Other Test Method 51 (OTM-51) - UAS Application of Method 21 for Surface Emission Monitoring of Landfills

Background on OTM-51

This method provides procedures for use of unmanned aerial systems (UAS) to perform surface emissions monitoring for municipal solid waste landfills. This method was submitted by Sniffer Robotics, LLC to EPA's Office of Air Quality Planning and Standards Measurement Technology group for (1) inclusion into the Other Test Method (OTM) category on EPA's Air Emission Measurement Center (EMC) website at: https://www.epa.gov/emc/emc-other-test-methods and (2) consideration as a broadly applicable alternative test method. OTM-51 has now been approved for use at municipal solid waste landfills for a several federal regulations. The list of regulations, the additional caveats and additional information on the broadly applicable approval can be found here.

The purpose of the **Other Test Methods** portion of the EMC website is to promote discussion of developing emission measurement methodologies and to provide regulatory agencies, the regulated community, and the public at large with potentially helpful tools.

Other Test Methods are test methods which have not yet been subject to the Federal rulemaking process. Each of these methods, as well as the available technical documentation supporting them, have been reviewed by the EMC staff and have been found to be potentially useful to the emission measurement community. The types of technical information reviewed include field and laboratory validation studies; results of collaborative testing; articles from peer-reviewed journals; peer review comments; and quality assurance (QA) and quality control (QC) procedures in the method itself. The EPA strongly encourages the submission of additional supporting field and laboratory data as well as comments regarding these methods.

These methods may be considered for use in federally enforceable State and local programs (e.g., Title V permits, State Implementation Plans (SIP)) provided they are subject to an EPA Regional SIP approval process or permit veto opportunity and public notice with the opportunity for comment. The methods may also be considered as candidates for alternative methods to meet Federal requirements under 40 CFR Parts 60, 61, and 63. However, they must be approved as alternatives under 60.8, 61.13, or 63.7(f) before a source may use them for this purpose. Consideration of a method's applicability for a particular purpose should be based on the stated applicability as well as the supporting technical information outlined in the table. The methods are available for application without EPA oversight for other non-EPA program uses including state permitting programs and scientific and engineering applications. As many of these methods are submitted by parties outside the Agency, the EPA staff may not necessarily be the technical experts on these methods. Therefore, technical support from EPA for these methods is limited. Also, be aware that these methods are subject to change based on the review of additional validation studies or on public comment as a part of adoption as a Federal test method, the Title V permitting process, or inclusion in a SIP.

Method History

Initial Posting – 12/14/2022

EPA advises all potential users to review the method carefully before application of this method.

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Scope and Application

1.1. Analytes

Analyte	CAS No.
Methane (CH_4)	74-82-8

1.2. Scope. This method is an alternative test method for determining compliance with the surface methane operational standard for landfills in lieu of the procedures set forth in the regulations presented in Table 1, including EPA Method 21 by reference. Note: This alternative method does not apply to the Tier 4 surface emission monitoring provisions in the following Subparts and cited sections, 40 CFR 60, Subparts XXX and Cf, §60.764(a)(6) and 60.35f(a)(6) and 40 CFR 62, Subpart OOO, §62.16718(a)(6).

TABLE 1: SECTIONS OF 40 CFR PARTS 60, 62 AND 63 CONTAINING APPLICABLE REGULATIONS

WWW (NSPS)	XXX (NSPS)	Cf (EG)	AAAA (NESHAP)	OOO (Federal Plan)
40 CFR §60.753(d)	40 CFR §60.763(d)	40 CFR §60.34f(d)	40 CFR §63.1958(d)	40 CFR §62.16716(d)
40 CFR §60.755(c) - (e)	40 CFR §60.765(c) - (d)	40 CFR §60.36f(c) - (e)	40 CFR §63.1960(c) - (d)	40 CFR §62.16720

1.3. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods and provide a means to bring new technology to quarterly mandated surface emissions monitoring without sacrificing measurement rigor.

2. Summary of Method

2.1. This alternative test method seeks to replicate, to the greatest extent possible, EPA Method 21 and the applicable method clarifications (leak concentration definition, pattern definition, etc.) to EPA Method 21 in the regulations identified in Table 1, but automate Surface Emission Monitoring (SEM) by utilizing a methane detection payload on an unmanned aerial system (UAS) coupled with a ground level to UAS sampling system. The methane detector payload includes a hose and custom nozzle design that, when carried by the UAS, places the nozzle inlet within 5-10 cm of the ground. The UAS transmits the geo-located methane readings to the operator via a wireless communication system. The UAS is used to sample large areas for increased meter readings, each of which are then inspected in the existing method of manual inspection defined in the Subparts listed in Table 1 coupled with EPA Method 21.

