Formal Methane Alternative Test Method

EPA Alternative Test Method Application

Periodic Screening

Submission date

2025-01-10

Focus

This document is part of Qube's application package for regulatory approval as a periodic screening alternative test method at a minimum detection threshold of 15 kg/hr as per Title 40 CFR part 60 NSPS OOOO Rules Section §60.5398b(b) and §60.5398b(d).

The document focus is to provide a description of the Qube method protocol.

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Methane Alternative Test Method – Qube Technologies 15 kg/hr Periodic Screening System

1 Scope and Application

This document outlines an alternative testing methodology (ATM) for the periodic assessment of methane emissions, leveraging a continuous monitoring system to be deployed at oil and natural gas production facilities in the United States. It details the procedures and information required for the implementation, operation, and use of the Qube Technology Methane Monitoring System as a tool for periodic screening, in accordance with the regulations set forth in §60.5398b(b) and §60.5398b(d).

1.1 Analytes

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

1.2 Scope

This method describes the Qube Technologies (Qube) emissions monitoring system used for periodic screening at a minimum detection threshold of 15 kg/hr. The Qube emissions monitoring system is used for the detection of methane emissions using a network of fixed devices on a site designed to detect, locate, and quantify methane emissions. This method uses technology that consists of three components: (i) an Industrial Internet of Things (IIoT) device housing metal oxide semiconductor (MOS) sensors and digital electro-chemical (DEC) sensors that measure gas concentration and environmental sensors that measure meteorological data. The IIoT device is battery powered and solar recharged and transmits data to the cloud via cellular or wireless networks, (ii) a cloud-based platform that records and analyzes data received by the IIoT device and uses physics-based models to convert device data into leak locations and quantities, and (iii) a web-based dashboard that aggregates critical insights of the analyzed data. The Qube IIoT devices are placed at or near the facility property boundary. This method is a methane alternative test method applicable for the detection of fugitive emissions from affected facilities and the determination of compliance through the inspection and monitoring of covers and closed vent systems in lieu of the procedures set for in the regulations presented in Table 1, including optical gas imaging (OGI) and EPA Method 21.

Table 1: Sections of 40 CFR Part 60 Containing Applicable Regulations

OOOOa (NSPS)	OOOOb (NSPS)	OOOOc (EG)
40 CFR §60.5397a	40 CFR §60.5397b	40 CFR §60.5397c
40 CFR §60.5416b(a)(1)(ii), (a)(2)(ii) and (iii), (c)(1)(ii) through (iv), (c)(2)(iv), and (d)(1)(ii) through (iv)	40 CFR §60.5416b(a)(1)(ii) and (iii), (2)(ii) through (iv), and (3)(iii) and (iv)	40 CFR §60.5416c(a)(1)(ii) and (iii), (2)(ii) through (iv), and (3)(iii) and (iv)

1.2.1 This method detection sensitivity is 15 kg/hr with a 90% probability of detection.

1.2.2 This method applies to well sites, centralized production facilities, and compressor stations in the crude oil and natural gas source category in all basins of the United States.

1.2.3 This method characterizes emissions at a facility-level spatial resolution, meaning this method identifies emissions within the boundary of a well site, centralized production facility, or compressor station.

1.2.4 This method relies on local meteorological data (wind speed and direction, temperature, barometric pressure, and humidity) in addition to location data to assist with the identification of emission source locations.

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.

2 Summary of Method

2.1 Description of System

The Qube emissions monitoring system is a network of fixed devices on a site designed to detect, locate, and quantify methane emissions in real time. The technology consists of three components: (i) an Industrial Internet of Things (IIoT) device houses various sensors that measure gas concentration and environmental data and transmits this data to the cloud, (ii) a cloud-based platform records and analyzes data received by the IIoT device and uses physics-based models to convey device data into leak locations and quantities, and (iii) a web-based dashboard aggregates critical insights such as emission rates (*e.g.,* block averages) and alarms generated by the platform and identifies the remedial actions necessary to address the detected emissions.

2.2 Deployment

This method describes the deployment of Qube IIoT devices, including the determination of the number of devices needed for each site and the placement of these devices within 100m of potential emission sources.

2.3 Qube IIoT Devices

The Qube IIoT devices use MOS sensors to detect and quantify methane emissions. The working principle of MOS involves the absorption of methane into the active sensing layer, which leads to a change in electrical resistance and correlates to a methane concentration. As ambient methane concentration increases, more methane molecules interact with the tin oxide, resulting in a reduction in the sensor's electrical resistance. This change in resistance allows for the quantification of methane concentration in the air. By comparing the sensor's resistance in clean air to its resistance in the presence of methane, the concentration of methane in the environment can be determined. This comparison yields a mixing ratio that reflects the amount of methane present. Additional information on how MOS sensors detect gases is included in Reference 1 of Section 16.

