Innovative Approach for Measuring Ammonia and Methane Fluxes from a Hog Farm Using Open-Path Fourier Transform Infrared Spectroscopy

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Abstract

This paper describes a new approach to quantify emissions from area air pollution sources. The approach combines path-integrated concentration data acquired with any path-integrated optical remote sensing (PI-ORS) technique and computed tomography (CT) technique. In this study, an open-path Fourier transform infrared (OP-FTIR) instrument sampled path-integrated concentrations along five radial beam paths, in a vertical plane downwind from an area source. The innovative CT technique, which applies the smooth basis function minimization (SBFM) method to the beam data in conjunction with measured wind data, was used to estimate the total flux from the area source. Results are presented from a field experiment designed for quantifying ammonia and methane emissions before and after a bioactive cover was added to control odors from a hog farm waste lagoon near Jacksonville, NC. This field study provides new insight to the processes taking place in these facilities. The suggested technologies may provide robust and real-time estimates of gaseous emission fluxes and near-field dispersion parameters for near-ground-level area sources.

Introduction

Several methods have been developed and applied [1-9] to estimate emission rates from fugitive sources such as landfills [3], coal mines [5-6], or water treatment plants [7-8], using PI-ORS technologies. All previous methodologies combine downwind path-integrated concentration (PIC) data, wind measurements, and plume dispersion modeling to retrieve the total emission rate. Recently, an innovative CT technique was proposed[10] and evaluated[11,12], which applies the SBFM method[13-15] to the beam data in conjunction with measured wind data, to estimate the total flux from the area source. The approach combines path-integrated concentration data acquired with any PI-ORS technique and CT data analysis. Moreover, this approach is independent of dispersion model assumptions. In this study, an OP-FTIR instrument sampled path-integrated concentrations along five radial beam paths, in a vertical plane downwind from the lagoon source.

Emissions from animal waste lagoons have increased as production has shifted from the family farm to concentrated industrial operations[16]. Air emissions of interest include greenhouse gases (methane and nitrogen dioxide) and fine particle precursors (ammonia) The test site is a 0.3 hectare (3/4 acre) lagoon serving a single 980 head finishing barn. The lagoon is being used to test the effectiveness of a bioactive cover for controlling ammonia emissions. The cover consists of a punched polyester felt fabric held afloat by recycled closed cell polyethylene foam blocks upon which a thin layer of zeolite is spread. Bacteria form colonies within the zeolite using the ammonia as the food source.

Experimental Setup

The setup of the beam geometry and upwind area source in this experiment is illustrated in Figure 1. The beam geometry is in a vertical plane downwind from the lagoon area source. The beam geometry consists of five beam paths, three scanning the OP-FTIR device to ground level retroreflectors, and two slanted beam paths scanning to elevated (5 and 9 m heights)