3. Definitions

3.1. *Calibration gas* is the reference compound (in this case, methane at nominally 500 ppm) at a known concentration approximately equal to the operational limit of 500 ppm above background.

3.2. *Calibration precision* means the degree of agreement between measurements of the same known value, expressed as the relative percentage of the average difference between the meter readings and the known concentration to the known concentration.

3.3. *Increased meter reading* means a single or series of meter reading(s) above 200 ppm of methane.

3.4. *Response time* means the time interval from a step change in methane concentration at the input of the sampling system to the time at which 90 percent of the corresponding final value is reached as displayed on the instrument readout meter with the instrument configured with all impedance and tubing of the desired field sampling configuration.

3.5. *Instrument-only response time* means the time interval from a step change in methane concentration at the input of the sampling system to the time at which 90 percent of the corresponding final value is reached as displayed on the instrument readout meter with the instrument configured with the minimal amount of tubing for sample transport.

3.6. *Unmanned aerial system (UAS)* commonly known as a drone, is an aircraft without any human pilot, crew or passengers on board. In this context, a UAS includes multiple rotors such that the minimum speed is not limited by stall and can be reduced all the way to zero (hover).

3.7 *Nozzle offset distance* is the horizontal distance between the UAS and the distal end of the nozzle when flown at a fixed above ground level (AGL) and a known nozzle tube length.

4. *Interferences [Reserved]*

5. Safety

5.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to performing this test method. Operators of the UAS must have proper accreditation and clearance to fly UAS at any applicable location.

5.2. Hazardous Pollutants. Methane, leaks of which may be determined by this method, and other compounds commonly found in the municipal solid waste sector may be irritating or corrosive to tissues or may be toxic. Nearly all are fire hazards. Compounds in emissions should be determined through familiarity with the source. Appropriate precautions can be found in reference documents, such as reference No. 4 in Section 16.0 of EPA Method 21.

6. Equipment and Supplies

6.1. The methane detection payload shall have the following specifications:

6.1.1. The methane detection payload shall collect and respond to methane in the air samples; standoff or remote detection technologies are not applicable. Detector types that may meet this requirement include, but are not limited to, flame ionization, non-dispersive infrared absorption (NDIR) and tunable diode laser absorption spectroscopy (TDLAS).

6.1.2. The methane detection payload shall be capable of measuring methane in the range from zero through the increased meter reading up to and above the operational limit of 500 ppm specified in the regulation.

6.1.3. The scale of the methane detection payload shall be readable to ±2.5 percent of the increased meter reading level of 200 ppm methane.

6.1.4. The methane detection payload shall be equipped with a pump that provides the detector a constant sample flow rate. The nominal sample flow rate, as measured at the sample probe nozzle, shall be at least 0.5l /min when the probe is fitted with the full impedance stack of tubing, filters, and nozzle.

6.1.5. The methane detection payload shall have a known instrument-only response time. Instrument-only response time shall be measured for the methane detection instrument prior to being placed into service but does not have to be repeated at subsequent intervals. Instrument-only response time shall be measured by measuring the T90 response time for a minimum of 5 unique tube lengths less than 10m, fitting a linear regression to the measured T90 response times and recording the y-intercept as the instrument only response time if the r^2 of the linear regression is greater than 0.95.

6.2. The ground level sampling system shall have the following specifications:

6.2.1. The ground level sampling system shall be equipped with a single nozzle with inside diameter such that the air speed into the nozzle (per the nominal sample flow rate defined in Section 6.1.4) is at least 0.3 m/s.

6.2.2. The ground level sampling system shall be designed to maximize the time the distal end of the nozzle is within 10 cm of ground level during flight. The nozzle shall be sufficiently weighted and the final 30 cm of the distal end of the nozzle shall be rigid.

6.2.3. The ground level sampling system shall include a hose of sufficient length to drag the nozzle on the ground such that the nozzle is in fluid communication with the methane detection payload.

6.2.4. Before putting the ground level sampling system into service, determine the nozzle offset distance. If the tube length of the ground sampling density changes or the planned AGL for the ground level sampling system changes, repeat measurements to determine the nozzle offset distance.

6.3. The UAS shall have the following specifications:

6.3.1. The UAS shall carry the methane detection payload and the ground level sampling system and use an automated, real-time measurement and control system to fly at a constant AGL of ±1 meter.

6.3.2. The UAS shall include a data acquisition system to record both timestamped drone position (GPS coordinates with an accuracy of no worse than ±2 meters) and methane concentration. The data shall be logged at a frequency of at least the instrument-only response time per 6.1.5.

