# EVALUATION OF AMMONIA EMISSIONS FROM SWINE OPERATIONS IN NORTH CAROLINA

by

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## BACKGROUND

Historically, the primary methods available for determining emissions from large area sources were point-sampling techniques employing flux chambers or evacuated canisters followed by analysis of the appropriate gas samples. These techniques can produce accurate results when conducted within a statistical framework and when an iterative approach to sampling is adopted. However, point-sampling techniques are expensive, time consuming, and open to the risks of missing significant emissions from a non-homogenous source. Remote sensing techniques are now available for quantifying emissions from large, heterogenous area sources, such as municipal wastewater treatment facilities, waste lagoons, and surface coal mines. These techniques produce a path-integrated concentration, typically reported in units of parts per million-meter (ppm-m), of the species of interest, eliminating concern over source heterogeneity.

Open-path Fourier transform infrared (OP/FTIR) spectroscopy is one of the remote sensing techniques which, within the last decade, has received wide attention. Extensive development and optimization work of a mobile OP/FTIR system for analyzing emissions from area sources was performed in the early 1990's by Kansas State University, the University of Kansas, and the U. S. Environmental Protection Agency.[1-8] Further comparative studies between OP/FTIR and canister sampling were conducted by Russwurm et al.[9] and by Carter et al.[10] Somewhat broader treatments of the subject were produced by Minnich et al.[11] and by Kagann et al.[12] Recently, papers have been published by Piccot et al.[13-15] and Kirchgessner et al.[16] describing a validation of the single-path OP/FTIR technique using methane emissions and $SF_6$ tracer releases from area sources. The validation included a comparison to evacuated canister samples taken simultaneously with the OP/FTIR data.[13] OP/FTIR techniques have been successfully applied to the measurement of methane emissions at western U.S. coal mines.[14,16] Piccot et al.[15] have also described a medium scale test of the plane-integrated technique for analyzing emissions from a simulated volume source. In this series of tests, over 90% of the runs measured emissions within 20% of known emissions, and half of the tests were within 10%. The use of OP/FTIR is also documented in a paper by Thorneloe et al.[17] describing the single-path OP/FTIR technique applied to methane, tropospheric ozone precursors, and nitrous oxide.

The data presented in this paper are from the initial phase of a study to extend the application of the plane-integrated method to agricultural sources of fine particulate precursors. All of the information was gathered with the classical single-beam approach to develop a baseline to which the performance of the plane-integrated technique can be compared.

## SITE DESCRIPTION

An integrated commercial farrow-to-finish swine production facility hosted these tests. The facility is shown in figure 1. The barns are aligned east to west to utilize the prevailing southerly breezes in the summer months for ventilation. The western row of four barns are farrowing barns, and the nine eastern finishing barns are where the hogs grow to market size. The capacity of the finishing barns is 7200 head with the population during testing between 5400 and 6000. The barns are ~13 m wide, ~ 80 m long, and spaced ~15 m apart. Mounted at the end of the barns are five exhaust fans: three 3 foot (0.9 m) diameter fans and two 4 foot (1.2 m ) diameter fans. The exhaust fans turn on when the temperature exceeds 24 °C inside or by timer to prevent the concentration of ammonia reaching a level not tolerated by the hogs. The timing of the fans is irregular, and one could not exactly predict when they would turn on. Around the perimeter of the barn area is a chain link fence which prevented contamination of the hogs by outside visitors, and severely restricted the accessibility to the barns for sampling. A 6 acre (2.4 hectare) wastewater lagoon is located 30 m directly east of the barns. The waste from the barns is flushed to a pump station at the base of the lagoon's 6-foot (1.8-m) berm and from there pumped to the lagoon. Rotated crops surround the barns on three sides with a forest buffer on the northern boundary. The lagoon is allowed to fill to within a specified depth window with periodic spray application of the wastewater to the crop fields controlling that depth.

Several paths (figure 2) were chosen and surveyed so the FTIR could be moved as dictated by the target source and prevailing daily wind. A general concentration survey was conducted in November 1997 to ascertain the operational range of the instrument necessary for this site. The planned focus of the measurement activities was the wastewater lagoon, but (as can be seen in table 1) the concentrations found when measuring across the exhaust fans of the finishing barns were at least as significant. This development, along with the complex air flows caused by the close coupling of the raised lagoon and the barns, led us to emphasize analyzing the fan exhaust data.

