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4.3 Applications

Methane detection and quantification technologies can be used for a wide range of applications related to the mitigation of methane emissions starting at oil and gas production and processing sites and continuing all along the natural gas supply chain. An "application" is the physical scenario to be measured, which describes the targeted types of emissions and the intended scale for detecting the emissions. The "platform" is the specific strategy, devices, and specific deployment method used to make the methane emission measurement for the target application. An application reflects the user's desired goals, scale of application, accuracy and frequency of measurement, and assumptions about the distribution of emissions. The application selected depends upon the user's goals, which can be determined using these questions (see discussion below for further description of these questions):

- What type of methane emissions are we trying to detect?
- How do the target emissions behave?

The answers to those questions then lead to follow on questions that determine the application:

- What do we need to determine about the emission source?
- When (with what frequency) do we want to inspect?
- At what scale are we applying the detection?

The platform will be the device used, the deployment method, and the processing required. The same technology may be deployed in different methods in some cases. Portable deployment methods are small and lightweight enough to be carried as handheld or backpack mounted devices. Vehicle-mounted technologies are transported by ground-based vehicles such as all-terrain vehicles or automobiles. Aerial deployments may be on fixed-wing aircraft, helicopters, or unmanned aerial vehicles. Satellite-based deployments are possible for some measurement technologies. Stationary technologies are installed at fixed locations located at or near the areas being monitored. Many technologies can be deployed on several platforms depending on their size, weight, and power requirements.

What type of methane emissions are we trying to detect?

As shown in Section 2 (Characterization of Emissions), emissions result from some very distinct and different sources along the natural gas supply chain. The emissions may be continuous or discontinuous.

- Normal fugitive emissions result from imperfect seals on sealed and packed surfaces, such as flange gaskets, screwed connections, closed valve seats (called "open-ended lines"), valve stem packing, pressure relief valve seats, compressor rod packing, and even pinhole leaks in pressure pipes. This narrow "fugitives" focus allows a variety of typical leak detection tools to be used.
- Intentional vented emissions (e.g., pneumatics devices, gas well liquid unloading blowdowns, equipment blowdowns for maintenance, and venting from tank flashing) may require unique measurement approaches if individual sources are measured.
- Unintentional emissions result from maintenance issues or malfunctions, such as unlit flares/combustors, stuck dump valves on separators, and unintentional venting from a variety of sources. Many of these vented sources require more complex measurements, as many cannot be measured with typical leak detection tools. They also may require root cause analysis, in order to separate them from intentional, already reported, and accounted for venting.
- Combustion products from engines and heaters result in the exit of some unburned methane from the exhaust.

A user may be focused on all of the above. Each of these answers will result in the selection of different applications.

How do the target emissions behave?

The emissions from the simplest fugitive sources are assumed to always leak once it starts. Therefore, a periodic emission measurement would catch most of the leaks occurring at a set point in time.

Some vented sources may behave this way also, but for some emissions from vented sources, the source may start and stop, such as pneumatic device emissions, tank flashing emissions, and blowdown emissions. A specialized measurement approach that can cover variable rates and can integrate enough time would be needed for these discontinuous emissions.

Emission studies continue to reveal that almost all emissions categories are known to have a highly skewed, non-normal distribution, with a minority of the sources contributing a majority of the emissions. Therefore, effective measurement requires an approach that can detect these few large important sources.

Once the user determines the answers to the above questions, they have determined their focus for measurement. Now they must ask the following questions that can help determine the application and platform:

What do we need to determine about the emission source?

Do we need exact location? Do we need to quantify it? Do we need to just find and fix it? Do we need to separate out normal allowed emissions from abnormal unintentional emissions?

When (and with what frequency) do we want to inspect?

If we have determined that the sources behave with unpredictable temporal variability, then we may need to have continuous measurement. Otherwise, a single measurement may suffice to find all the emissions that exist at a set point in time.

