed with automatically adjusting air intake louvers. However, if excessive temperatures (i.e., > 980 ^{o}C [1,800 ^{o}F]) are observed, controls for these louvers should be inspected.

5.6.3.1.3. LFG PARAMETERS. Methane, oxygen, and carbon dioxide levels should be recorded to verify that the operating concentrations are within acceptable ranges for the flare.

5.6.3.2. FREQUENCY. Monthly monitoring is recommended unless suggested otherwise by the manufacturer. Certain operating parameters, including LFG flow rates, LFG supply pressure, minimum operating temperature, and inflow LFG parameters should be measured and recorded more regularly.

5.7. MAINTENANCE REQUIREMENTS. The O&M of a LFG management system should be structured to maintain the operation goals (e.g., 98% reduction of NMOCs). An O&M program can be divided into the following categories:

- Routine O&M;
- Non-routine maintenance; and
- Emergency services.

5.7.1. ROUTINE MAINTENANCE. A routine maintenance program includes periodic maintenance and preventive maintenance. During routine maintenance, testing and checking of the following components should be performed:

- Extraction wells;
- Collection header;
- Monitoring wells and probes;
- Oil change for blower;
- Flame arrestor cleaning;
- Condensate handling;
- LFG detection system;
- Pilot/auxiliary fuel; and
- Periodic leak testing or screening using field instrumentation (e.g., FID) of major valves and equipment for LFG losses.

5.7.1.1. PILOT/AUXILIARY FUEL REFILLING and equipment cleaning should be performed at least weekly. In particular, the combustion mechanism requires regular cleaning to assure that the gases are burned completely. Air and oil filters should be checked and changed routinely after a specific number of hours as recommended by the manufacturer. This will prevent more costly and time consuming repairs down the line. Preventive maintenance includes blower bearing lubrication and flame sensor cleaning.

5.7.1.2. REGULAR OIL CHANGES should also be performed on the blower (positive displacement blowers), compressor, gearbox, and combustion systems. This will help ensure that the process operates smoothly and efficiently, and it also reduces the chance of costly downtime associated with more significant repairs.

5.7.2. NON-ROUTINE MAINTENANCE. Non-routine maintenance activities consist of corrective repair or maintenance of work identified during the routine inspection. These may include:

- Repair or replacement of failing components; and
- Testing and adjusting the collection system if air intrusion is observed.

5.7.3. EMERGENCY SERVICES. Emergency services are those requiring immediate response to prevent human injury, property damage, or regulatory noncompliance. These activities may include:

- Responding to system failure or shut down; and
- Executing contingency plans, if required.

5.7.4. EQUIPMENT CALIBRATION. The instruments used for measurements are customarily correct to within a certain percentage of the “true” value. This accuracy is generally expressed by the instrument’s manufacturer as the “inherent error of the device”. Instrument calibration does not lead to elimination of error; it does allow the equipment to provide representative numbers for the subject measurement to the best of the machinery’s ability. Routine calibration and servicing are necessary to assure the quality of measurements made using these instruments. Permanently installed equipment used for measurements should be calibrated according to the manufacturer's recommendations and the quality assurance program.

5.7.5. SYSTEM ADJUSTMENTS BASED ON MONITORING DATA. Landfill operators have to adopt a variety of monitoring parameters, techniques, and frequencies to balance the vacuum system to optimize the volume of collected LFG and/or contain the LFG in all parts of the landfill. For example, the LFG flow rate at the station may need to be reduced due to landfill aging and corresponding reductions in LFG generation. Throttling the control valve on the blower inlet side or at individual extraction wells usually accomplishes the necessary adjustments to reduce total system LFG extraction rate.

5.8. RECORD-KEEPING AND CONTINGENCY PLAN. All inspection and maintenance records must be saved and kept at a location that is easily accessible. If measured methane levels at the compliance points are in excess of regulatory levels or the flare emissions are out of compliance, then the facility must report the results to the appropriate regulatory agency and take steps to correct the situation. An increased frequency of monitoring should then be made until the situation is corrected.

6. REGULATORY REQUIREMENTS

6.1. INTRODUCTION. This is a discussion of representative environmental regulations as they pertain to landfill gas (LFG) emissions. Regulations include federal Resource Conservation and Recovery Act (RCRA) solid and hazardous waste management requirements, Clean Air Act (CAA) requirements, and Clean Water Act (CWA) requirements associated with LFG generation and emissions. Many of the regulations discussed below apply to currently operating or recently closed landfills, and may not be appropriate for landfills that stopped receiving wastes prior to 1987. It is important that personnel know the federal and state regulatory framework under which the LFG control is being done (e.g., general non-hazardous solid waste/refuse disposal, CERCLA remediation, RCRA Corrective Action, etc.) in order to determine which, if any, of the following requirements must be met. The discussion of applicable regulations and legal requirements here is only meant to make the reader aware of some of the many requirements that may potentially apply to LFG emissions and disposal of condensate. This discussion is not intended to stand in place of any applicable law, regulation, or standard, and may not reflect the current standards embodied in law and regulation. Statutes and regulations are the controlling rule of law and should always be consulted to determine how they apply to a particular set of circumstances to assure compliance before action is taken.