2.4 Data Collection and Transmission

Methane concentrations and environmental data (*e.g.,* wind speed, wind direction, temperature, barometric pressure, humidity, and device location) are transmitted to Qube's cloud-based analytics platform, where the data is converted from concentrations into mass emission rates using physics-guided models.

2.5 Data Storage

Individual dashboards are utilized by Qube to provide operators with summary information including site emissions, and alerts from periodic screening surveys with confirmed detections. Operators utilize these dashboards to provide information such as ground-based confirmation of emissions, and mitigation steps.

3 Definitions of Method

DEC sensor means a digital electrochemical sensor used to collect information on other gases, such as carbon monoxide, hydrogen sulfide, and sulfur dioxide.

Detection radius means the radius from a single device within which a methane concentration reading can reasonably be expected to be detected. The detection radius of this methane cannot exceed 100m.

Device concentration time series refers to the continuous recording and analysis of concentration levels of methane, measured by a device over a period. This data is collected at regular intervals, creating a sequence of concentration values that reflect changes over time.

Device downtime refers to the measurement of time when a device has not delivered at least one methane reading within a 6-hour timespan.

IIoT means an industrial internet of things, which is a network of devices, sensors, and other instruments that are connected to industrial applications via the internet.

MOS sensor means a metal oxide semiconductor sensor used to detect concentrations of methane gas.

Qube IIoT device refers to the Industrial Internet of Things device which houses the MOS methane sensor along with the power and communications systems required to send continuous data from the field to the cloud

Sensor baseline means refers to the standard or reference level of measurement that a MOS sensor records under normal, stable conditions without the presence of any external stimuli or targeted substances. This baseline serves as a control or benchmark against which any deviations or changes in sensor readings can be compared.

4 Interferences

4.1 General Interferences

Qube's IIoT devices must be positioned within a leak's plume to acquire methane measurements, therefore siting according to Qube's deployment protocol described in Section 8.2 is critical.

4.2 Offsite and Confounding Emissions

Qube's sensors may detect methane emissions from non-target oil and gas facilities or unrelated sources, such as livestock or wetlands. Siting according to Qube's deployment protocol described in Section 8.2 provides additional data for use in the physics-guided models used by Qube to determine source location. See Section 12 for a description of the physics-guided models used for this test method.

4.3 Communication from the Devices to the Cloud

Timely communication of data from the Qube IIoT devices to the cloud is critical to ensure that methane emissions are identified in near real-time. The Qube devices use embedded LTE CAT-M1 modules to communicate with the cloud. These modules are FCC (US) & ISED (Canada) certified (FCC ID: 2AEMI-B404X, ISED: 20127-B404X) and they support 3GPP Release 14. The modules are compatible with AT&T, T-Mobile, and Verizon networks in the US.

4.4 Power

The Qube IIoT devices included in this method are battery-powered and solar-charged. The lithium titanate battery used for this method is well suited to extremely low temperatures and is rechargeable down to temperatures of -20°C (-4°F) and is sized for up to 8 days of operation in the absence of solar generation or extreme cold temperatures.

4.5 Humidity and Bump Testing with Calibration Gases

Qube's MOS methane sensors employed in this test method require >10% humidity to detect calibration gases. It is therefore required that any bump tests using calibration gas in the field or in the lab follow the conditions specified in Section 7.

See Section 10 for additional description of the calibration steps used by Qube for this method.

4.6 Operational Ranges

Table 2 provides a summary of the detailed system specifications, including operational ranges (concentration, temperature, and relative humidity), minimum detection limit, data measurement, and transmission frequencies that are necessary for this method using Qube's IIoT devices.

Table 2: Overall Qube IIoT system performance specifications for this method

Metric	Range/Value
Concentration measurement range	0 – 1,000 ppm
Concentration measurement accuracy	± 1%
Concentration measurement precision	± 1 ppm
Detection temperature range[1]	-40 to 70 °C (-40 to 158 °F)
Detection relative humidity range[2]	10 – 100%
90% Probability of detection limit[3]	1.5 kg/hr
Measurement frequency[4]	3 – 5 seconds
Transmission frequency[4]	1 – 20 minutes

Quantification frequency	1 minute
Connectivity	LTE Cat M1: bands 2, 4, 5, 12, 13
Solar panel	30 – 45 W
Battery[5]	Lithium titanate with 8 days of reserve

[1] Temperature detection range varies depending on whether high-temperature or standard methane sensors are deployed. Standard temperature range is -40 to +50°C. The High-temperature sensor range is -10 to 70°C.
[2] The relative humidity range varies depending on whether high-temperature or Standard methane sensors are deployed. Standard RH range is 10-90% RH. The High-temperature sensor RH range is 10-100%.
[3] The minimum detection limit was verified through blinded 3rd party testing at METEC and through single-blinded testing performed in collaboration with Highwood Emission Management. See References 2 and 3 in Section 16.
[4] Measurement and transmission frequencies vary depending on compression at the device level, only meaningful data is transmitted (e.g., if measurements plateau, for example in a period of no gas exposure, then only the first and last measurements are transmitted to conserve bandwidth and power).
[5] Battery can discharge at -40°C, but solar recharge is limited at <-20°C, so a reserve of 8 days at 100% is included.