The temporal scale of an application denotes the time period of detection or quantification. An instantaneous scale such as a single OGI image provides a snapshot of emissions at the time of measurement. A discrete scale is a fixed interval that produces either a series of instantaneous readings or a time-averaged value. For example, some mobile monitoring approaches collect data for at least 15 minutes at each site before calculating an emission rate. Continuous scale refers to a technology that is permanently installed to monitor a location. Although continuous applications are designed to always collect data, environmental conditions such as wind direction may limit the value of the data to discrete intervals where conditions are appropriate for the detection.

At what scale are we applying the detection?

Are we measuring an entire basin, a single site, or a single piece of equipment? This answer can set whether the device must closely examine each piece of equipment or would be applied only to know larger emissions from an entire site or combination of sites.

The spatial scale of an application refers to the size of the area or volume being targeted for detection or quantification. Some applications such as remote sensing, quantify emissions at a scale larger than individual sites such as a basin or a satellite's spatial resolution. Although these applications have limited value for equipment level leak detection, they can identify areas of high emissions to prioritize finer scale surveys. Other applications identify the individual site where emissions occur, but do not resolve the exact location of the source. Finer scale surveys can localize the emission source to varying degrees of resolution from the approximate area of a site down to the exact component.

Applications can be described by general parameters such as their spatial scale, temporal scale, detection sensitivity, sampling efficiency, and platform. They also can be defined by their desired end results: application goals can include detecting fugitive emissions, precisely locating emission sources, quantifying their emission rate, speciating gases, or a combination of these aims. For each of these objectives, there are several methods for measuring and analyzing data that may be applicable under different sets of parameters and objectives. Understanding these applications is a critical step for designing and implementing evaluation programs.

The following sections give examples of applications that meet particular methane measurement and mitigation goals that will drive the selection of a particular measurement device and platform.

4.3.1 Application to Fugitive Emission Sources at an Equipment Level

Fugitive emission sources are a subset of all sources at a site. Enhanced methane concentrations can be caused by onsite fugitive emission sources, onsite vented sources, offsite sources, and/or elevated methane background. For many LDAR programs, only the fugitive emissions are targeted for application because of regulatory drivers and because on-site fugitive sources represent unintentional emissions that may be repaired by the operator.

An application's primary goal can be to detect onsite fugitive sources without assessing their precise location or emission rates. Typically, a scan is used to identify the leak sources which are then prioritized for repair and maintenance. Avoidance of false positives is critical for fugitive emission detection since mistakenly identifying an offsite or vented source as an onsite fugitive can trigger unnecessary site visits.

For imaging technologies, distinguishing onsite fugitive emissions can be accomplished easily if emissions are detected from a source that should not have emissions when operating properly. Imagery can also identify abnormal emissions from vented sources, such as continuous emissions from an intermittent pneumatic controller. However, a longer viewing period and knowledge of equipment operations may be required to determine confidently that emissions are not venting normally from operational equipment.

For applications that use methane concentration data, onsite fugitive sources can be distinguished from other sources by calculating values such as the approximate location, emission rate, temporal profile, or speciation of emissions. In general, this approach involves determining the baseline profile of offsite and onsite vented sources that can be encountered at the target site. Leak detection systems only indicate the presence of a leak when enhanced concentrations appear to originate from an onsite location not associated with a vented source. In practice, determination of fugitive sources can be highly complex and dependent on meteorological conditions. Methods for localizing sources and quantifying emission rates will be discussed in detail in the following sections. Only approximate estimates may be needed for distinguishing onsite fugitive sources, but greater accuracy is required if fugitive and vented sources have similar locations or emission rates. The temporal profile of emissions can also be used to distinguish fugitive sources under some circumstances. For example, continuous methane concentration enhancement from an intermittent pneumatic controller may indicate a malfunction that causes abnormal emissions between actuations. Finally, speciation may provide useful information about the likely source of emissions. For example, a technology that measures carbon stable isotope ratios of methane can indicate if enhanced concentration is from biogenic sources such as landfills or cattle.