## EXPERIMENTAL METHODS

Before going into the field, we calculated the longest and shortest path lengths in which the OP/FTIR system could operate before becoming optically dense. These calculations assume that the gas we were measuring is homogenous throughout the entire path length. These calculations are only an estimate used to set up the hardware and software. Using a maximum absorbance of 0.7 to limit non-linear response, we calculated the maximum path length to be 269 m which was greater than our longest surveyed path of 233 m.

Spectral data were collected with a Midac (Irvine,CA) bistatic FTIR monitor, which was operated with Midac version of Grams32 (Galactic Industries, Nashua, NH) data acquisition software. Each spectrum consisted of 16 co-averaged scans recorded at a nominal 0.5 $cm^{-1}$ resolution. Triangular apodization was applied to the interferograms prior to performing the fast Fourier transform. The acquisition of each spectrum required approximately 1 minute, and spectra were collected without any time lapse between scans. Blackbody radiation spectra were recorded before the external IR source was turned on. The blackbody radiation spectra were subtracted from the background and field spectra before analyzing the data.

Absorbance files were created by ratioing the single-beam spectra to a synthetic background. Reference spectra of ammonia at the appropriate concentration - pathlength products were developed using the FASCODE[18] software package. The absorbance files were analyzed using the Midac Autoquant classical least squares (CLS) package and these reference spectra. An example ammonia spectrum from the barns is shown in figure 3 along with a reference spectrum.

The meteorological instrumentation was set up and taken down daily. During setup, the wind vane and cup anemometer, which were located on the same support arm, were attached to a pole on top of the FTIR instrument. The wind instruments were approximately 2.1 to 2.4 m above the ground. The temperature and humidity sensors were attached to the underside of the FTIR support tripod approximately 1 m above the ground. Both sensors were sheltered from direct sunlight by several layers of cardboard. All meteorological instruments were connected to a Campbell 21X Micrologger (Campbell Scientific, Logan, UT) data logger which can store up to 5 days worth of data. For our purpose, the data logger was started every morning before sampling and downloaded at the end of the sampling day using a laptop computer.

## FINISHING BARN DATA ANALYSIS

The FTIR measurement path was located at the center height of the fans and 1 m away from the end of the fan shroud. The total path can be visualized as passing through the projected plume from each fan and the open space between the fans and the space between each barn. Three tests with winds blowing from the west, which brought emissions from the farrowing barns as well as the finishing barns, showed path average concentrations of 1.22 to 2.25 ppm of ammonia, but when the winds shifted from the east the concentration dropped to 0.87 ppm. Because we could not set up to measure the contribution from the farrowing barns, we could not calculate the contribution from those sources for the westerly wind data. We did, however, have the data from the western berm of the lagoon which could be used to approximate the non-fan plume path concentration under easterly wind conditions. Thus, under easterly winds, we can estimate the concentration from the finishing barns by counting the number of fans operating during sampling operations to estimate a total plume absorption path length and assume that the remaining path absorption is from the measured lagoon concentration.

Mathematically this can be expressed as:

$$\text{Path concentration} = [(NH_3)_{fans} \times \text{fan path length}] + [(NH_3)_{lagoon} \times (\text{total path length} - \text{fan path length})]$$

For the November 1997 test, thirteen 3 foot (0.9 m) fans, on average, were operating, and the plume is assumed to expand to 1 m wide at the measurement plane.

$$202 \text{ ppm-m} = [(NH_3)_{fans} \times 13 \text{ m}] + [0.268 \text{ ppm} \times (233\text{-}13) \text{ m}]$$

Yielding,

$$\text{Fan exhaust concentration} = 11.0 \text{ ppm } NH_3$$

For the 3-foot fans rated by the manufacturer at 11000 cfm (5.2 $m^3/s$)

$$\text{Emissions per fan} = [NH_3] \times \text{flow} \times \text{units conversion factor}$$

$$= 2.4 \text{ g/min/fan}$$

With 13 fans operating,

$$\text{Total emissions} = 45.3 \text{ kg/day or } 7.5 \text{ g/hog/day (for 6000 head population)}$$

Additional testing of the finishing barns was conducted in January and May 1998 to look for seasonal variations. Lower ambient temperatures in January reduced the number of fans operating to an average of 10 and yielded an emission factor of 13.0 g/hog/day. In the summer conditions of May, all fans were operating in an effort to cool the animals, but the emission factor of 9.2 g/hog/day suggests that little seasonal variation exists. The lack of a seasonal effect is not surprising as these animals are kept in a reasonably constant environment with little stress from outside environmental factors.