5 *Safety*

5.1 Disclaimer

This method may involve hazardous materials, operations, and equipment. This methane alternative test method may not address all the safety problems associated with its use. It is the responsibility of the user of this methane alternative test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to performing this methane alternative test method.

5.2 Hazardous Pollutants

Methane, leaks of which may be determined by this method, and other compounds commonly found in the crude oil and natural gas 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 of EPA Method 21.

6 *Equipment and Supplies*

This section describes the primary physical equipment and supplies needed to deploy the Qube IIoT device described in this method.

6.1 Qube Industrial Internet of Things (IIoT) Device

Figure 1 provides an illustration of each Qube IIoT device deployed at a site included in this method. Further description of the key components is provided in the subsections below.

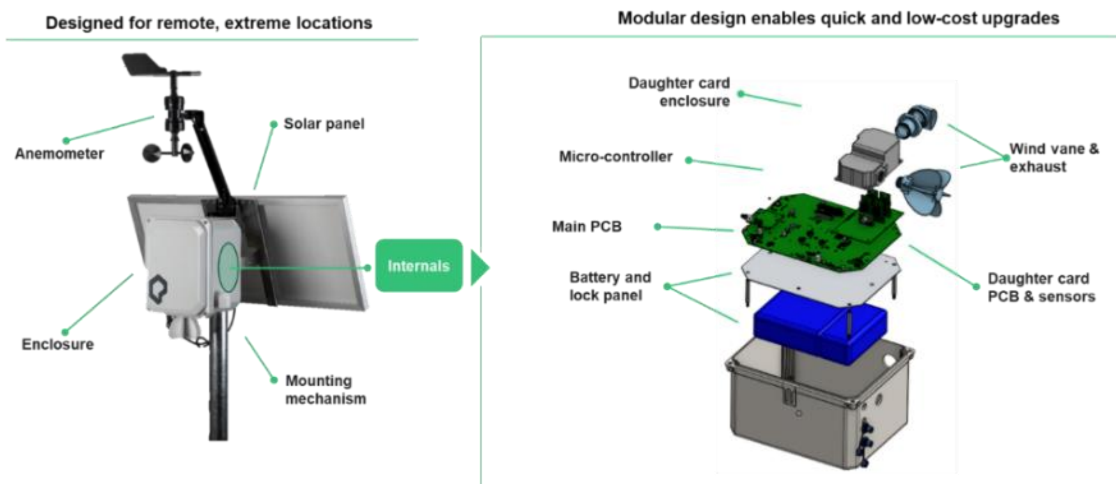

Figure 1: Qube IIoT device and individual components included in this method

6.1.1 Enclosure

The enclosure is a Polycase ZQ-100806. It has been designed for outdoor operations with waterproofing and UV-resistant coating making it capable of withstanding significant exposure to the elements (*e.g.,* extreme temperatures, wind, sun, etc.). The enclosure has an Ingress Protection level of 54 (IP54) which protects the internal components from airborne solid materials (e.g., dust and sand) and liquids (*e.g.,* rain). The enclosure also has a flame rating of UL94 5VA making it ideal for use in oil and gas operations.

6.1.2 Micro-controller and communications module

Each Qube IIoT device deployed for this test method contains a micro-controller, allowing it to collect and process sensor data. Embedded on the microcontroller is a modem that is designed to transmit data through the cellular and wireless internet networks. The modem is compatible with LTE Cat M1 bands enabling deployment of the same Qube device in various regions around the world.

6.1.3 Power source (solar panel and battery)

A 30W-45W solar panel (depending on region) designed to operate in remote, off-grid locations is required to support power generation for the Qube IIoT device. Devices are powered by a rechargeable battery with an expected 10-year lifespan. The rechargeable pack can provide power for approximately 179 hours or 7.5 days without sunlight.

6.1.4 Environmental sensors

The Qube IIoT devices include commercially available environmental sensors that provide data as follows:

- Anemometer and wind direction sensor to measure and record wind speed and direction
- Temperature sensor to measure and record temperature

- Barometer to measure and record barometric pressure
- Humidity sensor to measure and record humidity
- GPS to measure the positioning of the device

6.1.5 Gas sensors

Each Qube IIoT device deployed on a site using this test method is equipped with a Figaro TGC 2611-C00 metal oxide sensor on a proprietary printed circuit board. Each MOS sensor must be calibrated as described in Section 10.1 prior to deployment at the facility. Additional electrochemical sensors can be added to the Qube devices to augment the methane readings or to leverage the Qube IIoT platform for other use cases (*e.g.,* hydrogen sulfide and sulfur dioxide sensors to detect odors). These additional sensors are not relevant to this method.

