Determination of Volatile Organic Compound and Greenhouse Gas Leaks Using Optical Gas Imaging

1.0 Scope and Application

1.1 Analytes.

Analytes	CAS No.
Volatile Organic Compounds (VOCs)	No CAS number assigned.
Methane	74-82-8
Ethane	74-84-0

1.1.1 This protocol is applicable to the detection of VOCs, including hazardous air pollutants (HAPs), and hydrocarbons, such as methane and ethane.

1.2 Scope. This protocol covers surveys of process equipment using Optical Gas Imaging (OGI) cameras in sectors where the majority of compounds (>75 percent by volume) in the emissions streams have a response factor of at least 0.25 when compared to the response factor of propane and can be imaged by the equipment specified in Section 6.0. The specific component focus for the surveys is determined by the referencing subpart, and can include, but is not limited to, valves, flanges, connectors, pumps, compressors, open-ended lines, pressure relief devices, and seal systems.

1.3 Applicability. This protocol is applicable to facilities when specified in a referencing subpart. This protocol is intended to help determine the presence and location of leaks and is not currently applicable for use in direct emission rate measurements from sources.

2.0 Summary

2.1 A field portable infrared (IR) camera capable of imaging the target gas species is employed to survey process equipment and locate fugitive or leaking gas emissions. By restricting the amount of incoming thermal radiation to a small bandwidth corresponding to a region of interaction for the gas species of interest, the camera provides an image of an invisible gas to the camera operator. The camera type and manufacturer are not specified in this protocol, but the camera used must meet the specifications and performance criteria presented in Section 6. The keys to becoming proficient and maintaining leak detection proficiency using OGI cameras are proper camera operator training with sufficient field experience and conducting OGI surveys frequently throughout the year.

3.0 Definitions

Ambient air temperature means the air temperature in the general location of the component being surveyed.

Camera configuration means different ways of setting up an OGI camera that affect its detection capability. Examples of camera configurations that can be changed include the operating mode (*e.g.,* standard versus high sensitivity or enhanced), the lens, the portability (*e.g.,* handheld versus tripod), and the viewer (*e.g.,* OGI camera screen versus an external device like a tablet).

Delta temperature (delta-T or ΔT*)* means the difference in temperature between the emitted process gas temperature and the surrounding background temperature. It is an acceptable practice in the field to assume that the emitted process gas temperature is equal to the ambient air temperature.

Dwell time means the time required to survey a scene in order to provide adequate probability of leak detection. The dwell time is the active time the operator is looking for potential leaks and does not begin until the scene is in focus and steady.

Fugitive emission or leak means any emissions observed using OGI from components regulated by the referencing subpart.

Imaging is the process of producing a visual representation of emissions that may otherwise be invisible to the naked eye.

Monitoring survey means imaging equipment with an OGI camera at one site on one day. Changing the site being surveyed or changing the day of imaging constitutes a new monitoring survey.

Operating envelope means the range of conditions (*i.e.,* wind speed, delta-T, viewing distance) within which a survey must be conducted to achieve the quality objective.

Optical gas imaging camera means any field portable instrumentation that makes visible emissions that may otherwise be invisible to the naked eye.

Persistent leak is any leak that is not intermittent in nature.

Referencing subpart means a subpart in 40 CFR part 60, 61, 62, 63, or 65 that requires the monitoring of regulated equipment for fugitive emissions or leaks, for which this protocol is referenced.

Response factor means the OGI camera's response to a compound of interest relative to a reference compound at a concentration path-length of 10,000 part per million-meter. Response factors are specific to the OGI camera model and can be obtained from peer reviewed articles or may be developed according to procedures specified in Annex 1 of this appendix.

Senior OGI camera operator is a camera operator who has conducted OGI surveys for a minimum of 1400 hours over the entirety of his/her career, including at least 40 hours in the past 12 months, and has completed or developed the classroom camera operator training as defined in Section 10.2.1. Previous 12 months means the 365-calendar days prior to the day of the activity that requires a senior OGI camera operator. The hours spent by the senior OGI camera operator performing comparative monitoring, either as part of initial training, retraining, or auditing other OGI camera operators, can be included when determining the senior OGI camera operator's experience both over his/her career and the past 12 months.

4.0 Interferences

4.1 Interferences from atmospheric conditions can impact the operator's ability to detect gas leaks. It is recommended that conditions involving steam, fog, mist, rain, solar glint, high particulate matter concentrations, and extremely hot backgrounds are avoided for a survey of acceptable quality.

5.0 Safety

5.1 Site Hazards. Prior to applying this protocol in the field, the potential hazards at the survey site should be considered; advance coordination with the site is critical to understand the conditions and applicable safety policies. This protocol does not address all of the safety concerns associated with its use. It is the responsibility of the user of this protocol to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to implementing this protocol.

5.2 Hazardous Pollutants. Several of the compounds encountered over the course of implementing this protocol may be irritating or corrosive to tissues (*e.g.*, heptane) or may be toxic (*e.g.*, benzene, methyl

alcohol, hydrogen sulfide). Nearly all are fire hazards. Chemical compounds in gaseous emissions should be determined from process knowledge of the source. Appropriate precautions can be found in reference documents, such as reference 13.1.

6.0 Equipment and Supplies

6.1 An OGI camera model meeting the following specifications is required. This testing can be performed by the owner or operator, the camera manufacturer, or a third party. As required by Section 8.1, this testing must be performed initially, prior to using the OGI camera to conduct surveys. The determination in Section 6.1.1 must also be made any time the OGI camera will be used to survey components on equipment that was not previously included in monitoring surveys or whenever there are process changes that are expected to cause the gaseous emissions composition to change. The determination in Section 6.1.2 is only required initially.

6.1.1 The spectral range of infrared radiation measured by the OGI camera must overlap with a major absorption peak for the chemical target of interest, meaning the OGI camera must be sensitive with a response factor of at least 0.25 when compared to the response factor of propane for the majority of constituents (>75 percent by volume) of the expected gaseous emissions composition.