6.2. SUMMARY OF APPLICABLE REGULATIONS. Regulations affecting LFG management are addressed under various legislation, which may include the following:

- RCRA, which regulates solid and hazardous waste management, such as the landfill itself;
- CAA, which regulates air emissions; and
- CWA, which regulates discharges of water such as LFG condensate and storm water runoff. A brief summary of potential federal regulations applicable to LFG management follows.

6.3. RESOURCE CONSERVATION AND RECOVERY ACT REGULATIONS. Under RCRA, if LFG is emitted or condensate is treated and/or disposed, RCRA requirements may have to be met. Primary RCRA requirements pertaining to LFG emission and condensate disposal are found in the following regulations:

- 40 CFR Part 258 [regulations for LFG emissions from MSW (non-hazardous) landfills];
- 40 CFR Parts 260-261 [regulations for characterization and disposal of condensate as a hazardous waste];
- 40 CFR Part 262 [regulations pertaining to hazardous waste generator requirements]; and
- 40 CFR Part 268 [regulations for hazardous waste land disposal restrictions].

6.3.1. RESPONSE ACTIONS taken under CERCLA (IRP, FUDS, BRAC or Superfund) are not required to obtain RCRA permits for on-site treatment or storage. However, compliance with substantive requirements, such as physical storage requirements and containers, will most likely have to be met.

6.4. CLEAN AIR ACT REGULATIONS. Since passage of the Federal CAA in 1970, many rules and regulations have been adopted that could potentially affect LFG operations. The applicability of these rules and regulations are governed by specific factors, such as the implementation schedule of the rule, size of the facility, the equipment and type of operations conducted at the site, and the emissions from these operations. For example, to establish whether the CAA New Source Performance Standards (NSPS) or Engineering Guideline (EG) controls are applicable to a specific landfill, the non-methane organic compound (NMOC) maximum annual emissions must be greater than or equal to 50 million grams per year (Mg/yr). If the maximum annual NMOC emission rate is greater than or equal to 50 Mg/yr and the design capacity and applicability cut-off dates are triggered, the landfill may be subject to the NSPS or EG. Personnel need to be familiar with the specific requirements of each regulation prior to deciding whether or not the requirements apply to their project. Potentially applicable CAA regulations include:

- 40 CFR Part 60 [NSPS];
- 40 CFR Part 63 [National Emission Standards for Hazardous Air Pollutants (NESHAPs)];
- 40 CFR Part 70 [Title V operating permits]; and
- state and local air quality regulations.

6.4.1. USEPA DESIGNED the Title V operating permit program as a central mechanism to regulate emissions, monitoring data needs, compliance schedules, fee payments, and other conditions associated with the issuance, compliance, and enforcement of operating permits. Personnel involved in designing LFG control systems should ensure that the customer is made aware of calculated LFG emissions and what control devices will be used to control them. This information is important to the customer who is ultimately responsible for determining the need to obtain a Title V operating permit or to revise an existing permit. Any questions regarding the need to obtain an operating permit for the LFG control system should be discussed with the customer and the project team.

6.4.2. RESPONSE ACTIONS taken under CERCLA (IRP, FUDS, BRAC or Superfund) are not required to obtain CAA permits for on-site emissions and treatment systems. However, compliance with substantive requirements, such as the attainment of emission criteria and use and design of specific treatment technologies, will most likely have to be met.

6.5. CLEAN WATER ACT REGULATIONS. Under the CWA, if LFG condensate is disposed of by treatment and effluent discharged to regulated “waters of the United States”, a National Pollution Discharge Elimination System (NPDES) discharge permits is required. Separate NPDES regulatory and permit requirements may also cover storm water run-off associated with a landfill. An NPDES permit would most likely include effluent concentrations/limits that must be met based on a state's water quality standards for the receiving surface water body into which the effluent is being discharged. Effluent analyses that may be required as part of an NPDES permit could include:

- Biochemical oxygen demand (BOD);
- Chemical oxygen demand (COD);
- Total organic carbon (TOC);
- Total suspended solids (TSS);
- Ammonia (as nitrogen);
- Temperature;
- pH; and
- Flow.

6.5.1. RESPONSE ACTIONS taken under CERCLA (IRP, FUDS, BRAC, or Superfund) are not required to obtain NPDES discharge permits. However, substantive requirements, such as numerical discharge limits, may still have to be established and met at these sites, especially when condensate is discharged via a point source to regulated “waters of the United States”.

6.5.2. OTHER ANALYSES MAY BE required if other pollutants are expected to be present. Permittees may also be required to test their discharge for toxicity. If the condensate is disposed of by indirect discharge through a publicly owned treatment works (POTW), sewer effluent conditions would be imposed by the local jurisdiction as regulated by local ordinances or federal requirements.

6.6. STATE AND LOCAL REQUIREMENTS. Many states and local authorities have also adopted rules that impact LFG emissions and disposal of condensate. The CAA, RCRA, and CWA all contain provisions that generally subject federal facilities to state and local requirements, both substantive and procedural, controlling the same subject matter as the respective federal laws. States can, and frequently do, have regulations that are more stringent than the federal requirements. It is crucial that personnel know the specific requirements of the state in which the project is located, and whether those requirements apply in a specific circumstance, in order to ensure compliance with applicable regulations.