7 Reagents and Standards

7.1 Calibration gases

7.1.1 The gas must contain a methane concentration of less than 2,500 ppm (100 ppm is recommended).

7.1.2 The gas must be a “balanced air” gas containing air (including oxygen) and methane.

7.1.3 The gas must be hydrated with a relative humidity of at least 10%.

8 Sample Collection, Preservation and Storage

Pre-deployment and planning steps are required before field deployment of Qube IIoT devices. These activities include but are not limited to collecting information on the characteristics of the site and determining suitable device locations.

8.1 Site Characteristics

8.1.1 Onsite Characteristics

The following site characteristics are required inputs for Qube’s deployment planning methodology.

8.1.1.1 Latitude and longitude coordinates of the site to which the Qube system will be deployed

8.1.1.2 Latitude and longitude coordinates and heights of potential emission sources (*e.g.,* location of separator, tanks, compressors, flare stack, vapor recovery unit, etc.)

8.1.1.3 A historic wind data source from a nearby weather station or site with an existing Qube system

8.1.1.4 A defined set of possible device installation locations that avoid any interference with areas of routine operation (*i.e.,* truck traffic), structures, or natural features that may impact solar panel performance

8.1.1.5 A communications check ensuring adequate cellular network connectivity or the need for satellite communications or local WiFi connection

8.1.2 Offsite Interferences

To the extent possible, identify and record potential off-site source interferences (*e.g.,* neighboring industrial facilities, livestock operations, or wetlands).

8.2 Determining Qube Device Locations

8.2.1 Number and Placement

The number and placement of the Qube devices depends on the size, the shape of the site footprint, the prevailing wind direction, and the location of emission sources. Aerial photographs or site maps may be used to determine the size and shape of the facility. Place the Qube devices along the perimeter of the site encompassing a detection radius of 100m across all potential emission sources as shown in Figure 3 in Section 9.2.

8.2.1.1 The Qube devices may be located along the property boundary at a distance no more than 100m (328ft) from potential emission sources. Qube devices are not currently certified for hazardous zones.

8.2.1.2 The Qube devices must be located downwind of emission sources based on the prevailing wind direction for the site, as determined by historic wind data and Qube's placement algorithm. Historic wind data is pulled from public weather data sources including at minimum 12 months of data to account for seasonal variability, or nearby sites with existing Qube systems. Additional devices may be placed upwind of emission sources to allow detection of offsite interferences.

8.3 Qube Device Installation

8.3.1 Each MOS sensor must be calibrated following the procedures specified in Section 10.1 prior to deployment in the field.

8.3.2 Each Qube device must be installed and mounted according to the steps outlined in this section.

8.3.2.1 Remove the device and anemometer box from the main box. Inspect for damage.

8.3.2.2 Open the anemometer box and check contents. Contents should include the anemometer, the inlet vent piece, 4x self-tapping metal screws for securing the main bracket to the mounting pole, and 4x 10-32 machine screws for attaching the anemometer to the top of the main bracket.

8.3.2.3 Slide the main bracket over the 2" outer diameter (OD) mounting pole. The mounting pole can be attached to fence posts using stainless steel worm gear hose clamps or T-bolt clamps. For sites without fencing, piles or stands can be used. Qube recommends a height of 5 to 8 feet for most applications.

8.3.2.4 Remove the anemometer set screw, insert the mounting shaft into the body of the anemometer, and reinsert and tighten the set screw. Note: Insert the anemometer mounting shaft straight into the body of the anemometer. Do not twist or rotate.

8.3.2.5 With the body of the anemometer positioned over the grey device enclosure, attach the anemometer to the main bracket, using the 4x 10-32 machine screws.

8.3.2.6 Thread on the inlet vent piece (hand-tighten).

8.3.2.7 Push-connect the color-coded anemometer and solar panel barrel connectors, aligning the red dots.

8.3.2.8 In temperate climates, adjust the solar panel tilt angle by changing the lower solar bracket bolt position. There are three available positions. The solar panel may be left in the default vertical position in climates with heavy snowfall.

8.3.2.9 Ensure that the outlet vent piece is tightly sealed against the side of the enclosure (hand-tighten).

8.3.2.10 Ensure that the device is oriented with the solar panel and the anemometer's south "S" indicator facing due south.

8.3.2.11 With the device correctly oriented, drill the self-tapping metal screws through the main bracket and into the mounting pole to prevent rotation. Ensure that the base of the pole is also secured to prevent rotation.

8.3.2.12 Remove the front cover panel by loosening the four Phillips head screws.

8.3.2.13 Locate the power jumper in the upper-left portion of the circuit board and pull it off the two pins. The power jumper can be inserted onto one of the two pins for storage.