6.1.2 The OGI camera must be capable of detecting (or producing a detectable image of) methane emissions of 17 grams per hour (g/hr) and either butane emissions of 5.0 g/hr or propane emissions of 18 g/hr at a viewing distance of 2 meters and a delta-T of 5 °Celsius (C) in an environment of calm wind conditions around 1 meter per second (m/s) or less, unless the referencing subpart provides detection rates for a different compound(s) for that subpart.

6.2 The following items are needed for the initial specification confirmation of each OGI camera model configuration, as required by Sections 6.1.2 and Section 8:

6.2.1 Methane test gas, chemically pure grade (99.5 percent) or higher.

6.2.2 Butane test gas or propane test gas, chemically pure grade (99 percent) or higher.

6.2.3 Release orifice, ¼ inch inner diameter.

6.2.4 Mass flow controller or rotameter, capable of controlling the gas emission rate within NIST traceable accuracy of 5 percent.

6.2.5 An industrial fan, capable of adjusting the sustained nominal wind speeds at regular intervals, with the ability to maintain a set speed within 20 percent of the target wind speed.

6.2.6 A meteorological station capable of providing representative data on ambient temperature, ambient pressure, relative humidity, and wind speed and direction at least once every hour, with equipment meeting the following minimum specifications:

6.2.6.1 Ambient temperature readings accurate to at least 0.5 °C, with a resolution of 0.1 °C or less, and a minimum range of -20 to 70 °C.

6.2.6.2 Ambient pressure readings accurate to at least 1.0 millibar (mbar), with a resolution of 0.1 mbar or less, and a minimum range of 700 to 1100 mbar.

6.2.6.3 Wind speed readings accurate to at least 0.2 m/s, with a resolution of 0.1 m/s or less, and a minimum range of 0.1 to 20 m/s.

6.2.6.4 Wind direction readings accurate to at least 5 degrees, with a resolution of 1 degree or less.

6.2.6.5 Relative humidity readings accurate to at least 5 percent, with a resolution of 0.5 percent or less, and a minimum range of 10 to 90 percent noncondensing.

6.2.7 A temperature-controlled background large enough for viewing the emissions plume and capable of maintaining a uniform temperature. Uniform is defined as all points on the background deviating no more than 1 °C from the average temperature of the background.

6.2.8 T-type probe thermocouple and readout, accurate to at 1 °C, for measuring the test gas at or near the point of release.

6.2.9 T-type surface skin thermocouple and readout, accurate to at 1 °C, for measuring the background immediately behind the test gas.

6.2.10 Device to measure the distance between the OGI camera and the release point (*e.g.*, tape measure, laser measurement tool), accurate to at least 2 centimeters (cm), with a resolution of at least 1 cm.

7.0 Camera Calibration and Maintenance

7.1 The camera does not require routine calibration for purposes of gas leak detection but may require calibration if it is used for thermography (such as with ΔT determination features). Operators should follow manufacturer recommendations regarding maintenance and calibration, as appropriate.

8.0 Camera Specification Confirmation and Development of the Operating Envelope

8.1 Determine that the OGI camera meets the specifications in Section 6.1 prior to conducting surveys with the OGI camera. The determination in Section 6.1.1 must also be made any time the OGI camera will be used to survey components on equipment that was not previously included in monitoring surveys or whenever there are process changes that are expected to cause the gaseous emissions composition to change. The determination in Section 6.1.2 is only required initially. The results of this determination must be documented.

8.2 Field conditions such as the viewing distance to the component to be monitored, wind speed, ambient air temperature, and the background temperature all have the potential to impact the ability of the OGI camera operator to detect a leak. It is important that the OGI camera has been tested under the full range of expected field conditions in which the OGI camera will be used.

8.3 An operating envelope must be established for field use of the OGI camera. Imaging must not be performed when the conditions are outside of the developed operating envelope.

8.3.1 The operating envelope is specific to each model of OGI camera. The operating envelope can be developed by the owner or operator, the camera manufacturer, or a third party. The operating envelope must be developed initially, prior to conducting surveys with the OGI camera. The operating envelope may be updated or expanded at any time, following the procedures in this section.

8.3.2 The operating envelope must be confirmed for all potential configurations that could impact the detection limit, such as high sensitivity modes, available lenses, and handheld versus tripod. Conversely, separate operating envelopes may be developed for different configurations. If, in addition to or in lieu of the display on the camera itself, an external device (*e.g.*, laptop, tablet) is intended to be used to visualize the leak in the field, the operating envelope must be developed while using the external device. If the

external device will not be used at all times, use of the external device is considered a separate configuration, and the operating envelope testing must be performed for both configurations.

8.4 Development of the operating envelope is to be performed using the test gas composition, flow rate, and orifice diameter described in Section 6.1.2, and must include the following variables:

8.4.1 Delta-T, regulated through the use of a temperature-controlled background encompassing approximately 50 percent of the field of view, with no potential for solar interference;

8.4.2 Viewing distance from the OGI camera to the component being imaged; and

8.4.3 Wind speed, controlled through the use of an industrial fan.

8.5 Determine the operating envelope using the following procedure:

8.5.1 Set up the methane test gas at a flow rate of 17 g/hr.

8.5.2 For this flow rate, the ability of the OGI camera to produce an observable image is challenged by ranges of the variables in Sections 8.4.1 through 8.4.3.

8.5.3 A panel of no less than 4 observers who have been trained using the OGI camera and who have a demonstrated capability of detecting gaseous leaks will observe the test gas release for each combination of delta-T, distance, and wind speed. A test emission is determined to be observed when at least 75 percent of the observers (*i.e.*, 3 of the 4 observers) see the image.

8.5.4 Repeat the procedures in Sections 8.5.2 and 8.5.3 using either a butane test gas at a flow rate of 5.0 g/hr or a propane test gas at a flow rate of 18 g/hr.

8.5.5 The operating envelope to be used in the field for each OGI camera configuration tested is the more restrictive operating envelope developed between the two test gases.

8.5.6 Repeat the procedures in Sections 8.5.1-8.5.5 for each camera configuration that will be used to conduct surveys in the field.

8.6 The results of the testing to establish the operating envelope, including supporting videos, must be documented.

9.0 Conducting the Monitoring Survey

Each site must have a monitoring plan that describes the procedures for conducting a monitoring survey. One monitoring plan can be used for multiple sites, as long as the plan contains the relevant information for each site. At a minimum, the monitoring plan must include the elements in this section.