6.3.3. The UAS shall have a gimbaled camera that is remotely viewable and controllable by a remote operator in near real-time. The camera and display shall have high enough resolution for the operator to discern indicators of elevated concentrations of landfill gas, including distressed vegetation, cracks or seeps in the cover and cover penetrations from the defined flight AGL. Pictures taken shall be georeferenced via metadata or similar to the GPS accuracy defined in 6.3.2.

6.3.4. The UAS shall be in communication with an operator display that shows the methane concentration, as measured by the methane detection payload.

6.3.5. If automated flight plans are used to control the path of the UAS, the UAS shall be controllable by the remote operator to deviate from said flight plans to inspect areas where visual observations indicate potential elevated concentrations of landfill gas, such as distressed vegetation, cracks or seeps in the cover and cover penetrations.

6.3.6. The UAS shall be equipped with a method to control the forward speed to the value determined to meet the limit under Section 8.3.1.

7. Reagents and Standards

7.1. Two gas mixtures are required for methane detection payload calibration and performance evaluation:

7.1.1. Zero Gas. Air, less than 10 parts per million by volume (ppmv) methane.

7.1.2. Methane Calibration Gas. Obtain a known standard in air at a concentration approximately equal to the 500 ppm above background operational limit specified in the regulation.

7.2. Cylinder Gases. If cylinder calibration gas mixtures are used, they must be analyzed and certified by the manufacturer to be within 2 percent accuracy, and a shelf life must be specified. Cylinder standards must be either reanalyzed or replaced at the end of the specified shelf life.

8. Sample Collection, Preservation, Storage, and Transport

8.1. Methane Detection Payload Performance Evaluation. Assemble and start up the methane detection payload according to the manufacturer's instructions for recommended warm-up period and preliminary adjustments.

8.1.1. Calibration Precision. The calibration precision test shall be completed prior to placing the methane detection payload into service and at subsequent 3-month intervals or at the next use, whichever is first.

8.1.1.1. Make a total of three measurements of both the zero and the methane calibration gas by alternately introducing them where the measurement is collected via the ground level sampling system with all filters, the full tube length, and nozzle present. The introduction of the gas must be done such to not change the flow rate of the system or to pressurize the measurement cell. Record the meter readings. Calculate the average algebraic difference between the meter readings and the known value. Divide this average difference by the known calibration value and multiply by 100 to express the resulting calibration precision as a percentage.

8.1.1.2. The calibration precision shall be equal to or less than 10.0 percent of the calibration gas value.

8.1.2. Response Time. The response time test shall be completed prior to placing the methane detection payload and ground level sampling system into service and at subsequent 3-month intervals or at the next use, whichever is first. If a modification to the sample pumping system or flow configuration is made that would change the response time, a new test is required before further use.

8.1.2.1. Introduce zero gas into the nozzle of the ground level sampling system. When the meter reading has stabilized, switch quickly to the specified calibration gas. After switching, measure the time required to attain 90 percent of the final stable reading. Perform this test sequence three times and record the results. Calculate the average response time.

8.1.2.2. The response time shall be equal to or less than 30 seconds. The instrument pump, ground level sampling system with all filters, tubing, and nozzle lengths, which will be used during testing shall all be in place during the response time determination.

8.1.3. Nozzle Offset Distance. The nozzle offset distance shall be measured prior to placing the methane detection payload into service by recording the time between the UAS passing a known point in space and the nozzle passing the same point in space at a known, consistent speed, hose length and AGL. The horizontal offset distance is the measured temporal offset of the UAS to the nozzle, multiplied by the known, consistent speed.

8.1.4. Offset Calculation. Derive the temporal offset from UAS GPS measurement to receipt of quantified methane measurement for each combination of AGL and methane detection payload configuration by adding the response time to the nozzle offset distance divided by speed. Record this time offset for input to the data acquisition system and offset the reported location of all methane measurements along the actual traversed path by this offset (i.e., if the offset is "X" seconds, the location of the measurement shall be reported as the location of the UAS "X" seconds in the past).

8.1.5. Flow Rate. The flow rate test shall be completed prior to placing the methane detection payload and ground level sampling system into service and at subsequent 3-month intervals or at the next use, whichever is first. If a modification to the sample pumping system or flow configuration is made that would change the flow rate, a new test is required before further use. Measure the flow rate at the distal end of the collection nozzle with a flow meter readable to at least 0.1 l/min per the flow meter manufacturer's specification. Record the flow rate; the flow rate shall be greater than 0.5 l/min.