8.3.2.14 Monitor the status indicator LED below the cellular modem. During this startup procedure it will cycle through several states. A slow teal "breathing" pulse indicates that the device is in its operational state. Prior states may include flashing green (searching for signal), and periodically blinking purple (firmware update in progress).

8.3.2.15 Replace the front cover. Note the device number located on the label on the side of the device.

8.4 Qube Device Registration

Each Qube device must be registered following installation to allow for data transmission following the registration procedures outlined in this section. Registration can be completed via mobile device.

8.4.1 Scan the QR code on the label on the side of the device.

8.4.2 Log in to the client-specific Qube account.

8.4.3 Confirm the device number and click "Next".

8.4.4 Allow use of location devices when prompted. This is vital in order to accurately record the device coordinates, ensuring accurate localization results.

8.4.5 Select the correct site on which the device is installed. The closest available site will be selected by default. Note: sites must be pre-configured by Qube during the Qube deployment evaluation.

8.4.6 Wait approximately 15 seconds for the mobile device GPS coordinates to stabilize, then click "Use My Location".

8.4.7 Confirm the device location on the map. Manually adjust on the map as necessary.

8.4.8 Review the installation details. Click “Save” to complete the registration process.

8.4.9 Optionally, view live data and click “Done”.

8.5 Data Collection

8.5.1 The Qube IIoT devices convert input signals from the sensors into concentration data using a predefined calibration curve and sensor-specific calibration coefficients. The devices send both the input signals and the resulting processed values to the Qube Platform for diagnostics and troubleshooting purposes.

8.5.2 The devices store the data in an internal storage buffer using a data compression algorithm, which detects which data points are necessary for rebuilding the signal. If subsequent readings return identical values within a small threshold, the unnecessary data points are discarded. When a value is detected beyond the threshold, the points required to rebuild the signal are saved and ultimately transmitted. In the absence of methane, the devices can go up to one hour without transmitting data..

8.5.3 The compression algorithm ensures that all meaningful data is sent at full frequency, allowing Qube’s models to localize and quantify emissions accurately as they happen (see Section 12). In the absence of any detected methane, the devices conserve bandwidth and power by transmitting only the important information.

8.5.4 In the case of a communications issue, where the platform does not confirm receipt of the sent data, the device will continuously retry. The device storage buffer can store between 4-8 hours of raw data, depending on compression. Once the buffer is filled, the oldest data will be discarded first. Since data is expected from each device at least once every hour, the platform can flag a device or communications issue for the Qube support team as soon as an hour passes without receiving any data.

8.5.5 Device data is transmitted securely over 2G, 3G, LTE, or Wi-Fi. Where cellular network connectivity is an issue, a Wi-Fi variant can be used, connecting to a local LTE backed Wi-Fi modem, SpaceX Starlink, or a facility’s existing Wi-Fi network.

8.6 Data Storage

8.6.1 Device data is ingested by the cloud-based Qube Platform and is stored in a secure time-series database. All data is encrypted in transit and at rest.

9 Quality Control

9.1 Device QA/QC

Qube implements a QA/QC process before deploying devices to clients. The following steps are included in this method:

9.1.1 Design Verification

This phase involves thoroughly reviewing the product’s design specifications, engineering drawings, and simulation models to identify and resolve any potential issues or design flaws.

9.1.2 Manufacturing Quality Control

Multiple quality control checkpoints are employed during device production. In-process inspections are conducted to verify part dimensions, materials, assembly procedures, and workmanship. Statistical process control techniques are used to monitor key parameters and maintain design tolerances. Tests are performed at the subassembly and final assembly stages to identify any defects before the product is completed. Figure 2 presents these quality control processes. All individual building blocks of the device are tracked including the printed circuit board, individual sensors, battery, solar panel, anemometer, and microcontroller/modem. Test reports and historical data are stored on Qube's database.