9.1 The monitoring plan must include a description of a daily verification check to be performed prior to imaging to confirm that the camera is operating properly. This verification must consist of the following at a minimum:

9.1.1 Confirm that the OGI camera software loads successfully and does not display any error messages upon startup;

9.1.2 Confirm that the OGI camera focuses properly at the shortest and longest distances that will be imaged;

9.1.3 Confirm that the OGI camera produces a live IR image using a known emissions source, such as a butane lighter or a propane cylinder;

9.1.4 Confirm that the OGI camera can perform the delta-T check function as expected if this function will be used meet the requirement in Section 9.2.3.

9.2 The monitoring plan must include a procedure for ensuring that the monitoring survey is performed only when conditions in the field are within the operating envelope established in Section 8. This procedure must include the following:

9.2.1 Description of how the viewing distance from the surveyed components, the wind speed, and the delta-T will be monitored and how the operator will deal with changes in site conditions during the survey to ensure that the monitoring survey is conducted within the limits of the operating envelope;

9.2.2 Description of how the operator will ensure an adequate delta-T is present in order to view potential gaseous emissions, *e.g.*, using a delta-T check function built into the features of the OGI camera or using a background temperature reading in the OGI camera field of view;

9.2.3 Description of how the operator will recognize the presence of and deal with potential interferences and/or adverse monitoring conditions, such as steam, fog, mist, rain, solar glint, extremely high concentrations of particulate matter, and hot temperature backgrounds;

9.3 The site must conduct monitoring surveys using a methodology that ensures that all the components regulated by the referencing subpart within the unit or area are monitored. This must be achieved using one of the following three approaches or a combination of these approaches. The approach(es) chosen and how the approach(es) will be implemented must be described in the monitoring plan.

9.3.1 Use of a route map or a map with designated observation locations. The map must be included as part of the monitoring plan, with a predetermined sequence of process unit monitoring (such as directional arrows along the monitoring path) depicted or designated observation locations clearly marked.

9.3.2 Use of visual cues. The facility must develop visual cues (*e.g.*, tags, streamers, or color-coded pipes) to ensure that all components regulated by the referencing subpart were monitored. The monitoring plan must describe what visual cue method is used and how it will be used to ensure all components are monitored during the survey.

9.3.3 Use of global positioning system (GPS) route tracing. The facility must document the path taken during the survey by capturing GPS coordinates along the survey path, along with date and time stamps. GPS coordinates must be recorded frequently enough to document that all components regulated by the referencing subpart were monitored. The monitoring plan must describe how often GPS coordinates will be recorded and how the route tracing will ensure all components regulated by the referencing subpart are monitored.

9.4 The monitoring plan must include a procedure that describes how components will be viewed with the OGI camera. In general, a component should be imaged from at least two different angles, and the operator must dwell on each angle for a minimum of 2 seconds per component in the field of view before changing the angle, distance, or focus and dwelling again. The procedure must discuss changes, if necessary, to the imaging mode of the OGI camera that are appropriate to ensure that leaks from all components regulated by the referencing subpart can be imaged.

9.4.1 For a complex scene of components, the operator must divide the scene into manageable subsections and dwell on each angle for a minimum of 2 seconds per component in the field of view (e.g., for a subsection with 5 components, the minimum dwell time would be 10 seconds). It may be necessary to reduce distance or change angles in order to reduce the number of components in the field of view.

9.4.2 The operator may choose to reduce the dwell time for complex scenes based on the monitoring area and number of components in the subsection as prescribed in Table 14-1, provided the manageable subsection for the angle fills greater than half of the field of view of the camera. Use of Table 14-1 is optional and is not required if the operator uses the minimum dwell time in Section 9.4.1.

9.5 The monitoring plan must include a plan for avoiding camera operator fatigue, as physical, mental, and eye fatigue are concerns with continuous field operation of OGI cameras. The OGI camera operator should not survey continuously for a period of more than 30 minutes without taking a rest break. Taking a rest break between surveys of process units may satisfy this requirement; however, for process units or complex scenes requiring continuous survey periods of more than 30 minutes, the operator must take a break of at least 5 minutes after every 30 minutes of surveying. Operators can complete tasks related to the monitoring survey, such as documentation, during the 5-minute rest break, so long as the operator is not actively imaging components.

Note: If continuous surveying is desired for extended time periods, two camera operators can alternate between surveying and taking breaks.

9.6 The monitoring plan must include a procedure for documenting monitoring surveys. The information documented must include:

9.6.1 The name of the facility, date, and approximate start and end times for each monitoring survey.

9.6.2 The weather conditions, including ambient temperature, wind speed, relative humidity, and sky conditions at the start and end of each monitoring survey. For monitoring surveys conducted for more than four hours, record the weather conditions every two hours.

9.7 The site must have a procedure for documenting fugitive emissions or leaks found during the monitoring survey according to one of the following approaches. If no emissions are found, no recorded footage is required to demonstrate that the component was not leaking.

9.7.1 If a leak is found, capture either a short video clip or photograph that depicts the leak and the component associated with the leak. If the leak is not immediately repaired, the leaking component must be tagged for repair. The date, time, location of the leak, and identification of the component associated with the leak must be recorded and stored with the OGI survey records.

9.7.2 A full video of the monitoring survey must be recorded. The video must document the monitoring results for each piece of regulated equipment. Leaking components must be tagged for repair, and the date, time, location of each leak, and identification of the component associated with each leak must be recorded and stored with the OGI survey records.

9.8 The monitoring plan must include a quality assurance (QA) verification video for each OGI operator at least once each monitoring day. The QA verification video must be a minimum of 5 minutes long and document the procedures the operator uses to survey *(e.g.*, dwell times, angles, distances, backgrounds) and the camera configuration.

9.9 The monitoring plan must describe the process that will be used to ensure the validity of the monitoring data as detailed in Section 11.

10.0 Camera Operator Training

10.1 The facility or company performing the OGI surveys must have a training plan which ensures and monitors the proficiency of the camera operators. Training should include classroom instruction and field training on the OGI camera and external devices, monitoring techniques, best practices, process knowledge, and other regulatory requirements related to leak detection that are relevant to the facility's OGI monitoring efforts. If the facility does not perform its own OGI monitoring, the facility must ensure that the training plan for the company performing the OGI surveys adheres to this requirement.