8.2. Instrument Calibration. Calibrate the methane detection payload according to Section 10.0.

8.3. Individual Source Surveys.

8.3.1. Surface Emission Monitoring via UAS and Follow-up Ground-based Surveys

Set the UAS terrain following system to fly at the constant AGL for the ground level sampling system characterized in Section 6.2.3. Ensure the remote operator can control the gimbaled camera on the UAS and that the resolution is adequate to make visual observations that indicate elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover and cover penetrations.

Take off and fly the UAS (at the predefined constant AGL) at a speed such that the instrument-only response time multiplied by the forward flight speed does not exceed 4 meters along a pattern that traverses the landfill at 30-meter intervals (or a site-specific established spacing). The aggregation of all the surface sampling traverses shall include the perimeter of the collection area, and all locations where visual observations from the gimbaled camera or aerial imagery taken within 120 days indicate elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover. Surface sampling traverses in accordance with this test method shall only occur during typical meteorological conditions.

During flight, take georeferenced pictures from the UAS gimbaled camera of features that indicate elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover and cover penetrations. Inspect these locations per Section 8.3.1.1.

8.3.1.1. Increased Meter Readings. If an increased meter reading is observed or recorded by the UAS data acquisition system refer to Section 8.3.1 of Method 21 as well as the applicable subpart list in Table 1 to survey the area of the GPS coordinate of the increased meter reading and the area within a radius of at least 15 meters. While inspecting the increased meter readings and traversing the landfill between said increased meter readings, make visual observations to identify areas that indicate elevated concentrations of landfill gas, such as distressed vegetation, cracks or seeps in the cover and cover penetrations and inspect said areas as increased meter readings.

8.3.1.2. Cover Penetrations. In addition to conducting ground-based surveys where increased meter readings were detected, refer to Section 8.3.1 of Method 21 as well as the applicable subpart list in Table 1 to survey applicable cover penetrations or openings within the landfill area.

8.3.1.3. Monitoring Route. All measurement points compliant with the specifications of this alternative method shall be plotted on a map that encompasses and includes the perimeter of waste. Any points that deviate from this test method, including but not limited to, manual deviations to the AGL that exceed the specification of 6.3.1, GPS accuracy worse than 6.3.2, presumed or measured flowrate less than that defined in 6.1.4, ground sampling density worse than that required in 8.3.1, etc. shall not be plotted. Any location on the map greater than 15m from a measurement point shall be noted and justified (e.g., noted as an active area, noted hazards that prevent inspection detail, etc.).

8.3.1.4. Re-monitoring. Refer to Method 21 and the applicable subpart for re-monitoring of previously identified exceedances.

9. Quality Control

Section	Quality control measure	Effect
8.1.1	Instrument calibration precision check	Ensure precision and accuracy, respectively, of instrument response to standard.
10.0	Instrument calibration	

10. Calibration and Standardization

10.1. Calibrate the methane detection payload as follows. After the appropriate warm-up period and any internal zero calibration procedure, introduce the calibration gas at the inlet of the ground level sampling system to include all filter, tubing, and the nozzle. Per the manufacturer’s guidelines ensure the instrument readout corresponds to the calibration gas value within 10.0%.

Note: If the meter readout cannot be calibrated to the proper value and/or a malfunction of the methane detection payload is indicated, corrective actions are necessary before use.

11. 11.0 Analytical Procedures [Reserved]

12. 12.0 Data Analyses and Calculations [Reserved]

13. 13.0 Method Performance [Reserved]

14. 14.0 Pollution Prevention [Reserved]

15. 15.0 Waste Management [Reserved]

16. 16.0 References

1. Dubose, D.A., and G.E. Harris. Response Factors of VOC Analyzers at a Meter Reading of 10,000 ppmv for Selected Organic Compounds. U.S. Environmental Protection Agency, Research Triangle Park, NC. Publication No. EPA 600/2–81051. September 1981.

2. Brown, G.E., *et al.* Response Factors of VOC Analyzers Calibrated with Methane for Selected Organic Compounds. U.S. Environmental Protection Agency, Research Triangle Park, NC. Publication No. EPA 600/2–81–022. May 1981.

3. DuBose, D.A. *et al.* Response of Portable VOC Analyzers to Chemical Mixtures. U.S. Environmental Protection Agency, Research Triangle Park, NC. Publication No. EPA 600/2–81–110. September 1981.

4. Handbook of Hazardous Materials: Fire, Safety, Health. Alliance of American Insurers. Schaumberg, IL. 1983.

17.0 Tables, Diagrams, Flowcharts, and Validation Data [Reserved]