Measurements of Air Quality around Various Open Area Sources in USA

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***Abstract*—**Air quality around open-air contaminant sources, including dairy corrals, dairy and swine manure storage lagoons is being measured for two years at ten different sites in seven U.S. states. Ammonia is being measured with tunable diode lasers (TDL) in an open path configuration. Methane (Innova Model 1412), and hydrogen sulfide (Thermo Environmental 450i) are measured in air drawn through a line of inlets, positioned alongside the source. This is referred to as a Synthetic Open Path System (S-OPS). Measurements of the lagoon temperature, pH and oxidation reduction potential are also conducted, as these play a vital role in gas emissions. Although the study will not conclude until mid-2009, data collected thus far shows that the average concentrations of ammonia around open sources is below 0.2ppm; CH_4 is found to be less than 50ppm; H_2S less than 20ppb. The lagoon pH ranges from 7.1 to 8.8 while ORP ranges from -49 to -544 mV.

***Keywords*—**Open air source, synthetic open path system, tunable diode laser.

I. Introduction

GASEOUS emissions from animal production represent a significant economic and environmental problem. Most research has focused on quantification of ammonia (NH_3) and hydrogen sulfide (H_2S) emission from animal housing due to the potential health effects to animals and humans in confined spaces, rather than emissions to ambient air from anaerobic lagoons [1]. However, anaerobic lagoons have been shown to contribute 70-80% of odor emissions from swine facilities in Australia [2].

Animal agriculture is the largest global source of NH_3 emissions and on per cow basis dairy operations are the largest emitters [3]. NH_3 emissions from swine lagoons originate from the large input of urea in swine urine [4]. Urea is readily hydrolyzed into ammonium, which volatizes from solution as NH_3. Deposition of NH_3 in nutrient sensitive areas is suspected of contributing to eutrophication of surface water, and has deleterious health effects including irritation to the eyes, skin, mucous membranes, and upper respiratory system [5].

H_2S is a colorless, potentially harmful gas released from swine manure [6]. It is produced when manure decomposes anaerobically, resulting from the mineralization of organic sulfur compounds as well as the reduction of oxidized inorganic sulfur compounds such as sulfate by sulfur-reducing bacteria [6]. Low concentrations of H_2S and other gases associated with animal agriculture can potentially impact human health [7].

Methane (CH_4) is formed by breakdown of fatty acids and simple organic compounds by methanogenic bacteria in anaerobic lagoons. It is the most rapidly increasing greenhouse gas and accounts for about 27% of all climate forcing [8]. Total CH_4 emissions from the decomposition of animal manure in North America have been estimated at 2,300,000 metric tons per year with about 40% of the total from swine [9].

Previous studies on animal waste have also found lagoon temperature & pH to be a strong factor in controlling the release of NH_3 into the atmosphere [10]

As there are no long-term observations of air emissions throughout the USA, the present work aims to determine the air quality around the open air sources, including dairy corrals and dairy and swine manure storage lagoons and basins which can be used to develop a baseline of emissions.

II. Materials & Methodologies

A. Selection of Sites

Sites for monitoring (Fig.1) were selected on the basis of the location (relative to climate and typical practice), method of manure collection, type of manure storage, availability of power and communications, and physical configuration of buildings and lagoons/ basins. Average ranges of temperature and precipitation along with the Köppen classification of the selected sites are given in Table I.

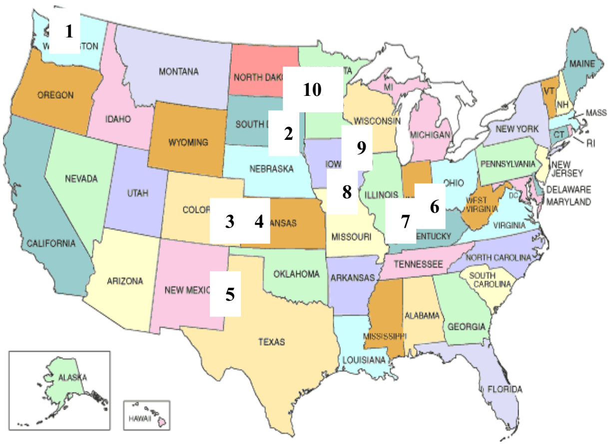

Fig. 1 Ten sites in 7 states

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TABLE I
SITE CLIMATE DESCRIPTION

Sites	Average precipitation (mm)	Range of monthly average temperature (°C)	Köppen classification
1 (dairy)	203.15	19 – 5.5	BW
2 (swine)	783	18 - 6	Cwa
3 (swine)	515	22 - 7	BS
4 (swine)	515	22 - 7	BS
5 (dairy)	515.112	21.6 – 6.6	BS
6 (swine)	1080	21 - 7	Cfb
7 (swine)	1080	21 - 7	Cfb
8 (swine)	984	19 - 6	Cfa
9 (dairy)	883	23.3 - -5.1	Dfa
10 (dairy)	659	12.1 – 1.2	Dwb