10.2 Prior to conducting monitoring surveys, camera operators must complete initial training and demonstrate proficiency with the OGI camera and any external devices to be utilized for detecting a potential leak.

10.2.1 At a minimum, the training plan must include the following classroom training elements as part of the initial training. Classroom training can be at a physical location or online.

10.2.1.1 Key fundamental concepts of the OGI camera technology, such as the types of images the camera is capable of visualizing and the technology basis (theory) behind this capability.

10.2.1.2 Parameters that can affect image detection (*e.g.*, wind speed, temperature, distance, background, and potential interferences).

10.2.1.3 Description of the components to be surveyed and example imagery of the various types of leaks that can be expected.

10.2.1.4 Operating and maintenance instructions for the OGI camera used at the facility.

10.2.1.5 Procedures for performing the monitoring survey according to the monitoring plan, including the daily verification check; how to ensure the monitoring survey is performed only when the conditions in the field are within the established operating envelope; the number of angles a component or set of components should be imaged from; how long to dwell on the scene before changing the angle, distance, and/or focus; how to improve the background visualization; the procedure for ensuring that all components regulated by the referencing subpart are visualized; and required rest breaks.

10.2.1.6 Recordkeeping requirements.

10.2.1.7 Common mistakes and best practices.

10.2.1.8 Discussion on the regulatory requirements related to leak detection that are relevant to the facility's OGI monitoring efforts.

10.2.2 At a minimum, the training plan must include the following field training elements as part of the initial training:

10.2.2.1 A minimum of 3 survey hours with OGI where trainees observe the techniques and methods of a senior OGI camera operator (see definition in Section 3.0) who reinforces the classroom training elements.

10.2.2.2 A minimum of 12 survey hours with OGI where the trainee performs the initial OGI survey with a senior OGI camera operator verifying the results by conducting a side-by-side comparative survey and providing instruction/correction where necessary.

10.2.2.3 A minimum of 15 survey hours with OGI where the trainee performs monitoring surveys independently with a senior OGI camera operator trainer present and the senior OGI camera operator providing oversight and instruction/correction to the trainee where necessary.

10.2.2.4 A final monitoring survey test where the trainee conducts an OGI survey of at least 2 hours and a senior OGI camera operator follows behind with a second camera to confirm the OGI survey results. If there are 10 or more leaks identified by the senior OGI operator, the trainee must achieve less than 10 percent missed persistent leaks relative to the senior OGI camera operator to be considered authorized for independent survey execution. If there are less than 10 leaks identified by the senior OGI operator, the trainee must achieve zero missed persistent leaks relative to the senior OGI camera operator to be considered authorized for independent survey execution.

10.2.2.5 If the trainee doesn't pass the monitoring survey test in Section 10.2.2.4, the senior OGI operator must discuss the reasons for the failure with the trainee and provide instruction/correction on improving the trainee's performance. Following the discussion with the senior OGI operator, the trainee may repeat the test in Section 10.2.2.4.

10.3 All OGI camera operators must attend a biennial classroom training refresher. This refresher can be shorter in duration than the initial classroom training but must cover all the salient points necessary to operate the camera (*e.g.*, performing surveys according to the monitoring plan, best practices, discussion of lessons learned). Refresher training can be at a physical location or online.

10.4 Performance audits for all OGI camera operators must occur on a quarterly basis with at least one month between two consecutive audits. Performance audits must be conducted according to one of the following procedures:

10.4.1 Performance audit by comparative monitoring. Comparative monitoring in near real-time is where a senior OGI camera operator reviews the performance of the employee being audited by performing an independent monitoring survey.

10.4.1.1 Following a survey conducted by the camera operator being audited, the senior OGI camera operator will conduct a survey of at least 2 hours in the same area to ensure that no persistent leaks were missed.

10.4.1.2 If there are 10 or more leaks identified by the senior OGI operator, the camera operator being audited must achieve less than 10 percent missed persistent leaks relative to the senior OGI camera operator. If there are less than 10 leaks identified by the senior OGI operator, the camera operator being audited must achieve zero missed persistent leaks relative to the senior OGI camera operator. If the camera operator being audited does not achieve this benchmark, then the camera operator being audited will need to be retrained as outlined in Section 10.4.3.

10.4.2 Performance audit by video review. The camera operator being audited must submit unedited and uncut video footage of their OGI survey technique to a senior OGI camera operator for review.

10.4.2.1 The videos must contain at least 2 hours of survey footage. If a single monitoring survey is less than 2 hour, footage from multiple monitoring surveys may be submitted; however, all videos necessary to cover a 2-hour period must be recorded and submitted for review. The senior OGI camera operator will review the survey technique of the camera operator being audited, as well as look for any missed leaks.

10.4.2.2 If the senior OGI camera operator finds that the survey techniques during the video review do not match those described in the monitoring plan, then the camera operator being audited will need to be retrained as outlined in Section 10.4.3. Additionally, if there are 10 or more leaks identified by the senior OGI operator, the camera operator being audited must achieve less than 10 percent missed persistent leaks relative to the senior OGI camera operator. If there are less than 10 leaks identified by the senior OGI operator, the camera operator being audited must achieve zero missed persistent leaks relative to the senior OGI camera operator. If the camera operator being audited does not achieve this benchmark, then the camera operator being audited will need to be retrained as outlined in Section 10.4.3.

10.4.3 At a minimum, retraining must consist of the following elements:

10.4.3.1 A discussion of the reasons for the failure with the OGI operator being audited and techniques to improve performance.

10.4.3.2 A minimum of 8 survey hours with OGI where the trainee performs the initial OGI survey with a senior OGI camera operator verifying the results by conducting a side-by-side comparative survey and providing instruction/correction where necessary.

10.4.3.3 A minimum of 8 survey hours with OGI where the trainee performs the survey independently with the senior OGI camera operator trainer present and the senior OGI camera operator provides oversight and instruction/correction to the trainee where necessary.

10.4.3.4 The audited camera operator must perform a final monitoring survey test as described in Section 10.2.2.4 and meet the requirements in Section 10.2.2.4 to be recertified.