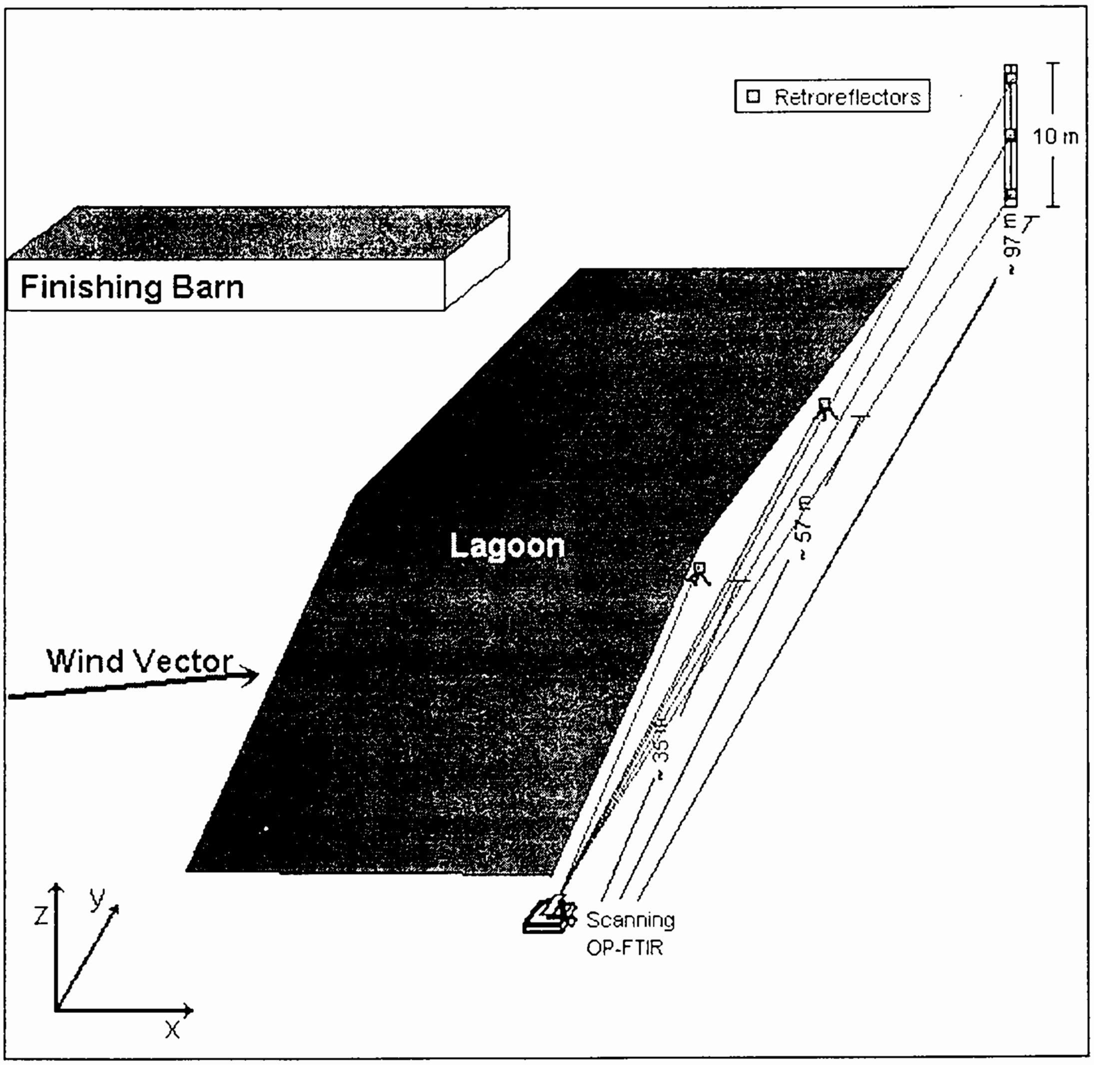


Figure 1 - Field configuration and OP-FTIR beam geometry.

