Detection and Quantification of Fugitive Emissions from Colorado Oil and Gas Production Operations Using Remote Monitoring

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INTRODUCTION

Western states contain vast amounts of oil and gas production. For example, Weld County Colorado contains approximately 25,000 active oil and gas well sites with associated production operations. There is little information on the air pollutant emission potential from this source category. Assessment is complicated by the fugitive nature of the emissions and by number of potential sources dispersed over large geographic areas. Fugitive emissions can include ozone precursors, hazardous air pollutants such as benzene, and greenhouse gases such as methane. Recently Colorado and Wyoming have seen increasing ozone levels that exceed national ambient air quality standards. Emissions of volatile organic compounds (VOCs) from these facilities may contribute to this observed increase and, in some cases, may present a concern for nearby residents.

To improve knowledge of this source category, the U.S. EPA is developing specialized measurement approaches and conducting several field campaigns. This report describes field studies conducted in 2009 and planned for 2010 which focus on detection and quantification of fugitive emissions from oil and gas production pads using a new rapid-assessment remote monitoring approach. This paper describes the measurement approach and presents results from a 2009 pilot study in Greeley CO which served as a test of the concept. The platform presentation will augment this information by providing results from the first multi-week field test campaign to be conducted in Greeley CO in May 2010. Plans to deploy the instrumentation and methods developed for the Colorado tests to other areas of the U.S. will also be discussed.

METHODS AND PILOT STUDY RESULTS

Recently developed fugitive emission assessment methods are a subset of EPA's Geospatial Monitoring of Air Pollution (GMAP) program which uses fast-response instruments and a

precise global positioning system in a mobile platform to map air pollution patterns.[1-2] The GMAP Remote Emission Measurement (REM) method has two embodiments which provide either emission measurements from large facilities using a Tracer Correlation (TC) approach[3-6] or fugitive emission localization and assessment with a close-coupled Direct Measurement (DM) approach. The GMAP-REM-DM technique, described here for the first time, was developed specifically for assessment of distributed fugitive emissions in complex source fields such as oil and gas production emissions in areas with high background signal. The DM approach for this project consists of three main elements: (1) fugitive localization, (2) methane (CH_4) emission estimation, and (3) VOC emission assessment by CH_4 ratio calculation.

Fugitive Localization

The first step in the DM approach is determining the location of fugitive emissions within a multi-kilometer survey area. For oil and gas emissions, this is accomplished by driving in close proximity to production sites using a vehicle that is instrumented to detect spatially elevated CH_4 levels. Methane is used as a fugitive indicator since it is the primary emission species from this source category in this area and is also easily measured. Methane concentration data are acquired using a high performance wavelength-scanned cavity ring-down spectroscopy system (G1301-fc, Picarro Inc.) fitted with a high-resolution GPS (R100, Hemisphere GPS). The G1301-fc has a 1σ precision of 3 ppbv at 10 Hz operation, well-suited for high time-resolution concentration mapping applications. The integrated GPS (2 Hz operation) provides high accuracy, time-aligned position data facilitating localization of fugitive emission in a real-time, drive-by fashion. Figure 1 illustrates this point with data from the November 2009 pilot study showing multiple production pad leaks superimposed on an aerial view (Google Earth).

Figure 1: Localization of fugitive emissions from multiple production pads

The DM sampling platform is based on a 4x4 Ford Explorer SUV and is fitted with deep cycle lead acid batteries to allow sampling with the engine off. The sampling probe for the G1301-fc is fixed at approximately 1.5 m above ground level on a front-mounted telescopic mast which remains fixed during the mobile survey. The sampling probe consists of a 0.95 cm input tube split at the point of sampling into four 0.64 cm dia. inlets set 5 cm apart in a square pattern to assist in spatial averaging of the plume. The sample flow is 8 slm and the 10 Hz sampling rate is averaged down to 2 Hz for additional smoothing without loss of fidelity. A solenoid switch system allows periodic canister filling of a shared flow stream (described below). The platform includes a compact auto-north weather station (AIO, Climatronincs Corp.) with the 1 Hz data stream integrated into the G1301-fc. A 3-D ultrasonic anemometer (81000, R. M. Young) is fixed to the top of the mast and is used for wind field diagnostics in stationary vertical profiling mode. The pneumatic mast extends to a maximum 8.7 m with height recorded by a laser sensor (Acuity AR1000, Schmitt Industries Inc.) with position set by feedback control loop. An experiment control computer reads in the G1301-fc-intergrated data stream and other data inputs, performs control functions and in-field calculations, and provides a user interface with experiment step instructions based on data quality indicator analysis. Additionally, an infrared video camera (Gas Finder IR, Flir Systems) is used to document leaking components when present above camera detection limit. For the 2009 pilot study, a variable vertical mast sampling strategy was not yet available so several elevated fixed-point (≈ 3 to 5 m) mobile transects were executed as proof of principle and gradients in concentration were easily observed based on leak height.