10.4.4 If an OGI operator requires retraining in two consecutive quarterly audits, the OGI operator must repeat the initial training requirements in Section 10.2.

10.4.5 If a camera operator is not scheduled to perform an OGI survey during a quarter, then the audit must occur with the next scheduled monitoring survey.

10.5 If an OGI camera operator has not conducted a monitoring survey in over 12 months, then the operator must complete the retraining requirements in Section 10.4.3 prior to conducting surveys. If an OGI camera operator has not conducted a monitoring survey in over 24 months, then the operator must complete the biennial classroom training in Section 10.3 and complete the retraining requirements in Section 10.4.3 prior to conducting surveys.

10.6 Previous experience with OGI camera operation can be substituted for some of the initial training requirements in Section 10.2 as outlined in this Section 10.6.1 and 10.6.2.

10.6.1 OGI camera operators with previous classroom training (either at a physical location or online) that included a majority of the elements listed in Section 10.2.1 do not need to complete the initial classroom training as described in Section 10.2.1, but if the date of training is more than two years before [THE DATE OF PUBLICATION OF THE FINAL RULE IN THE **FEDERAL REGISTER**], the biennial classroom training in Section 10.3 must be completed in lieu of the initial classroom training in Section 10.2.1.

10.6.2 OGI camera operators who have 40 hours of experience over the 12 calendar months prior to [THE DATE OF PUBLICATION OF THE FINAL RULE IN THE **FEDERAL REGISTER**] may substitute the retraining requirements in Section 10.4.3, including the final monitoring survey test, for the initial field training requirements in Section 10.2.2.

11.0 Quality Assurance and Quality Control

11.1 As part of the facility's monitoring plan, the facility must have a process which ensures the validity of the monitoring data. Examples may include routine review and sign-off of the monitoring data by the camera operator's supervisor, periodic comparative monitoring using a different camera operator as part of a continuing training verification plan described in Section 10, or other due-diligence procedures.

11.2 For each monitoring day, the daily OGI camera verification must be performed as described in Section 9.1. Additionally, the daily QA verification video for each operator must be recorded as described in Section 9.8 for each operator for each monitoring day.

11.3 The following table is a summary of the mandatory QA and quality control (QC) measures in this protocol with the associated frequency and acceptance criteria. All of the QA/QC data must be documented and kept with other OGI records.

Summary Table of QA/QC

Parameter	**QA/QC Specification**	**Acceptance Criteria**	**Frequency**
OGI Camera Design	Spectral bandpass range	Must overlap with major absorption peak of the compound(s) of interest.	Once initially (prior to using the OGI camera to conduct surveys), when survey components on equipment that was not previously included in monitoring surveys, whenever there are process changes that are expected to cause the gaseous emissions composition to change.
OGI Camera Design	Initial camera specification confirmation	Must be capable of detecting (or producing a detectable image of) methane emissions of 17 g/hr and either butane emission of 5.0 g/hr or propane emissions of 18 g/hr at a viewing distance of 2 meters and a delta-T of 5 °C in an environment of calm wind conditions around 1 m/s or less.	Once initially (prior to using the OGI camera to conduct surveys).
Developing the Operating Envelope	Observation confirmation	Leak is observed by 3 out of 4 panel observers for specific combinations of delta-T, distance, and wind speed.	Once initially (prior to using the OGI camera to conduct surveys) and prior to using a new camera configuration for which an envelope was not previously established. The operating envelope may be updated or expanded

Parameter	QA/QC Specification	Acceptance Criteria	Frequency
			at any time, following the procedures in Section 8.
OGI Camera Functionality	Verification Check	Meet the requirements of Section 9.1 to confirm that the OGI camera software loads successfully and that the camera focuses properly, produces a live IR image, and, as applicable, performs the delta-T check function.	Each monitoring day, prior to conducting a survey.
Camera Operator Training	Classroom training	Meet the requirements of Sections 10.2.1 and 10.3 with the issuing of a certificate or record of attendance.	Prior to conducting surveys (except as noted in Section 10.6.1), with a biennial refresher.
Camera Operator Training	Field training	Meet the requirements of Section 10.2.2 while maintaining the records of survey hours by the trainee along with a certificate or record of completion issued upon passing the final monitoring survey test in Section 10.2.2.4 with the date of the survey recorded.	Except as noted in Section 10.6.2, prior to conducting surveys and if retraining is required following two consecutive quarterly audits.
OGI Camera Operator Performance	Quarterly performance audits	Comparative monitoring or video review. Meet the benchmarks in Section 10.4.1.2 or 10.4.2.2.	Every 3 months, with at least 1 month between consecutive audits or at the next scheduled monitoring survey if a camera operator is not scheduled to perform an OGI survey during the quarter.
Camera Operator Training	Field retraining	Meet the requirements of Section 10.4.3 while maintaining the records of survey hours by the trainee along with a certificate or record of completion issued upon passing the final monitoring survey test in Section 10.2.2.4 with the date of the survey recorded.	After failing to meet the benchmarks in Section 10.4.1.2 or 10.4.2.2 during a quarterly audit or after a prolonged period (greater than 12 months) of not performing OGI surveys. May be substituted for initial field training as noted in Section 10.6.2.
OGI Camera Operator Performance	QA verification video	Record a video that is a minimum of 5 minutes long that documents the procedures the operator uses to survey *(e.g.*, dwell times, angles,	Each monitoring day.

Parameter	QA/QC Specification	Acceptance Criteria	Frequency
		distances, backgrounds) and the camera configuration.	

12.0 Recordkeeping

12.1 Records must be kept for a period of 5 years, unless otherwise noted below or otherwise specified in a referencing subpart. Records may be retained in hard copy or electronic form.

12.2 The facility must maintain the following records in a manner that is easily accessible to all OGI camera operators. These records must be retained for as long as the site performs OGI surveys. Older versions of these records that are no longer relevant because they have been replaced by newer versions must be retained for a period of 5 years past the date on which they are replaced.