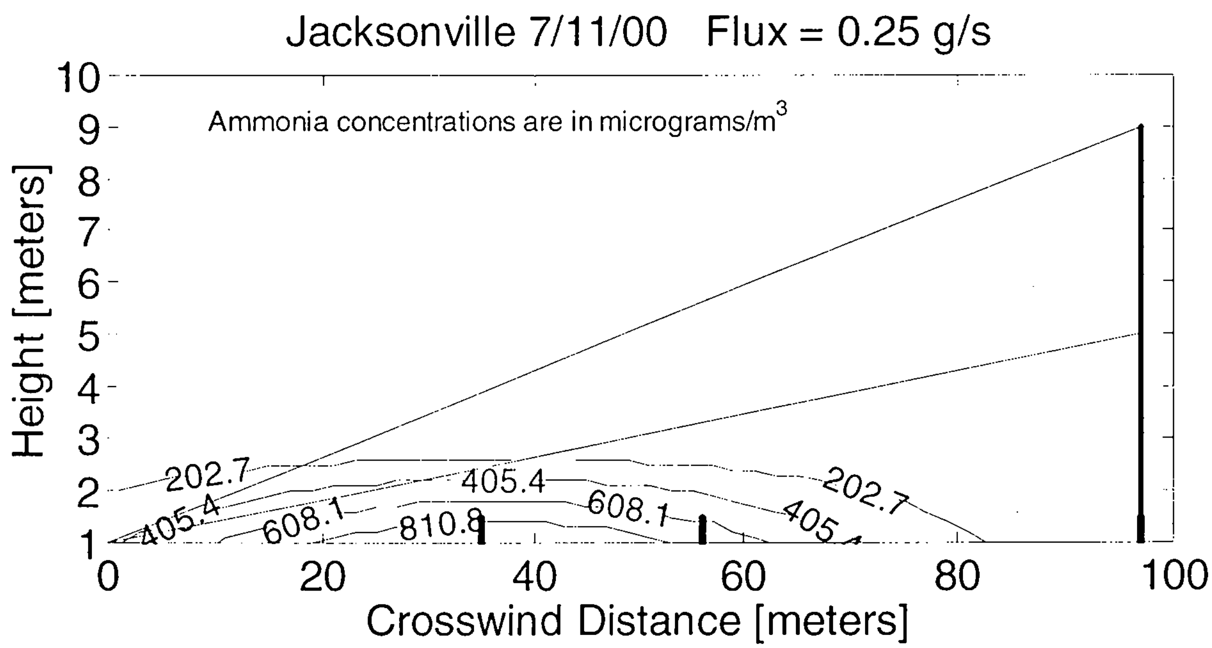
retroreflectors mounted on a tower. Establishing this plane across the plume allows measurement of the flux through it.[17] North is parallel to the *y*-axis. A Midac OP-FTIR mounted on an EPA designed and built two axis scanner moves among the beam paths. The spectral data are collected following EPA guidelines.[18] Spectral interpretation and quality assurance follow techniques developed specifically for open-path spectrometry.[19] Each path is sampled for 1 minute per scan with the total sampling period at least 20 minutes long to minimize data variations and to allow a buildup of an approximate Gaussian plume. Ethylene is released from the southeast corner of the barn to indicate scans containing barn emissions, which are not used in the analysis. Wind speed and direction data are collected and averaged over the same time interval.

The SBFM reconstruction approach used a two-dimensional smooth basis function (bivariate Gaussian) in order to reconstruct the smoothed mass equivalent concentration map. In the SBFM approach, a smooth basis function is assumed to describe the distribution of concentrations, and the search is for the unknown parameters of the basis function. Since the interest is in the plane-integrated concentration and not the exact map of concentrations in the plane, only one smoothed basis function (one bivariate Gaussian) is used to reconstruct the smoothed map. However, this methodology does not assume that the true distribution of concentration in the vertical plane is a bivariate Gaussian. Earlier computational studies showed that one may fit a single bivariate Gaussian function to many kinds of skewed distributions and still retrieve a reasonably good estimate of the plane-integrated concentration. Examination of the fit of a single bivariate Gaussian function to a multiple mode distribution finds that the reconstructed plane-integrated concentration conserved the test input plane-integrated concentration. In each iterative step of the SBFM-CT search procedure, the measured PIC values are compared with assumed PIC values, calculated from the new set of parameters. In order to compute the assumed PIC values, the basis function is integrated along the beam path's direction and length. The concordance correlation factor (CCF) is used as a measure of the goodness-of-fit of the reconstructed concentrations with the measured PIC values.

Once the parameters of the function are found for a specific run, the concentration values are calculated for every 2x2 m square elementary unit in a vertical domain size of 100x15 m and then integrated incorporating wind speed data at each height level to compute the flux. The concentration values are converted from parts per million by volume to micrograms per cubic meter using the molecular weight of the gas and ambient temperature. Using wind speed data in meters per second, this enables the calculation of the fluxes in grams per second.

Results and Discussion

Average results over 2 hours of data collection for methane and ammonia emission fluxes, from the first field campaign prior to the installation of the bioactive cover (July 2000), are given in Figure 2. Both the methane and ammonia reconstructed plumes are from the same data set. Figure 3 presents data from the second field campaign, about a week after the installation (August 2000). For an average wind speed of 1.5 m/sec for the day, the emissions of 72 kg/ha/day are more than the 57.6 kg/ha/day calculated from Aneja et al.[20] and the 2.9-10.5 kg/ha/day reported by Harper et al.[21] Comparing the two figures, substantial reduction in ammonia emission fluxes occurs between the two visits, while the methane emission flux actually went up by 20%. It is not clear whether the reduction in ammonia release results from the bioactivity or just the reduction in liquid surface area. It has been noted that the concentration of nitrogen compounds increased in the lagoon liquor in this same time period. This suggests that at least some of the reduction can be attributed to sequestering of the ammonia in the liquor.