## DISCUSSION

Very limited data exist in the literature for emissions from swine finishing barns. Van Der Hoek[19] presents an emission factor used by the European Community (EC) as 2.89 kg/hog/yr (7.9 g/hog/day). Extending our data to a similar yearly value by averaging the seasonal data suggests an emission factor of 3.69 kg/hog/yr with an individual seasonal range of 2.74 - 4.75 kg/hog/yr. A difference of less than 25% is noted between the EC's and our emission factors.

Our estimates may present an upper bound to the emission factor. The data have been collected during daylight, and one would expect that waste production would be reduced at night, so the integrated daily emission factor should be less. Additionally, the exhausts of the farrowing barns are about 10 m from the end of the finishing barns, and it is possible that some of these plumes could be captured by the inlets to the finishing barns even when the wind is from the east and provide a significant background. These data are taken from only one farm, and a broader scope of sites would be useful to improve confidence in the emission factor representing an industry.

The much higher path average concentration noted when the westerly winds bring the plume from the nursery and farrowing barns through the path suggests that these sources need to be examined. Van Der Hoek used an emission factor three times higher for sows in these facilities which reinforces this need. We plan to add a measurement path between the farrowing and finishing barns to develop a separate emission factor for these barns.

The impact of the barns locally and regionally may be affected by the thermal buoyancy of their plumes. With a 15-20 °C differential between the barn plume and the ambient winter temperature, a condensation defined plume could be visibly traced rising quickly above the 20-30 m tree canopy and, thus, moving off-site. In the summer, we measured path average concentration reductions of less than 30% at the base of the lagoon berm, indicating little plume rise when no temperature difference existed between the barns and the ambient. One would expect that ecological interactions on or near the farm site would be more likely because the plume remains near the ground.

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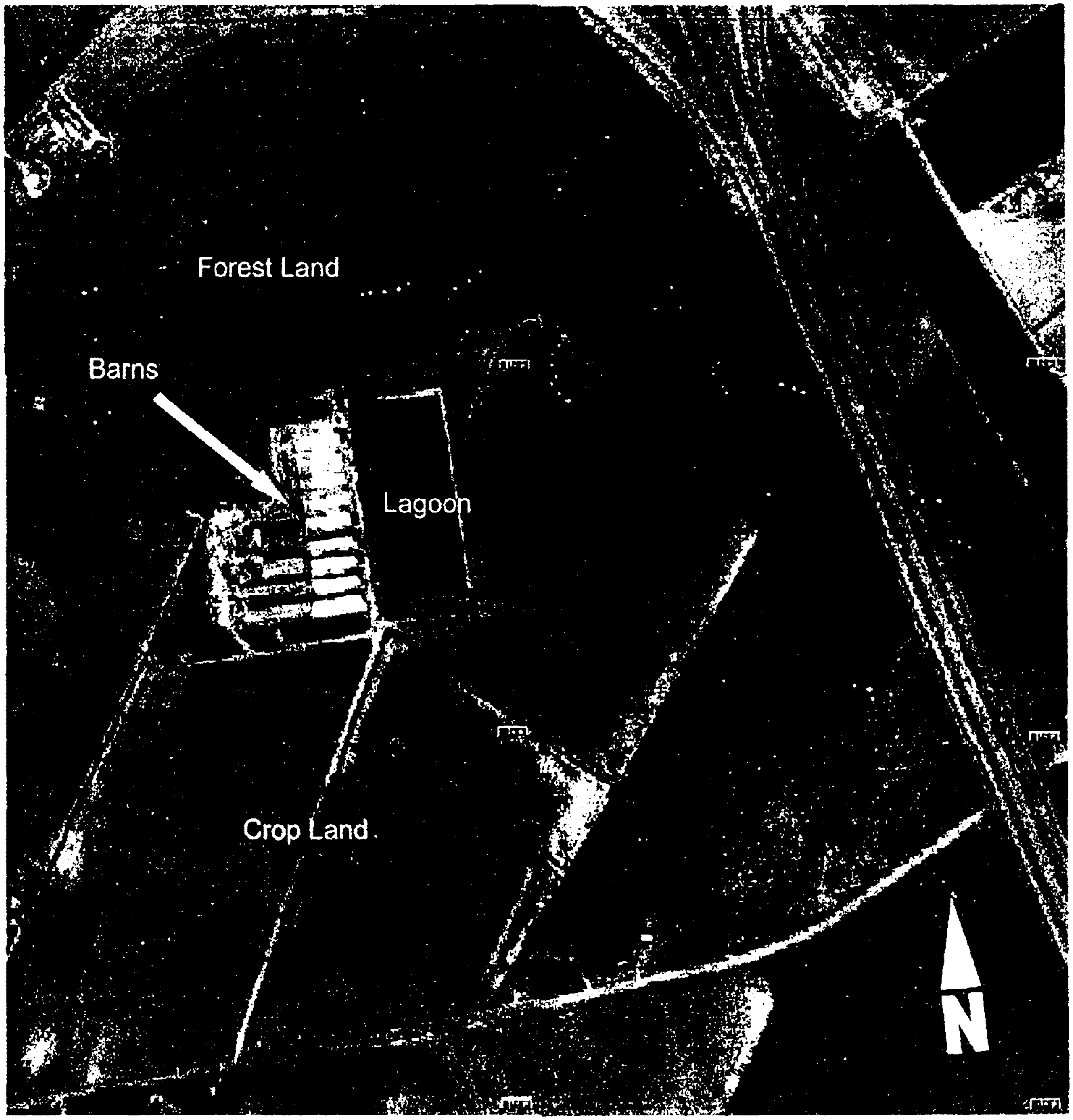