Methane Emission Estimation

The second step in the DM approach is to estimate the mass flux of the CH_4 fugitive emission through a combination of downwind horizontal plume transect measurements (y-direction) coupled with stationary vertical plume profiling (z-direction). An average horizontal plume shape is established by driving through the plume multiple times and combining the data with a convolution algorithm resulting in a function, *f(y)*. Multiple transects are needed due to plume and background variability. This is illustrated in Figure 2 and Table 1 which present an example transect from the pilot study showing a production pad with multiple leaks (verified by IR camera) in a high background area with multiple animal feedlot and small farming operations. The observable leaks were ≈ 4 m above ground level and ≈ 25 m from the roadway center. The sampling point was on the vehicle at 2 m above ground level and it is noted that a slower 0.4 Hz response time analyzer was used for the 2009 pilot study. The turn-around points for

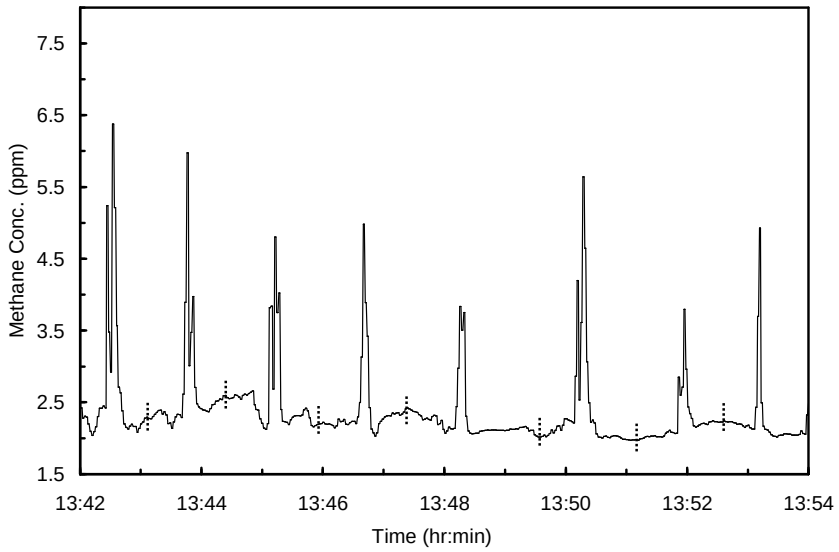

Figure 2: Repeat transect of multiple leaks in high background

the transects are noted by vertical dashed lines. The individual traces show significant variability in maximum concentration which is due to plume and background concentration variations and the slower than optimal sampling rates used in the pilot study. The multiple leaks are resolved in most cases and the variation in background concentrations is evident for this case. The average plume width is approximately 25 m. Figure 3 shows a composite of these transects, *f(y)*, done using a custom convolution algorithm. The local background concentration for the data of Figure 3 was approximately 2.19 ppm.