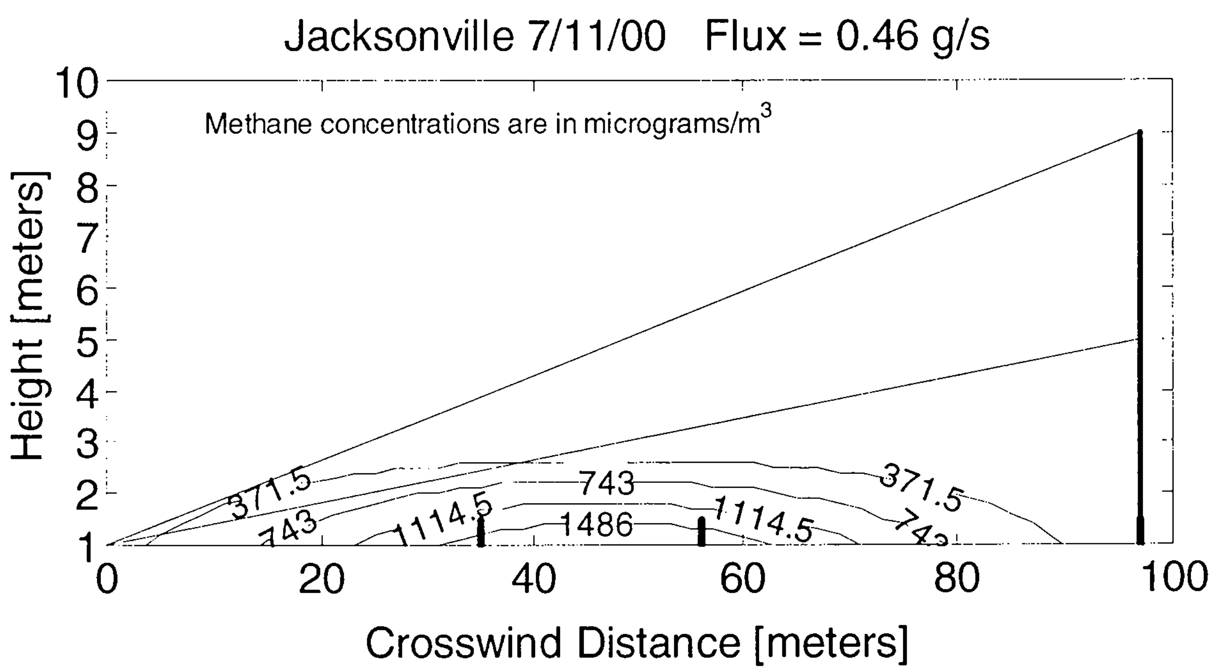


Figure 2 - Average results over 2 hours of data collection for ammonia and methane emission fluxes, from the first field campaign prior to the installation of the bioactive cover (July 2000).