4.3.2 Application of Optical Gas Imaging at Various Scales

Several technologies exist which produce an image of methane emissions. In general, these technologies measure the effect of methane molecules on reflected light, which can be either sunlight or light from an active source on the aircraft (typically a laser). By measuring the reduction of the light intensity, the amount of methane along a given path can be determined.

Images of these concentrations are produced either by collecting light through an optical system or by scanning a laser source across a scene. Depending on the spatial resolution of the system and the height of the platform, the images can then show the full geometry of a methane plume, allowing a source location to be determined. It is also possible to make source intensity estimates based on the concentration heat map and ancillary measurements or assumptions.

To date, none of these systems offer direct speciation. However, they produce concentration maps of plumes that usually indicate the source of the methane clearly.

The advantages of using OGI includes accurate identification of locations of unknown sources, lower false positive rates, and potential cost savings (less expensive). The disadvantages include the lack of speciation, poorer minimum detection thresholds, and a lower ability to estimate overall emission rates of a large area.

4.3.3 Applications Requiring Quantified Emission Rates

Some applications require actual rate quantification of an emission and not just simple detection of an emission. Examples of such application needs include emission inventories, determining emission rates (or emission factors) for a particular source category, or applications that require proof of reduced emission rate by measurement.

There are a few options that produce emission rate estimates:

- Direct flow measurement (individual source scale) may be done by bagging, temporary flowstacks with meters, high-volume dilution sampling
- Engineering and fluid dynamic calculations
- Downwind tracer flux (typically site scale)
- Inverse dispersion modelling
- Mass balance (aerial box models, larger scale)
- Quantitative imaging

Some of these methods are discussed in more detail below.

Direct flow measurement – high volume dilution sampling is a quantification approach that measures a component's emission rate by drawing in a source's total emissions with a known air flow. The high-flow dilution sampler is a backpack-sized, portable instrument used to measure continuous leak emission rates of gaseous hydrocarbons such as methane. The device has been commercially available for 20 years and used in many studies and LDAR programs, especially in the natural gas supply chain (Figure 11). Unlike most other leak detection and screening analyzers that simply detect concentration of a species in air, the high volume dilution sampler produces a rate of emission measurement. Compared to other devices like flame ionization detectors and photo ionization detectors that simply measure concentration in a very small sample of air, the high volume dilution sampler draws in a very large flow rate of air (between 5 and 10.5 cfm), with the result that the device can calculate an emission rate from the known air flow and the measured concentration. This approach assumes that the entire emission rate is captured by the high volume dilution sampler. This can be tested by allowing the device to pull in less air and check to see that it still calculates the same emission rate. The high volume dilution sampler utilizes two sensors, a catalytic oxidation sensor for gas concentrations ranging from 0 to 5% by volume of methane, and a thermal conductivity sensor for gas streams containing higher methane concentrations. The internal computer switches between the two sensors at certain concentration levels. The leak rate measurement is conducted by placing the instrument hose inlet in a manner that captures the emission source being sampled, with the concept being that the instrument draws in enough excess air to capture the entire leak. The high volume dilution sampler has been in common use in national emission measurement studies as well as in LDAR programs, where it is often paired with a faster screening device such as an OGI camera.

Engineering and fluid dynamic calculations often use principles of science first that produce an emission rate estimate. Examples would be calculation of tank flashing losses, well liquids unloadings, and vented quantities when equipment is depressurized for maintenance or emergencies. Often there are set protocols or models for these calculations. For example, there are simplified computer models and more complex equation-of-state models that can be used to calculate tank flashing emissions. There are also codified estimation techniques in regulations, such as the equations for gas well liquids unloadings that are presented in the USEPA's Greenhouse Gas Reporting program. Simple calculations of vented emissions from a maintenance depressurization event can be calculated from internal volume and known operating pressure before the event. Engineering calculations may also be used for a wider variety of emissions estimations that are not described here.