Table 1: Summary of the events shown in Figure 2

Plume Transect Time (hr:min:sec)	Peak CH_4 Conc. (ppmv)	FWHM (m)
13:42:52 – 13:43:21 PM	6.37	30
13:44:13 – 13:44:40 PM	5.97	15
13:45:38 – 13:46:00 PM	4.80	20
13:47:09 – 13:47:26 PM	4.98	30
13:48:44 – 13:49:02 PM	3.83	35
13:50:46 – 13:51:11 PM	5.64	20
13:52:38 – 13:52:48 PM	3.79	30
13:53:45 – 13:54:00 PM	4.92	20

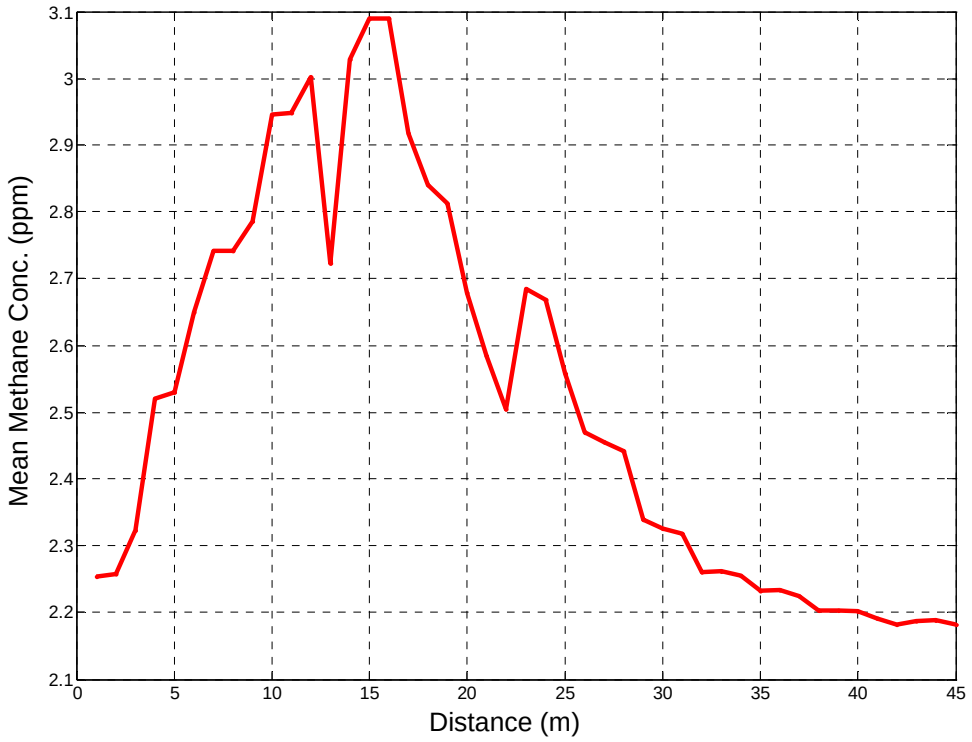

Figure 3: Mean CH_4 concentration profile, *f(y)*, of data in Figure 2

The next step in estimation of CH_4 emissions involves generation of a stationary vertical plume profile. In this step, the experiment control computer aids the operator in the placement of the vehicle at the position of highest ground-level plume concentration. The mast is then raised in a controlled fashion (≈ 0.1 m/s) to sample through the point of highest concentration and establish

a vertical cross section. The process is repeated several times to form a convolved plume profile *g(z)* using the same approach as described above.

The last step in the emission estimation process is to multiply the plane integrated concentration (*PLIC*) (derived from the horizontal and vertical plume profiles) by the normal component of the wind speed (*Ws*) to obtain the emission rate estimate, *Er*.

$$Er = PLIC \times Ws = \left(\iint_A f(y) g(z) dy\, dz \right) \times Ws \tag{1}$$

This functional form assumes that the plume shape in the two transverse dimensions can be correctly expressed as the product of two one-dimensional functions and assumes a constant spatial sampling rate.

The path integrated concentration (PIC) of *f(y)* is given from the 1-D trapezoidal integration of *f(y)* at the vertical position z_0 by breaking the convolved transect data into trapezoids of very fine discreetness. The areas of the trapezoids are then summed to yield the PIC along the axis. For the *y* direction, the area of each trapezoid can be expressed as:

$$A_j = \frac{1}{2}\left(f(y_j) + f(y_{j+1})\right)\left(y_{j+1} - y_j\right)\right) = \left(\frac{f(y_j) + f(y_{j+1})}{2} \right)\left(y_{j+1} - y_j\right) \tag{2}$$

Where:

A_j = equal to the area of each one of the trapezoids;
$f(y_j)$ = the height of the j^{th} trapezoid;
y_j = the base length of the j^{th} trapezoid;