12.2.1 Complete site monitoring plan with all the required elements.

12.2.2 The OGI camera operating envelope limitations.

12.3 All data supporting the OGI camera specification confirmation (initially and updated as required in Section 8.1) and development of the operating envelope. While the owner or operator does not need to have a copy of these records onsite if another entity performed the camera specification confirmation or development of the operating envelope, the owner or operator must: (1) ensure that the camera specification confirmation and development of the operating envelope were performed in accordance with the requirements of this Appendix K, (2) ensure easy access to these records, and (3) make the records available for review if requested by the Administrator. These records must be retained for the entire period that the OGI camera is used to conduct surveys at the site plus 5 years.

12.4 The training plan for OGI camera operators. The plan must be retained for as long as the site performs OGI surveys. Older versions of the plan that are no longer relevant because they have been replaced by a newer version must be retained for a period of 5 years past the date on which they are replaced. If the facility does not perform its own OGI monitoring, the owner or operator must: (1) ensure that the training plan for the company performing the OGI surveys adheres to the requirements of this Appendix K, (2) ensure easy access to the plan, and (3) make the plan available for review if requested by the Administrator.

12.5 For each OGI camera operator, the following records. These may be kept in a separate location for privacy but must be easily accessible to program administrators and available for review if requested by the Administrator. It may be necessary to retain the records in Section 12.5.3 for longer than 5 years to show the career experience hours for senior OGI camera operators. If the facility does not perform its own OGI monitoring, the owner or operator must: (1) ensure that the training plan for the company performing the OGI surveys adheres to the requirements of this Appendix K, (2) be able to easily access these records, and (3) make the records available for review if requested by the Administrator. The records must include the following information.

12.5.1 The date of completion of initial OGI camera operator classroom training;

12.5.2 The date of the passed final site survey test following the initial OGI camera operator field training or retraining;

12.5.3 The number and date of all surveys performed, and if the survey is part of initial field training or retraining, the amount of survey hours and notation of whether the survey was performed by observing a senior OGI camera operator, side-by-side with a senior OGI camera operator, or with oversight from a senior OGI camera operator;

12.5.4 The date and results of quarterly performance audits;

12.5.5 The date of the biennial classroom training refresher; and

12.5.6 Documentation to support the use of previous experience as a substitution for initial training requirements, including the date of previous classroom training and documentation of survey hours over the 12 calendar months prior to [THE DATE OF PUBLICATION OF THE FINAL RULE IN THE **FEDERAL REGISTER**], as appropriate.

12.6 Monitoring survey results shall be kept in a manner that is accessible to those technicians executing repairs and at a minimum must contain the following:

12.6.1 Daily verification check;

12.6.2 Identification of the site surveyed and the survey date and start and end times;

12.6.3 Name of the OGI camera operator performing the survey and identification of the OGI camera used to conduct the survey. The identification of the OGI camera can be the serial number or an assigned name/number labeled on the camera, but it must allow an operator or inspector to tie the camera back to the records associated with the camera (*e.g.*, maintenance, initial specification confirmation);

12.6.4 Weather conditions, including the ambient temperature, wind speed, relative humidity, and sky conditions, at the start and end of the survey and every two hours (if the survey exceeded four hours in length);

12.6.5 Video footage or photograph of any leak detected, or video footage of the entire survey, along with the date, time, and location of the leak, and identification of the component associated with the leak;

12.6.6 The daily QA verification video for each operator; and

12.6.7 GPS coordinates for the route taken, if Section 9.3.3 is used to ensure all components regulated by the referencing subpart are monitored.

12.7 Camera maintenance and calibration records over the entire period that the OGI camera is used to conduct surveys at the site. Older versions of these records that are no longer relevant because they have been replaced by newer versions must be retained for a period of 5 years past the date on which they are replaced. If the facility does not perform its own OGI monitoring, the owner or operator must be able to easily access these records and must make the records available for review if requested by the Administrator.

13.0 References

13.1 U.S. Department of Health and Human Services. (2010). NIOSH Pocket Guide to Chemical Hazards. NIOSH Publication No. 2010-168c. Also available from https://www.cdc.gov/niosh/docs/2010-168c/default.html.

13.2 U.S. Environmental Protection Agency. (2021). Technical Support Document: Optical Gas Imaging Protocol (40 CFR Part 60, Appendix K).

13.3 U.S. Environmental Protection Agency. (2020). Optical Gas Imaging Stakeholder Input Workshop Presentations and Discussion; Summary Letter Report.

13.4 Zeng, Y., J. Morris, A. Sanders, S. Mutyala, and C. Zeng. (2017). Methods to Determine Response Factors for Infrared Imagers used as Quantitative Measurement Devices. *Journal of the Air & Waste Management Association*, *67*(11), 1180-1191. DOI: 10.1080/10962247.2016.1244130. Available online at: https://doi.org/10.1080/10962247.2016.1244130.

13.5 Zimmerle, D., T. Vaughn, C. Bell, K. Bennett, P. Deshmukh, and E. Thoma. (2020). Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions. *Environmental Science & Technology*, *54*(18), 11506-11514. DOI: 10.1021/acs.est.0c01285.

14.0 Tables, Diagrams, and Flow Charts

Table 14-1. Reduced Dwell Time (in seconds) by Subsection Area and Scene Complexity (Optional)

	Components in Subsection				
Monitoring Area (m^2)	**2-3**	**4-5**	**5-10**	**10-20**	**>20**
0.125	2	4	6	8	10
0.25	2	6	8	10	12
0.50	4	6	10	12	*
1.0	4	8	12	*	*
>1.0	*	*	*	*	*

* The camera operator must either reduce the subsection area, the scene complexity, or both by moving closer to the components or changing the viewing angle.

Note: This table only applies when an OGI operator wishes to reduce the dwell time of a scene. Normally, the dwell time for each angle must be a minimum of 2 seconds per component in the field of view. The operator may reduce the dwell time based on the monitoring area and number of components as described in this table, provided the manageable subsection for the angle fills greater than half of the field of view of the camera. The operator must divide the scene into manageable subsections and image each subsection from at least two different angles. To use Table 14-1, the depth of components within the monitoring area must be less than 0.5 meters.

Annex 1 to Appendix K of 40 CFR part 60 – Development of Response Factors for OGI Cameras

1.0 Introduction

The purpose of this annex is to outline the protocol for the development of response factors (RF) for optical gas imaging (OGI) cameras. As defined in Section 3.0 of Appendix K, a response factor is the OGI camera's response to a compound of interest relative to a reference compound at a concentration path-length of 10,000 part per million-meter (ppm-m).

