An ultra-sensitive, six-species trace gas analyzer for continuously monitoring concentrated animal feeding operations

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ABSTRACT

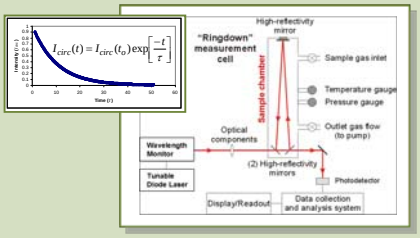
There are an estimated 1.3 million livestock and poultry farms located across the United States. The largest of these are defined as Concentrated Animal Feeding Operations (CAFOs). The rapid proliferation of CAFOs over the last decade has raised concerns about health effects of aerial emissions from animal production and waste management systems. Efforts to regulate air emissions from agricultural sources have been confounded by a lack of accurate aerial emissions data. The Animal Feeding Operations Air Compliance Consent Agreement was recently negotiated between the United States Environmental Protection Agency (EPA) and the livestock and poultry industry. This agreement mandates that the aerial emissions from CAFOs be quantified before regulations are formulated.

We have developed a ambient air analyzer capable of continuously monitoring hydrogen sulfide (H_2S), ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) under conditions found in CAFOs. This analyzer should provide significant benefits if EPA regulations mandate continuous monitoring or the periodic measurement of emissions from livestock and/or poultry facilities.

Background

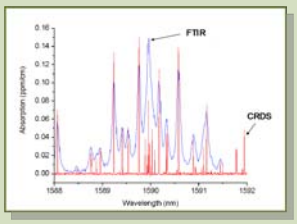
- The number of CAFOs has been growing rapidly.
- Respiratory diseases and dysfunction among workers within CAFOs well documented
- True extent to which agricultural activities contribute to air pollution is unknown
- Efforts to regulate emissions are confounded by a lack of accurate data

Cavity Ring-Down Spectroscopy



- Light from a semiconductor diode laser is directed into a high finesse optical resonator cavity containing the analyte gas.
- When the optical frequency matches the resonance frequency of the cavity, energy builds up in the cavity.
- When the build-up is complete, the laser is shut off.
- The energy decays from the cavity, or "rings down," with a characteristic decay time τ.
- The ringdown time is measured as a function of laser wavelength. When the gas in the cavity is strongly absorbing, the ringdown time is short; when the gas does not absorb, the ringdown time is long.
- The in-line high precision optical wavemeter permits extremely detailed spectral scans that cannot be done using FTIR.

Comparison of FTIR and Picarro's CRDS



Six-Species Analyzer

Specifications

- Targeted Precision (12 minutes total)
  - NH_3: < 1 ppbv
  - CH_4: < 1 ppbv
  - N_2O: < 10 ppbv
  - H_2S: < 2 ppbv
  - CO_2: < 500 ppbv
  - H_2O: < 500 ppmv

Picarro EnviroSense 6000

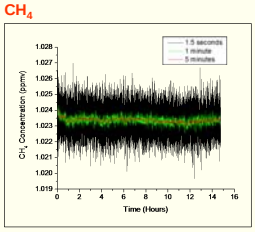
Issues with Current Instrumentation

Currently, the monitoring of ambient air around CAFOs is performed using a variety of gas analysis techniques. The existing instrumentation has issues that need to be dealt with during installation and use

- Measurements require several instruments rather than a single analyzer
- Device response is non-linear
- It is sensitive to water vapor concentration
- Susceptible to drift
- Sample conditioning required before the air is presented to the instrument
- Significant post processing is required to obtain usable results
- Requires frequent calibration to maintain accurate measurements
  - calibration standards are expensive— $1K to $2K for high accuracy

Measured Precision

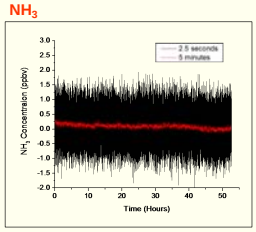
CH_4



- Precision
  - –1-sigma = 0.8 ppbv in 1.5 seconds
  - –1-sigma = 0.2 ppbv in 1 minute
  - –1-sigma = 0.15 ppbv in 5 minutes
- Zero Drift over 15 hours
  - –Peak to peak = 1.0 ppbv

Zero Drift

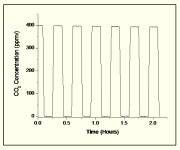
NH_3



- Zero Drift over 2 days
  - –Peak to peak = 300 pptv
- Precision
  - –1-sigma = 500 pptv in 2.5 seconds
  - –1-sigma = 70 pptv in 5 minutes

Repeatability

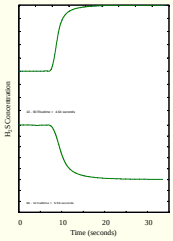
CO_2



- Repeatability
  - –Peak to peak = 500 ppbv
- Precision
  - –1-sigma = 500 ppbv in 1 minute

Sample Exchange

H_2S

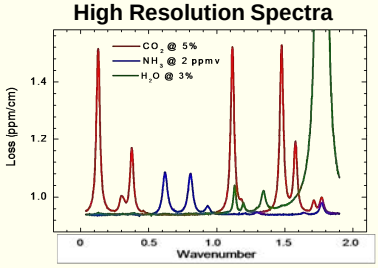


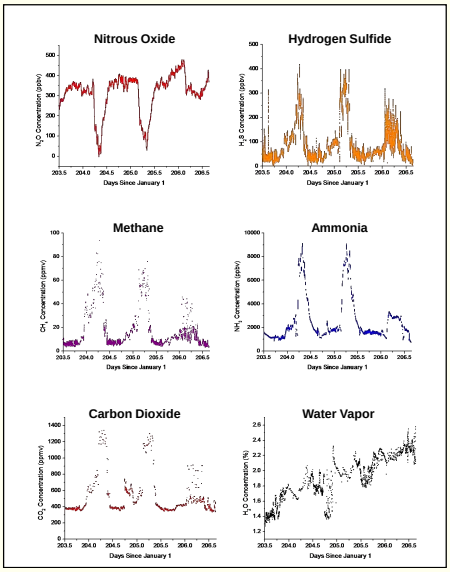
- Rise Time
  - –10% to 90% = 5 seconds
- Fall Time
  - –90% to 10% = 6 seconds

Field Data from a Swine Farm

- A six species analyzer has been placed in the field at an animal feeding operation.
- Hydrogen sulfide, methane, ammonia, nitrous oxide, carbon dioxide and water were continuously measured over the last two months.

High Resolution Spectra





Conclusions

- A six species analyzer capable of measuring H_2S, CH_4, NH_3, and N_2O at the low parts-per-billion level and CO_2 and H_2O at the parts-per-million level has been developed.
- Results indicate that the analyzer meets or exceeds the targeted sensitivity and precision requirements.
- Early stage assessment of the analyzer's long term reliability indicates that the analyzer meets the demanding requirements of the CAFO monitoring application

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An ultra-sensitive, real-time multi-species analyzer

Next generation analyzer for monitoring multiple species

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