The PIC for *f(y)* is then mathematically expressed as the sum of the area of all trapezoids:

$$\begin{aligned} \int f(y) dy &= \Delta y \frac{(f(y_1) + f(y_2))}{2} + \frac{(f(y_2) + f(y_3))}{2} + \frac{(f(y_3) + f(y_4))}{2} + ... \\ &= \Delta y \left(\frac{(f(y_1) + f(y_m))}{2} + \sum_{j=2}^{N-1} f(y_j) \right) \end{aligned} \tag{3}$$

Equation 2 is similarly applied along the vertical axis and the PLIC of Equation (1) is then expressed as:

$$PLIC = \Delta y \left(\frac{(f(y_1) + f(y_m))}{2} + \sum_{j=2}^{N-1} f(y_j) \right) \times \Delta z \left(\frac{(g(z_1) + g(z_m))}{2} + \sum_{k=2}^{N-1} g(z_k) \right) \tag{4}$$

Both *f(y)* and *g(z)* are in units of $\sqrt{\frac{g}{m^3}}$, and *dy* and *dz* are in units of meters. So the PLIC is in units of g/m yielding an estimate of CH_4 mass emission flux in units of g/s from Equation (1)

with *Ws* measured in m/s. The wind speed data are gathered from a combination of the roof mounted auto-north 2-D (AIO unit) and mast mounted 3-D ultrasonic anemometers. Height-resolved turbulence data from the 3-D unit will be used to investigate wind-field parameters and check for the influence of obstructions and compared to neighboring free-flow areas where needed. Quality assurance and measurement approach validation information on the DM technique will be acquired using controlled tracer-release/recover leak simulations prior to deployment for the intensive 2010 field study. QA and field test results will be included in the platform presentation.

VOC Emission Assessment by CH_4 Ratio Calculation

The estimate of fugitive VOC emissions is accomplished by a ratio approach using the CH_4 flux estimate and concentration data. After the stationary vertical plume profile data are acquired, the control computer will assist the operator in placement of the mast near the position of highest CH_4 concentration in the plume. A stationary CH_4 test of at least 30 seconds in duration will follow to establish that the plume concentration is stable enough for VOC assessment. The control computer will then activate a solenoid switch initiating a short duration canister draw (nominally 30 seconds) to capture a sample of the plume. The draw will occur from the primary slip-stream feeding the G1301-fc which is simultaneously measuring CH_4 concentration. The canister will be shipped to a certified analytical laboratory for EPA TO-14 speciated VOC analysis. The canister will also be analyzed for CH_4 concentration for comparison to the CH_4 real-time data gathered during canister sampling. The emission flux for a particular VOC will be estimated by ratio calculation with the measured CH_4 flux and concentration as shown in Equation 5.

$$Ft = \left[\left(\frac{Ct \times Fo}{Co} \right) \times \frac{Mt}{Mo} \right] \tag{5}$$

Where:

Ft	is the flux estimate of the target VOC in (g/s)
Ct	is the measured TO-14 canister concentration of the target VOC (ppmv)
Fo	is the calculated methane flux (g/s)
Co	is the measured methane concentration (g/s), by G1301-fc and canister
Mt	is the molecular weight of the target VOC (g/mol)
Mo	is the molecular weight of methane (g/mol)

In addition to comparison of the real-time and canister CH_4 concentration data, a duplicate and field blank canister strategy will be employed to assess data quality. These tests will be further described in the presentation and documented in the quality assurance project plan for the study.

SUMMARY

Fugitive emissions from distributed point sources, including oil and gas production, are of growing environmental importance. This paper describes a current EPA research effort to develop and utilize a robust method for rapid localization and assessment of distributed fugitives.

The remote emission measurement DM technique described here is built around a high performance cavity ring-down spectrometer for methane measurement but can be expanded to other compounds, instruments, and applications in the future. The presentation associated with this paper will discuss the DM measurement approach, results of QA testing and uncertainty analysis, and present the results of an oil and gas production pad fugitive emission pilot study (Nov. 2009) and intensive study (May 2010) near Greeley CO. Plans to deploy the instrumentation and methods developed for the Colorado tests to other areas of the U.S. will also be discussed.

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