1.1 Nomenclature.

1.1.1 The definitions listed in Section 3.0 of Appendix K apply to this annex.

1.1.2 Infrared (IR) radiance pixel area. The IR radiance pixel area is the average of a set of pixel IR radiance for an instantaneous measurement. There will be three different areas representing the reference cell, gas cell, and the raw blackbody surface. The pixel count for each area must be at a minimum of 1% of the total pixels of the detector. The pixel locations selected for an area must not change throughout the test.

1.1.3 Measurement data set. Measurement data set is the number of time independent IR radiance pixel areas that are taken. The minimum number of measured IR radiance pixel area within a data set is 31. For a 1 Hertz device, the minimum measurement data set would be 31 seconds. The number of measured IR radiance pixel area within a measurement data set should stay consistent throughout the test.

1.1.4 Reference Compound. The reference compound is the compound that provides the reference for determination of the response factor with the compound of interest. The reference compound for this annex is propane, unless otherwise specified in a referencing subpart.

2.0 Applicability and Analytical Principle

2.1 Applicability. This annex applies to the determination of compound specific response factors through empirical testing for use with Appendix K. This annex does not apply to other applications of OGI cameras or other instruments. This annex does not limit the use of other peer reviewed and published techniques and response factors per Section 3.0 of Appendix K.

2.2 Analytical Principle. OGI cameras work by providing an image or video with each pixel representing a measurement of the IR radiation. OGI cameras limit measurement to specific wavelengths of IR through the choice of the detector and generally through the addition of a bandpass filter. Limiting the measurement to specific wavelengths of IR allows the OGI camera to focus on a specific region of interest in order to increase the detection capabilities of particular compounds of interest. The combination of detector and bandpass filter, in addition to limiting the region of interest, will allow varying amounts of IR over the specific wavelength region.

3.0 Equipment and Supplies.

3.1 Section 6.0 of Appendix K lists equipment and supplies that may be used in this annex.

3.2 Blackbody Source. A sufficiently large blackbody source capable of maintaining high emissivity, as well as temperature stability and homogeneity.

3.2.1 The blackbody must have an emissivity of 0.95 or higher in the IR region of interest.

3.2.2 The source emissive area must have a uniform temperature, where uniform is defined as all points on the emissive area deviating no more than 0.1 degree Celsius (°C) from the average temperature of the emissive area. The temperature readings must be accurate to at least 0.1 °C. The blackbody must be able to maintain its temperature within 0.1 °C.

3.2.3 The source's surface area must be large enough to allow the OGI camera to take IR measurements of two gas cells and allow for the proper measurement of IR radiance through the gas and reference cell and IR radiance of the surface itself.

3.3 Test gas for each compound of interest, used for determining the response factor. The concentration of the gas in the cylinder must be vendor certified to ± 5 percent of the cylinder tag value and be in a balance of nitrogen. The concentration of the gas must be such that the gas cell concentration is 10,000 ppm-m with less than 2 percent error. Alternatively, the gas standard may be produced with dilution per Method 205 of 40 CFR part 51 Appendix M with the exception that the mid-supply gas may be vendor certified to ± 5 percent of the cylinder tag value.

3.4 Gas Cell. A windowed gas cell that is leak tight and has the ability to flow gas through the cell. The size of the cell should be such to allow for 10,000 ppm-m to be viewed by the OGI camera with less than 2 percent error. The windows should be 99 percent transmissive in the IR region of interest and deviate no more than 0.5 percent transmission over than region of interest. The cell must have associated temperature, flow, and pressure measurements.

3.5 Reference Compound Gas Standard. Propane gas standard, unless a referencing subpart specifies otherwise, used as the reference for determination of the response factor. The concentration of the gas in the cylinder must be vendor certified to ± 2 percent of the cylinder tag value and be in a balance of nitrogen. The concentration of the gas must be such that the gas cell concentration is 10,000. ppm-m with less than 2 percent error.

3.6 Reference Cell. A gas cell for the reference compound gas standard which meets all of the requirements in Section 3.4 of this annex.

3.7 Zero Gas. A 99.99 percent pure diatomic gas, typically nitrogen, that has no IR response from the OGI camera, used to assess the detection level of the system and baseline response of the gas cells.

3.8 OGI Camera is the specific OGI camera that is being tested. Response factors must be determined for each IR detector and bandpass filter combination. The OGI camera must have the ability to output the raw IR radiance at the pixel level.

3.8.1 The combination of IR detector and bandpass filter may be consistent over several models such that the developed RFs may be applicable to more than one model of OGI camera.

3.8.2 If the OGI camera model has exchangeable bandpass filters, more than one set of RFs may be needed for the OGI camera model to account for the differences between filters.

4.0 Pre-test Preparation and Evaluations

4.1 Room Preparation. The room where testing will occur must be prepared by removing all extraneous thermal sources, or at a minimum, isolating extraneous thermal sources with IR absorptive material before any testing is conducted.

4.2 Reference and Gas Cell Preparation. Perform leak checks on both the reference and gas cells. Ensure that the temperatures of the cells are within 0.1 °C and that the pressure measurements are working.

4.3 OGI Camera Preparation. Ensure the OGI camera is operating to manufacturer specifications and able to record in raw IR radiance on a per pixel basis.

4.4 Blackbody Preparation and Verification. Prepare the blackbody by setting the temperature 10.0 °C different than the gas and reference cell temperatures. Ensure the blackbody is working correctly by verifying the IR radiance homogeneity of the blackbody surface with the OGI camera.

4.5 System Preparation. Ensure the alignment of the cells, blackbody source, and OGI camera are all fixed in place and cannot deviate from their position during the testing.

4.5.1 The reference and gas cell windows must overlap the blackbody surface in a manner that provides sufficient viewing of the blackbody surface from the vantage point of the camera.

4.5.2 The reference and gas cells should be placed sufficiently away from the blackbody surface. The distance must be far enough to ensure that the reference and gas cells are not be heated or cooled by the blackbody surface.