B. Respondent Schedule/Producer's Event Form

Each farm owner or manager was asked to complete activity diary/questionnaire providing information related to farm characteristics, animal numbers, different activities of storing wastes etc. A questionnaire survey is a common way to document problems associated with the procedures at the farm. It also gives us an idea about the potential storage (basin, lagoon or tank), lifestyle and different activities of animals. An indication of whether adequate procedures/ methods are being followed can be determined from the survey. A questionnaire (respondent schedule) was prepared for the personal interview with the producers' of all monitoring sites. It was aimed to obtain a real picture of farm in general and about different activities, methods, problems, interferences which may be caused during monitoring the sites. Table II gives an example of the producer's completed questionnaire for one of the sites.

C. Methodology

Measurements at ten sites in 7 states of the USA began in the summer of 2007, and will continue through the summer of 2009. Two sites out of ten are each measured continuously for one year. Eight sites are sequentially measured for 10-20 days during each season of the year for two years.

An open-path tunable diode laser absorption spectrometer (TDLAS) is used for the measurement of NH_3 concentration near open-air area sources. The minimum detection limits of TDLAS units are about 2 ppm-m or less. A multigas analyzer (INNOVA Model 1412) is used to measure CH_4 in the air drawn from the analyzer manifold. The air drawn fills an acoustic cell and is exposed to pulses of specific wavelengths of infrared radiation. When a gas absorbs the infrared light, its temperature rises, causing a pressure wave pulse proportional to the concentration of the gas that is detected by two sensitive microphones inside the chamber. The wavelength of light used to quantify CH_4 is 968 μm. The stated minimum detection limit for CH_4 at this wavelength is 100ppb.

TABLE II
PRODUCER'S FILLED QUESTIONNAIRE FOR SITE 7

Descriptive parameters.	**Unit 1**
Livestock type	Sow (farrow-wean)
Year of facility construction	1994
Separation distance from barn fans, m	30.48
Type of storage (basin, lagoon or tank)	Lagoon
Stage of lagoon (1^{st}, 2^{nd}, 3^{rd})	1^{st}
Manure contributors to unit	
Animal 1 type (sows, cows, etc.)	Sows (farrow-wean)
Animal 1 average weight (Kg)	196.41
Animal 1 inventory (# head)	2000
Manure collection (flush, scrape, PPR)	Pit recharge
Source flush or recharge water (if any)	Lagoon
Lagoon loading interval, hr	1X per week
Volumetric loading rate, lb VS/d-1000m^3	0.05
Surface loading rate, lb VS/acre-d	692
Obstructions within 3X height of unit?	Yes
If yes, what kind? (e.g. trees, barns)	Trees
Height of worst obstruction, m	22.9
Distance from worst obstruction, m	45.7
Type of cover (crust, straw, none, etc.)	None
Are solids separated from influent?	No
Odor control: (digester, additives)	None
Sludge removal cycle, yr	15
Last time sludge removed (e.g., 1999)	Never
Agitation prior to pumpout?	No
Manure removal frequency, d	As weather permits
Pump out (contractor or producer)	Producer
Type of liner (clay, plastic, etc.)	Clay
Volume, m^3	56844.7
Surface area, m^2	23195.29
Berm slope (e.g. 3:1, 3.5:1, etc.)	3:1
Maximum side length, m	189
Minimum side length, m	124
Actual freeboard, m	-
Inner berm height, m	-
Outer berm height, m	-
Liquid depth, m	3.04 total
Sludge depth, m	0.71
Number of inlets (show on drawings)	1
Shape (rectangular, oval, etc.)	Rectangular

A Thermo Environmental 450i SO_2/H_2S analyzer is used to measure H_2S in the air drawn from the gas sampling system (GSS) analyzer manifold. The analyzer oxidizes the H_2S to determine the concentration as SO_2. The manufacturer stated MDL is 1 ppb. Both instruments analyze air drawn from a line of inlets along the side of the open source. The line is called a Synthetic Open Path System (S-OPS). Apart from the above mentioned measurements, ultrasonic anemometers are used to characterize the wind; sensors for other meteorological variables (air temperature, relative humidity, barometric pressure, surface wetness and solar radiation) are also used. Lagoon/basin measurements are used to characterize conditions during the measurement periods. The lagoon pH and ORP (oxidation reduction potential) state are measured using submersible plunger-style glass electrodes with a Teflon liquid junction (Innovative Sensors Model CSIM11 Sensor). The only difference between pH and ORP sensor is that ORP probe has a platinum band wrapped around the glass electrode to cause a response to the electron density of the fluid. The temperature is measured using a Campbell Scientific Model 107-L Thermistor. A probe float is used to place the pH, temperature, and ORP state probes at a depth of 0.3 m below the surface of the lagoon. Detailed descriptions of all the equipment used are presented by Grant et al [11].