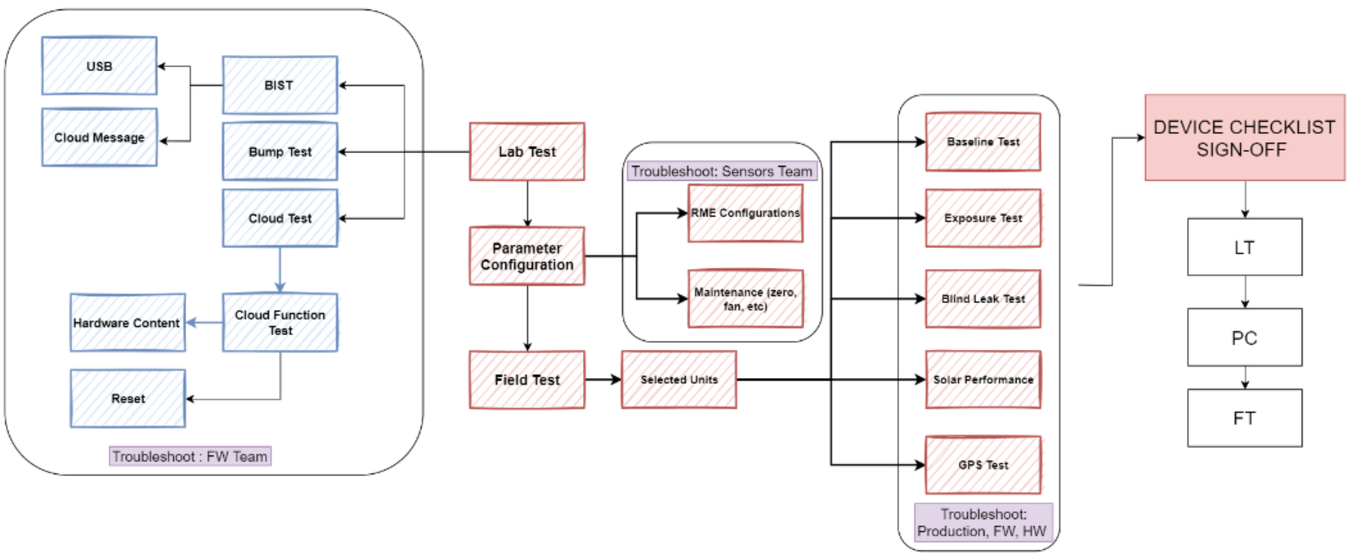

Figure 2: Qube's Manufacturing Quality Control Process

9.1.3 Final Product Testing

Once manufactured, the hardware goes through a comprehensive functional, environmental, and reliability testing. This includes testing for electrical, mechanical, and environmental performance under normal and extreme conditions. Products may be subjected to thermal cycling, shock, vibration, and other stresses to assess durability. Sample testing, such as destructive testing, may also be carried out.

9.1.4 Continuous Improvement

Throughout device production, data quality is closely tracked and analyzed. Any nonconformities or customer issues are thoroughly investigated using root cause analysis. Corrective and preventive actions are then implemented to continuously improve the QA/QC system and prevent recurrence of problems.

9.2 Qube Device Deployment Planning

Qube uses a device placement algorithm to optimize the number of devices required at the site to achieve the maximum emission source coverage given the prevailing wind direction. This device placement methodology is provided in Section 8.2. In this method, Qube ensures that devices are placed with overlapping detection radii over all potential emission sources on a site necessary to achieve the minimum detection limit of 0.1 kg/hr at 100 m from the emission source. Figure 3 provides an example of this overlap placement.

Figure 3: Example Qube device detection coverage per device using 100m radii circles

9.3 QA/QC Following Deployment and Installation of Qube Devices

9.3.1 Summary QA/QC Metrics for Qube Devices

A summary of all the key QA/QC metrics and corresponding acceptance criteria that assure the system is operating in a nominal state can be found in the table below.

Table 3: QA/QC metrics

Component / process	Specification	Acceptance criteria	Frequency of check
CH_4 sensor	Accuracy	Within ±1% when tested with 50, 100 and 250 ppm CH4 calibration gas	Manufacturer
CH_4 sensor	Precision	Within ± 1ppm when tested with 50, 100 and 250 ppm CH4 calibration gas	Manufacturer
CH_4 sensor	Baseline drift	Auto-baseline and recalibration algorithm triggered when baseline drift is detected	Every data packet
Anemometer	Wind speed accuracy	± 1km/h	Manufacturer
Anemometer	Wind direction accuracy	± 1°	Manufacturer
Anemometer	Wind speed bounds	Wind speed is not constant at 0km/hr or >150km/hr for 15-minute rolling periods	Every data packet
Anemometer	Wind direction variance	Direction varies by more than 1° every 15-minute rolling periods	Every data packet
Temperature	Operating window	>-40°C and <70 °C	Every data packet
Relative humidity	Operating window	>10% and <100%	Every data packet
Data transmission	Sensor data	Data transmitted and uploaded to cloud database	Every data packet
Power management	State of charge (SOC)	SOC > 30%	Every data packet
CH_4 mass emission rate calculation	CH_4 mass emission rate	Emission rate generated	Once every 5-minutes

10 Calibration and Standardization

This method requires the calibration of each MOS sensor that is deployed with the Qube IIoT device following Qube's calibration procedures described in this section.

10.1 Laboratory Calibration

Qube calibrates each individual MOS sensor prior to deployment in the field. This calibration is performed by Qube in a specially designed environmental chamber that is controlled for release rate using a mass flow controller, temperature, humidity, and pressure. Each MOS sensor is calibrated to the expected ranges of operating conditions and gas concentration, with an accuracy of 1 ppm or 1% of reading, whichever is greater. This calibration is designed to allow the detection of methane emissions at a minimum detection threshold of 0.1 kg/hr at a distance of 100m.