4.5.3 The OGI camera should be located at a distance such that the field of view allows the requirements of the IR radiance pixel area to be met. Additionally, the distance must be such that it does not nominally change the path length of the cell.

4.5.4 For both the reference cell and the gas cell, the depth of the cell and concentration of the gas must result in a concentration 10,000. ppm-m with less than 2 percent error.

4.6 Initial System Assessment.

4.6.1 Flow zero gas through both the reference and gas cell, and ensure the gas cell temperatures are within 0.1 °C.

4.6.2 Record the temperatures of the gas and reference cells, the blackbody surface, and the room. Record the pressures in the reference and gas cells. Record the flowrates into the reference and gas cells.

4.6.3 Measure the IR radiance of the reference cell, the gas cell, and the blackbody surface for a measurement data set. Calculate the average of the IR radiance pixel area, the standard deviation of the IR radiance pixel area, and the 99 percent confidence level of the IR radiance pixel area for the reference cell, gas cell, and the blackbody surface for the measurement data set.

4.6.4 The detection limit for the system will be the highest 99 percent confidence level.

4.6.5 If the standard deviation of the reference cell's and the gas cell's average pixel areas of interest have a difference greater than 5 percent, take corrective actions and repeat the assessment.

5.0 Sampling and Analysis Procedure

5.1 Flow reference compound gas through the reference cell and test gas for the compound of interest through the gas cell and ensure the cell temperatures are within 0.1 °C.

5.2 Record the temperatures of the gas and reference cells, the blackbody surface, and the room temperature. Record the pressures in the reference and gas cells. Record the flowrates into the reference and gas cells. If using Method 205 of 40 CFR part 51 Appendix M for dilution of the test gas for the compound of interest, record the appropriate parameters required by the method.

5.3 Adjust the gas flow if the pressure in the cell is not within an inch of water of ambient pressure. Ensure cell temperatures are within 0.1 °C of the room temperature.

5.4 Measure the IR radiance of the reference cell, the gas cell, and the blackbody surface for a measurement data set. Calculate the average of the IR radiance pixel area and the standard deviation of the IR radiance pixel area for the reference cell, gas cell, and the blackbody surface for the measurement data set.

6.0 Post-test Requirements

6.1 Post-test Assessment.

6.1.1 Flow zero gas through both the reference and gas cells and ensure the cell temperatures are within 0.1 °C.

6.1.2 Record the temperatures of the gas and reference cells, the blackbody surface, and the room. Record the pressures in the reference and gas cells. Record the flowrates into the reference and gas cells.

6.1.3 Measure the IR radiance of the reference cell, the gas cell, and the blackbody surface for a measurement data set. Calculate the average of the IR radiance pixel area, the standard deviation of the IR radiance pixel area, and the 99 percent confidence level of the IR radiance pixel area for the reference cell, gas cell, and the blackbody surface for the measurement data set.

6.1.4 If the average and standard deviation of the reference cell's and the gas cell's average pixel areas of interest have a difference greater than 5 percent between the pre-test and post-test assessment, then the test is invalid. Take corrective actions and repeat the test.

6.2 When the average of the IR radiance pixel areas for the compound of interest over the measurement set as determined in Section 5.4 of this annex is greater than the detection limit established in Section 4.6.4 of this annex, calculate the RF for the compound of interest as follows:

$$RF = \frac{\left(I_{Compound\ of\ Interest} - I_{Gas\ Cell}\right)}{\left(I_{Reference\ Compound} - I_{Reference\ Cell}\right)}$$

RF = response factor of the compound of interest (unitless)

$I_{\text{Compound of interest}}$ = average of the IR radiance pixel areas for the compound of interest over the measurement set as determined in Section 5.4 of this annex, $W \cdot m_{-2} \cdot sr_{-1}$.

$I_{\text{Gas Cell}}$ = average of the IR radiance pixel areas for the gas cell over the measurement set during the pre-test assessment as determined in Section 4.6.3 of this annex, $W \cdot m_{-2} \cdot sr_{-1}$.

$I_{\text{Reference Compound}}$ = average of the IR radiance pixel areas for the reference compound over the measurement set as determined in Section 5.4 of this annex, $W \cdot m_{-2} \cdot sr_{-1}$.

$I_{\text{Reference Cell}}$ = average of the IR radiance pixel areas for the reference cell over the measurement set during the pre-test assessment as determined in Section 4.6.3 of this annex, $W \cdot m_{-2} \cdot sr_{-1}$.

6.3 When the average of the IR radiance pixel areas for the compound of interest over the measurement set as determined in Section 5.4 of this annex is less than the detection limit established in Section 4.6.4 of this annex, the RF is equal to zero.

7.0 Reporting and Recording Requirements

7.1 Records, including all raw data and calculations, must be kept for a period of 5 years, unless otherwise noted below or otherwise specified in a referencing subpart. Records may be retained in hard copy or electronic form.

7.2 All records supporting the development of RFs under this annex must be maintained in a manner that is easily accessible to all OGI camera operators using the RFs. These records must be retained for as long as the site performs OGI surveys with a camera model that relies on the RFs. While the owner or operator does not need to have a copy of these records onsite if another entity performed the development of the RFs, the owner or operator must: (1) ensure that the RF development was performed in accordance with the requirements of this annex, (2) ensure easy access to these records, and (3) make the records available for review if requested by the Administrator. These records must be retained for the entire period that the OGI camera is used to conduct surveys at the site. Previous versions of these records that are no longer relevant because they have been replaced by newer versions or because the specific OGI camera model is no longer being used to conduct surveys at the site must be retained for a period of 5 years past the date on which the records are replaced or the OGI camera model is no longer being used to conduct surveys at the site.

8.0 References

8.1 U.S. Environmental Protection Agency. (2021). Technical Support Document: Optical Gas Imaging Protocol (40 CFR Part 60, Appendix K).

8.2 Zeng, Y., J. Morris, A. Sanders, S. Mutyala, and C. Zeng. (2017). Methods to Determine Response Factors for Infrared Imagers used as Quantitative Measurement Devices. *Journal of the Air & Waste Management Association*, *67*(11), 1180-1191. DOI: 10.1080/10962247.2016.1244130. Available online at: https://doi.org/10.1080/10962247.2016.1244130.