Figure 1. NC hog farm site

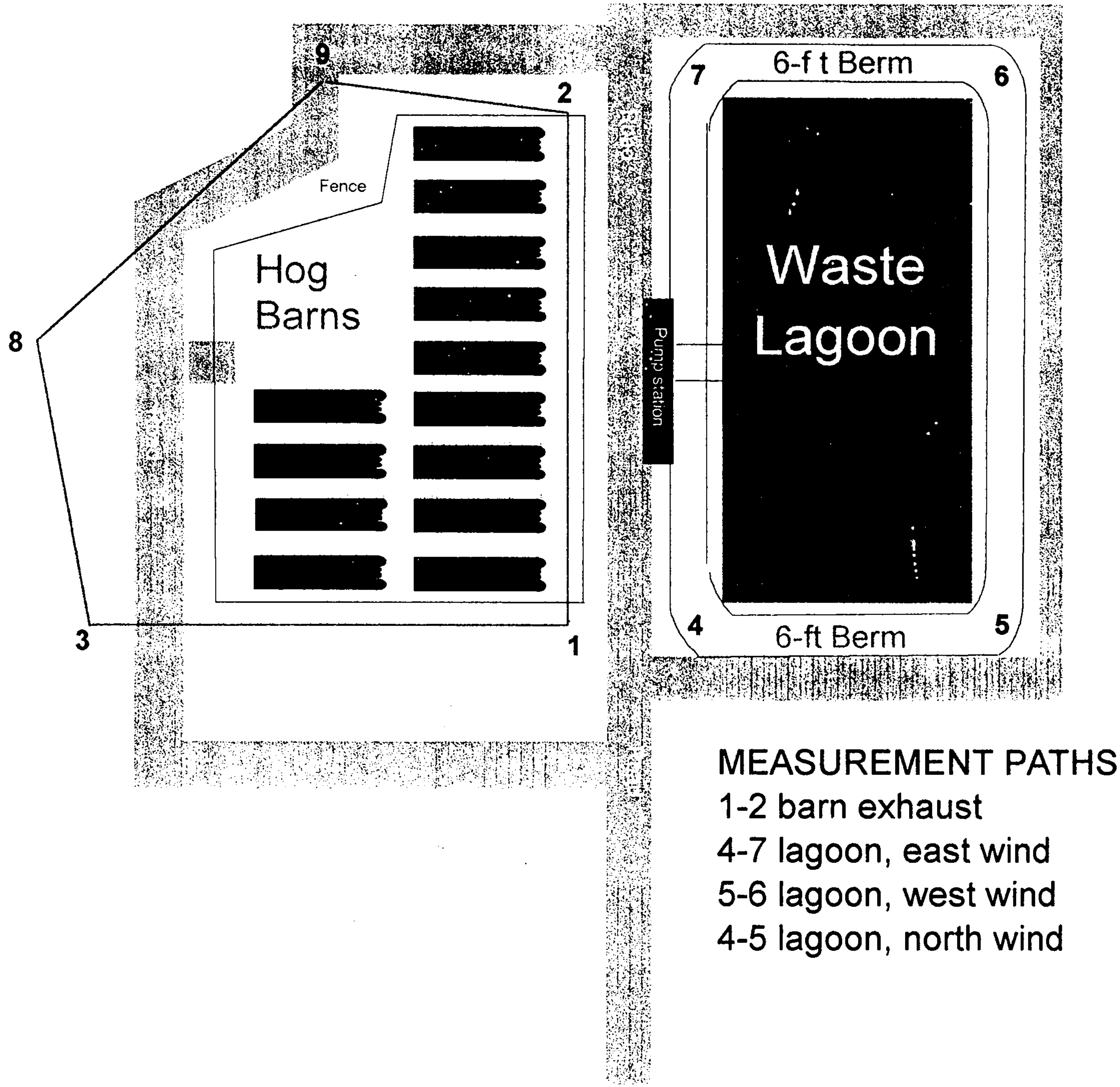


**Figure 2. Surveyed measurement paths**

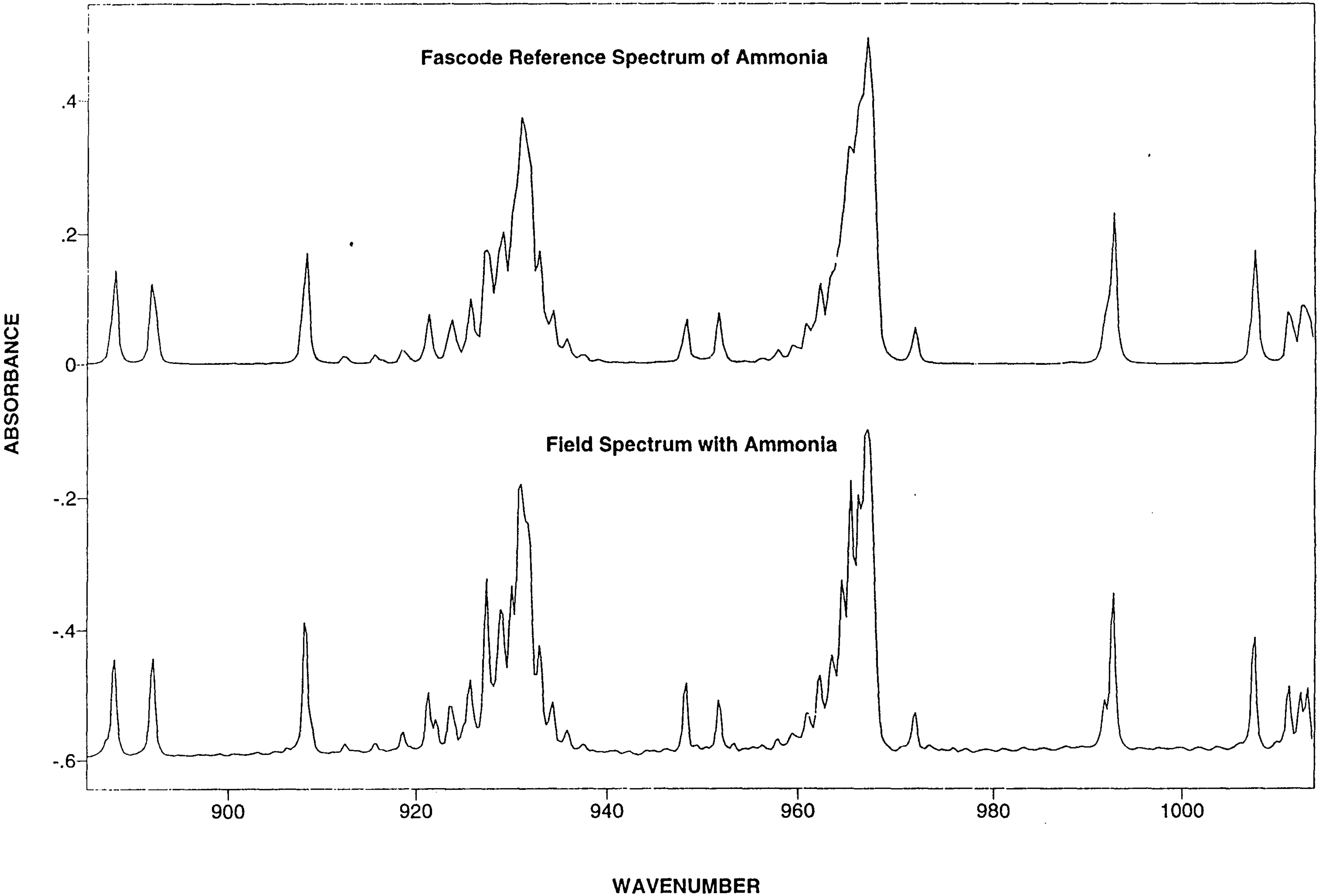


Figure 3. Comparison of ammonia Fascode reference & field spectrum

**Table 1. Hog Farm Fall 1997 Data**

| SUMMARY OF AMMONIA RESULTS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Site | Date | Data Points | Wind Speed Range (mph) Low | High | Avg Wind Speed | Concentration Range (ppm) Low | High | Avg Conc (ppm) |
| Barn, E | 4 Nov 97 | 100 | 3 | 10 | 5 | | | 2.17 |
| Barn, E | 5 Nov 97 | 100 | | | | | | 0.87 |
| Barn, E | 10 Nov 97 | 180 | 1 | 10 | 6 | | | 1.22 |
| Barn, E | 12 Nov 97 | 240 | 1 | 5 | 2.5 | | | 2.25 |
| | | | | | | | | |
| Lagoon, W | 5 Nov 97 | 147 | 5 | 12 | 8 | 0.089 | 0.402 | 0.268 |
| Lagoon, W | 10 Nov 97 | 60 | 1 | 10 | 6 | 0.147 | 0.295 | 0.229 |
| | | | | | | | | |
| Background, E | 6 Nov 97 | 60 | | | | | | None Detected |
| Lagoon, E | 18 Nov 97 | 357 | | | 6.73 | 0.099 | 0.236 | 0.161 |
| Lagoon, E | 19 Nov 97 | 250 | | | 5.34 | 0.144 | 0.379 | 0.241 |