10.2 Verification of Laboratory Calibration

Qube verifies laboratory calibration against reference monitors during controlled release tests at Qube's Controlled Release Testing Facility. These verification tests are conducted by comparing the methane concentrations of the MOS sensors co-located directly next to the inlet of a Los Gatos GGA-30p Off-Axis ICOS analyzer (LGA).

10.3 Field Calibration after Deployment

Qube deploys a proprietary auto-baseline and auto-calibration process on all MOS sensors deployed in the field. This process is continuously verifying sensor outputs against the environmental gas background at the site location and recalibrates automatically when a drift from the baseline is detected.

11 Procedures

Qube's periodic screening procedures is as follows:

11.1 Site Deployment Procedure

- Gather site information from the operator, including coordinates, satellite/aerial imagery, potential emission sources, and hazardous zones.
- Generate a wind rose using historical public wind data or data from nearby Qube-installed sites to identify predominant wind directions and speeds.
- Determine the number and placement of Qube devices, following the procedure in Section 8.2 and Section 9.2.
- Send the siting proposal to the customer for review. Once approved, proceed with installation according to the steps outlined in Section 8.3 and Section 8.4

11.2 Data Collection Procedure

- After deployment, Qube devices will continuously collect and transmit methane concentration and meteorological data, as outlined in Section 8.5.
- Concentration data is continuously analyzed by Qube's proprietary auto-baseline process to minimize sensor drift and assure data quality as outlined in Section 10.3.
- Device health data will also be sent continuously to ensure site coverage and minimize downtime, as described in Section 9.3.

- All data transmitted by Qube devices is stored on cloud-based servers that is maintained and managed by Qube

11.3 Data Processing Procedure

- Raw data from Qube devices is processed to calculate the mass emission rate, as outlined in Section 12.1.
- The average emission rate is then calculated over a 7-day period and compared to the detection threshold of 15 kg/hr.
- Emissions exceeding the threshold are reported in the periodic screening report.

11.4 Data Reporting Procedure

The results of each periodic screening are provided to the operator in a report, generated automatically within 72 hours of the screening. The report is sent via email and available for download on the Qube platform. It includes the following information for each site:

- Site information: name, location, lat/long coordinates
- Screening period: start time, end time, duration
- Screening results: number of emissions exceeding the threshold, timing and duration of each exceedance, inferred location of each exceedance, average emission rate of each exceedance, emission identification number for each exceedance.

11.5 Recordkeeping Procedure

This section defines which records are maintained by Qube and the operator related to the periodic screening conducted using this test method. Additional records that are required by the work practice specified in the applicable subparts, such as records related to OGI surveys and repairs are not specific to this test method and are defined within the applicable subparts.

11.5.1 The following records are maintained within the Qube platform and accessible to operators via dashboards.

- Name of screening operator (*i.e.,* Qube)
- Lat/long location of each Qube device on the site
- Date of each periodic screening survey (*i.e.,* 7-day period used for screening survey)
- Date that results of periodic screening are sent to the operator
- Aggregate detection threshold used for the screening survey and spatial resolution (*i.e.,* facility-level)
- Records of calibrations used during the screening if needed, including information in Section 7 and Section 10

- Results from periodic screening

11.5.2 The following records are maintained by the operator. The operator may choose to maintain these records within the Qube platform or separately. The operator is responsible for collecting this information and maintaining each record for compliance.

- Records of follow-up inspections from confirmed detections of emissions during periodic screening
  - Date of the inspection of fugitive emissions components and inspection of covers and closed vent systems
  - Name of operator(s) performing the survey or inspection
  - Identification of the monitoring instrument(s) used for surveys and instrument inspections
  - Records of calibrations for the instrument(s) used during the survey or instrument inspection, as applicable
  - Records of each fugitive emission from a fugitive emissions component affected facility and each leak or defect for each cover and closed vent system inspection as specified in 40 CFR 60.5424b(c)(6)(v)(A) through (F)
- Date when an investigative analysis is initiated, and the result of the investigative analysis in accordance with 40 CFR 60.5398b(b)(5)(vi) and (vii)
- Dates of implementation and completion of action(s) taken as a result of the investigative analysis and a description of the action(s) taken according to 40 CFR 60.5398b(b)(5)(vi) and (vii)
- Records of each OGI survey conducted as specified in 40 CFR 50.5424b(c)(9)(i) through (vii)
- Deviations from the monitoring plan or a statement that there were no deviations from the monitoring plan

12 Data Analysis and Calculations

The Qube platform continuously monitors methane gas concentrations and environmental data at each device, collecting measurements as described in Section 8.5 during a periodic screening survey. Qube utilizes the collected wind speed and wind direction data to estimate the trajectory of transported gas and identify potential source(s) of emissions. Inversion modeling is employed to support the estimation of emission rates, with real-time data analysis and processing occurring in the Qube platform. Results are produced every minute based on measurements gathered. Specific details of this process are provided in the following subsections.