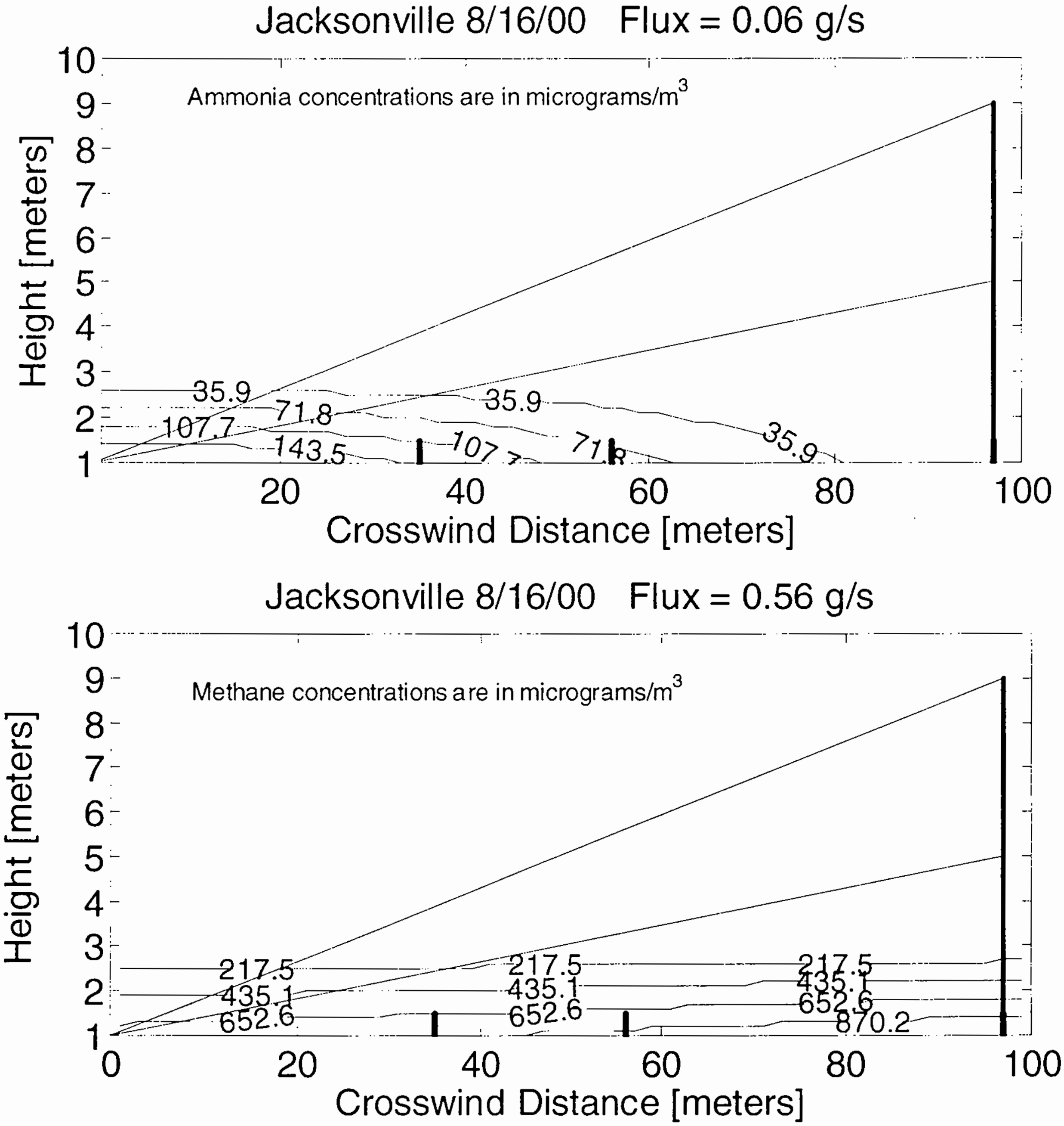


Figure 3 - Average results over 2 hours of data collection for ammonia and methane emission fluxes, from the second field campaign a week after the installation of the bioactive cover (August 2000).

The rise in methane may be related to a rise in wind speeds as shown in Table 1. Looking at time series of emissions, high positive correlations between the flux and the average wind speed are observed as suggested by lagoon ammonia mass transfer models.[22] Seasonal measurements will be made to determine if the covered lagoon emissions are variable, as has been found for uncovered lagoons.

Table 1 – Summary of ammonia and methane emissions along with meteorological data

	Ammonia Flux (g/s)	*Methane Flux (g/s)*	*Average CCF*	*Wind Speed (m/s)*	*Wind Direction (degrees)*
7/11/00	0.25	0.46	0.74	2.1	254
8/16/00	0.061	0.56	0.82	3.0	254

CONCLUSIONS

The combined OP-FTIR/CT method has demonstrated it can be used to determine emissions from actual area sources. Though applied to a small source, the technique should be useful for larger sites by substituting the appropriate optical source.

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Pollution	Spectroscopy	Pollution Control	13B	14B
Measurement	Fourier Analysis	Stationary Sources	14G	12A
Ammonia		Tomography	07B	
Methane			07C	
Swine			02E	
Hog Houses			02C	

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