| | | | | | | | | |
| Lagoon, 5 | 6 Nov 97 | 163 | 4 | 16 | 9.67 | 0.055 | 0.159 | 0.102 |
| Lagoon, 5 | 11 Nov 97 | | | | | 0.007 | 0.729 | 0.288 |

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15. SUPPLEMENTARY NOTES Author Harris' mail drop is 61. His phone number is 919/541-7807. For presentation at Emissions Inventory Conference, New Orleans, LA, 12/7-10/98.

16. ABSTRACT The paper describes the application of open-path Fourier transform infrared (OP/FTIR) spectroscopy to emission factor development from a commercial swine production facility. Concentration data around the edge of a large wastewater lagoon are presented, but complex air flows prevent determination of emission factors. The finishing barns are mechanically exhausted and the FTIR path could be set up through the fan plumes. Data from seasonal testing of these exhausts are presented and emission factors developed. OP/FTIR spectroscopy is one of the remote sensing techniques which, within the past decade, has received wide attention. Historically, the primary methods available for determining emissions from large area sources were point-sampling techniques employing flux chambers or evacuated canisters followed by analysis of the appropriate gas samples. Remote sensing techniques are now available for quantifying emissions from large, heterogenous area sources, such as municipal wastewater treatment facilities, waste lagoons, and surface coal mines. These techniques produce a path-integrated concentration, typically reported in units of parts per million-meter (ppm-m), of the species of interest, eliminating concern over source heterogeneity.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group | |
|---|---|---|---|---|
| Pollution | Fourier Analysis | Pollution Control | 13B | 12A |
| Ammonia | Spectroscopy | Stationary Sources | 07B | |
| Emission | Waste Water | Emission Factors | 14G | |
| Measurement | Lagoons | Open-Path Fourier | | |
| Swine | | Transform Infrared | 02E, 06C | |
| Remote Sensing | | Spectroscopy | 14B | |

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