12.1 Conversion of methane concentration measurement to mass emission rate

Three main data processing steps are utilized to convert methane concentration data to mass emission rates: (i) detection, (ii) localization, and (iii) quantification.

12.1.1 Detection

12.1.1.1 Qube's platform determines each sensor's baseline methane concentration from the rolling minimum concentration readings (on a per device basis) using each device's previous 3 hours of concentration readings. This baseline is representative of readings when no methane concentration spikes are observed.

12.1.1.2 The sensor baseline determined in 12.1.1.1 is subtracted from each device's concentration time series to obtain methane concentrations over the background.

12.1.2 Localization

Qube's platform collects wind speed and wind direction data from each device's anemometer to assist with determining the potential emission source(s).

12.1.2.1 Qube's platform transforms the collected wind speed and wind direction data into wind vectors. Where data is missing, the average wind vectors across the site are used.

12.1.2.2 Potential emission source(s) are identified by tracing adjoint plumes along the upwind paths from the sensor locations which is shown to be equivalent to forward dispersion in the following equations.

Advection-diffusion equation:

$$\frac{\partial C}{\partial t} + \nabla \cdot (C\mathbf{u} - D\nabla C) = S$$

Advection-diffusion adjoint:

$$\frac{\partial \lambda}{\partial t} + \nabla \cdot (-\lambda\mathbf{u} - D^T\nabla \lambda) = F$$

Where:

$\mathbf{u}$ = velocity

D = diffusivity

S = source term

t = time

λ = adjoint variable

F = adjoint source term

12.1.2.3 Qube's platform corrects for distance from sources using Gaussian plume modeling principles.

12.1.2.4 Qube's platform determines the correlation between concentration readings and potential emission sources located upwind of the sensor measuring emissions. These correlations are converted to determine the probability that each potential source was responsible for the detected emissions. The Pearson correlation coefficient (which measures the linear correlation between two data sets) is computed between the upwind mapping and the sensor readings for each potential emission source. The source with the highest correlation is assumed to be the most likely source of emissions.

12.1.2.5 Qube's platform compensates for potential offsite sources of emissions with offsite direction filtering and estimation of elevated concentrations from offsite sources. The relative positions of Qube IIoT devices and emission sources are known, and gas concentration measurements are associated with wind arrival angles from the anemometer data collected by each device, allowing for directional filtering of data to determine if emissions are from an offsite source. If there is a possibility that readings are related to an onsite emission source then the readings are included for quantification.

12.1.3 Quantification

Qube's platform utilizes a model following the steps outlined in this subsection to quantify methane mass emission rates.

12.1.3.1 Qube's model uses wind speed, wind direction, and methane concentration measurements to estimate a concentration distribution over an area and estimate the rate of emissions leaving the facility.

12.1.3.2 The model assumes that gas releases mix quickly with the surrounding air and that movement of the plumes is primarily driven by the wind. The model also assumes that a single emission dominates at a particular time.

12.1.3.3 Qube's model performs an inversion using processed and filtered device measurements to infer the release rate based on readings from each device and their assumed position within the plume.

$$C(x,y,z) = \frac{Q}{2\pi\bar{u}\sigma_y\sigma_z}\left[\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\right]\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

where:

C = concentration
x = distance downwind
y = horizontal distance from the plume centerline
z = vertical distance from the ground
H = height of the plume centerline (aka. effective stack height)
Q = emission rate
$\bar{u}$ = mean wind velocity in the x direction in the downstream direction along the plume centerline
σ_y = lateral dispersion coefficient (standard deviation of Gaussian distribution in y)
σ_z = vertical dispersion coefficient (standard deviation of Gaussian distribution in z)

This model has the following assumptions:

- No initial concentration is included (plume will be in addition to ignored background)
- Constant source rate is assumed
- No absorption or generation by the ground
- Constant wind in the horizontal direction (x as defined in the above equation)
- Inversion layers are ignored in the simple equation above
- Diffusivities vary only with downwind distance
- Negligible diffusion in flow direction compared with mean transport

12.1.3.4 Qube's platform post-processes individual sensor estimates, and downweighs or removes sensors with a weak signal-to-noise ratio.

12.1.3.5 Qube's platform uses the weighted average to consolidate estimated rates from individual sensor data and return a consolidated value.

12.1.3.6 Qube's platform time bounds the raw estimates of site-level emission rates and averages these values into a single emission event with a constant rate.

13 Method Performance

13.1 Performance Specifications

Section 4.6 specifies the operational ranges required for the Qube system.

13.2 Aggregate Detection Threshold

The aggregate detection threshold of this method is 1.5 kg/hr from distances ranging from 75 to 100m at a 90% probability of detection. These values were determined through independent third-party controlled releases found in references 2 and 3 in Section 16.

14 Pollution Prevention

[Reserved]

15 Waste Management

[Reserved]

16 References

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17 Tables, Diagrams, Flowcharts and Validation Data

[Reserved]