Downwind tracer flux correlation approaches use a controlled release of a tracer gas at a known emission rate to estimate emissions of methane based on the assumption of equivalent dispersion (Roscioli et al. 2015) (Mitchell et al. 2015). An ideal tracer can have its concentration precisely quantified with available equipment and has no other emission sources of the tracer near the target location. Common tracers used at O&G sites include acetylene, nitrous oxide, and sulfur hexafluoride. (Note: Care should be taken in selecting a tracer as the tracers themselves can have environmental impact). Downwind of the tracer and target emission source, concentrations of both methane and the tracer gas are quantified along a crosswind gradient, typically by driving a vehicle-based platform perpendicular to the wind direction or using multiple open path instruments. If methane and the tracer have equivalent atmospheric dispersion, then both gases will have equal ratios between their integrated concentration enhancement and emission rate. Since the emission rate of the tracer is known, methane emissions are calculated by multiplying the integrated methane concentration enhancement by the tracer ratio. To test the assumption of equivalent dispersion, the dual tracer correlation technique releases a second tracer near the target emission source. If both tracers and the methane emission source are dispersed equivalently, then all three gases will have overlapping plumes with highly correlated concentration enhancement. If the target site has a large area with many potential emission source locations, then the dual tracer approach can provide information on the approximate location of the source by releasing the two tracers near different potential sources. At near downwind distances, the tracer plumes will be distinct with methane concentration enhancement most highly correlated with the tracer closest to its emission source. Increasing the downwind distance will cause the plumes to converge until all three gas concentrations are correlated. The tracer flux correlation approach is a highly accurate method for quantifying site emissions and has been used to assess other methodologies. Disadvantages include the need for onsite or fence line access for tracer release and downwind access for the mobile platform or open path instruments.

Inverse dispersion modeling approaches use either mobile or stationary platforms for methane-in-air measurements and inversely apply the Gaussian dispersion equation to estimate site-level emissions. There are several ways in which this approach can be deployed. In one application, a vehicle drives downwind of the site perpendicular to the wind direction and determines the horizontal methane concentration gradient. Wind speed, wind direction, and atmospheric stability class are determined from either a platform-based anemometer or local meteorological station. Emission rates can be quantified in one of two ways. If the approximate source location is known, then the emission rate can be calculated by fitting the plume to a Gaussian model; since all other terms are known in the Gaussian dispersion equation, the emission rate can be back calculated from the concentration and meteorological data (Lan et al. 2015). If the location of the source is unknown, then a dispersion modeling approach can be used to estimate the approximate source location and emission rate (Yacovitch et al. 2015). The method chooses several potential source locations and uses a model to predict the shape of the plume encountered by the mobile platform (the shape of the plume is independent of the emission rate). Based on the fit of observed and predicted data, different source locations are modeled iteratively until there is an optimum fit with the observed data. The optimum source location then is used to estimate the emission rate using inverse Gaussian dispersion modeling.

Other Test Method 33A (OTM33A) is a special type of inverse dispersion modeling approach since it is considered by USEPA as a mobile inspection method (Brantley et al. 2014). A mobile platform with a high precision, fast response methane concentration analyzer and 3D sonic anemometer is positioned downwind of the target site in a stationary position. Methane concentrations are measured in tandem with wind speed, wind direction, and estimated atmospheric stability class. Based on the changes in methane concentration relative to variable wind direction, data are fitted to a Gaussian function to determine average peak methane concentration of the plume and then the source emission rate is calculated with a 2D Gaussian integration. Like most inverse dispersion model approaches, OTM33A does not require site access, but this may affect the accuracy of the results. The approach does require downwind access for the mobile platform. The method has an accuracy of ±56% (Robertson 2017) and may not be suitable in areas with rough topography, significant structures, or forested terrain where dispersion deviates substantially from Gaussian models.

Mass balance (e.g., aerial box models, larger scale) is an aerial approach that relies on the principle of conservation of mass to quantify emissions from an area bounded by upwind and downwind transects (Karion et al. 2013); (Pétron et al. 2014); (Karion et al. 2015); (Lavoie et al. 2015); (Conley et al. 2016). The general approach is to use an aerial platform to measure methane concentrations along an upwind and downwind transect within the atmospheric boundary layer and then integrate methane concentrations horizontally across the transect and vertically from the ground to the top of the boundary later. The methane emission rate from the area bounded by the transects is calculated as the difference in the upwind and downwind integrated methane concentrations multiplied by mean horizontal wind speed and the cosine of flight transect perpendicular to the horizontal wind direction. A variation of the approach omits the upwind transect and relies on the edges of the downwind transect to estimate background methane concentrations. Another variation uses a spiral flight path around the target area to more accurately assess upwind and downwind concentration differences across the vertical gradient. Depending on the length of the flight paths, atmospheric mass balance can be used to estimate emissions from a basin, individual site, or any size area in between. A successful mass balance measurement requires a steady wind speed and direction, constant boundary layer height, and no mass transfer across the boundary layer. Uncertainty depends on meteorological conditions and variability in background methane concentrations, but generally is in the range of ±30–50%.

Quantitative Imaging is a developing technology for estimating emission rates directly from optical imaging of the emission plume. These techniques produce rate estimates, not just plume concentration estimates and are not yet widely tested nor widely used as the other emission rate techniques mentioned above. Quantitative imaging can be developed in a number of ways, including correlations using the same device under the same environmental conditions for known or set emission rates. An advantage to quantitative imaging, should it prove to be robust, could be the real time development of emission estimates from simple imaging.

An existing example of quantitative imaging is quantitative optical gas imaging (QOGI) that is paired with existing OGI cameras. The emission rate estimate is produced by near real-time image processing of the OGI output. QOGI is based on a signal extracted from the gas plume using certain plume extraction algorithm, and calibration curves that are established between this signal and known leak rates under certain conditions. This allows the QOGI device to examine pixel movement and density of the plume and to then estimate an emission rate. This same concept may be applied to imaging from other devices as well.

4.3.4 Applications Requiring Speciation

At sites where multiple gases may be released, one of the goals of an approach may be related to speciation including identifying gas composition, detecting or quantifying only a subset of specific gases such as methane, or separately assessing individual gases. Some technologies, particularly sensors utilizing narrow-band absorption, only respond to methane. Other technologies such as passive IR OGI respond to multiple hydrocarbons and cannot distinguish methane from other gases such as ethane. For technologies that can respond to and distinguish among multiple gases, two general approaches are used: spectroscopy and mass spectrometry. Spectroscopy relies on the unique electromagnetic radiation absorption spectra of individual gases; this can involve measuring individual absorption bans that differ between commonly occurring gases or a hyperspectral approach that compares the full spectra. Mass spectrometry identifies gases by comparing their mass-charge ratio (m/z). Since many gases have similar m/z, mass spectrometry may be coupled with a separation technique such as gas chromatography to first separate gases based on their molecular properties. Unlike spectroscopy, which can work remotely by measuring absorbed or reflected light, mass spectrometry requires the gas to physically enter the detector.

4.4 Summary

Numerous, diverse technologies are currently available or in development for methane leak detection. Most of these technologies either produce an image gas, a measure point, or path methane concentrations. These data are used in a variety of applications including the detection, localization, and quantification of fugitive emission sources at oil and gas sites. The suitability of individual technologies for particular approaches is dependent on their performance on key metrics such as detection limit and response time. This section has summarized the state of knowledge at the time of writing to help stakeholders understand the variety of existing technologies. Due to the rapid advancements in this field, details such as commercial availability, cost, and detection limit likely will be outdated. Stakeholders should consult the most recent data and references to assure that information on individual technologies is accurate and up-to-date, including the availability of new technologies developed after the completion of this document.

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