D. Quality Assurance

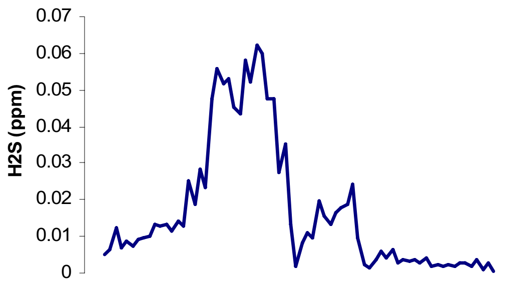
In order to ensure the validity of the data generated from the study and to meet the data quality objectives set forth by the study, it is imperative to establish quality assurance and quality control measures in each aspect of the study. Hence, to make the study more efficient and accurate, regular quality assurance checks are made. Every instrument is calibrated before and at the end of every monitoring period or 20 days, which-ever is less. The acceptance criterion for TDLAS for NH_3 is ±10 ppm-m, TEC450i for H_2S is ±0.05 ppm, INNOVA for CH_4 is ±1 ppm, all three represent ±10%of the calibration check concentration, CSMI11 pH sensor acceptance criterion is ±0.3 pH units and for CSIM11 ORP it is 30mV. While conducting calibration, calibration forms and control charts are completed; all these Quality Control records including calibration forms and control charts will be added to the final report.

III. Results & Discussion

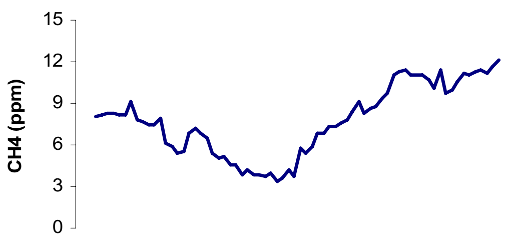
Data collection in this study is ongoing. From the data collected so far we find that the concentrations of NH_3 around open sources are around 0.2 ppm; CH_4 concentration is generally found to be less than 50 ppm; however, at some sites, regular peaks above 100 ppm concentration are also observed; H_2S concentrations are typically less than 20 ppb, but sometimes exceed 40 ppb.

Atmospheric NH_3, H_2S and CH_4 concentrations downwind of the open source are influenced by wind speed, wind direction, and wind direction deviation over the sampling period: An example of trends in concentration downwind is shown in Fig. 2 a, b, c & d. The trends in this data show that the emission patterns of different gases are dissimilar. Wind speed has effects on NH_3 and CH_4 gases but the entry of fresh waste from the barns has greater effects on H_2S, as during the period of fresh waste, there is an increase of H_2S concentration.

The emission of NH_3 is being determined from the concentration and wind measurements using a Gaussian plume fit approach (Radial Plume Mapping or 'RPM' method). The emission of H_2S is being determined ratiometrically from the RPM NH_3 emissions calculations and the difference in upwind and downwind concentration measurements along paths similar to NH_3 concentration measurements as well as using a backward Lagrangian stochastic method (bLS) [11].



(a)



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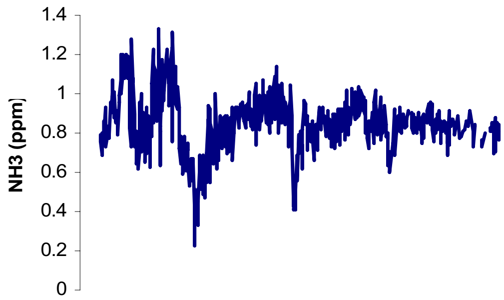

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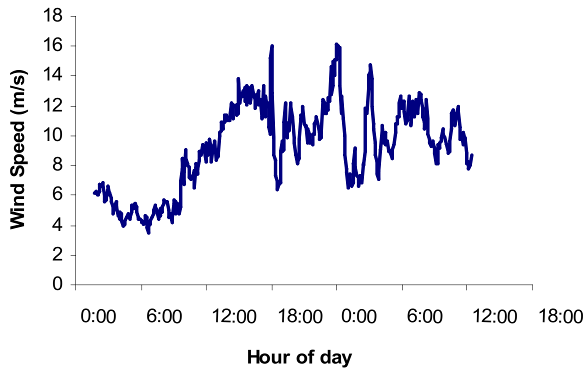

(d)

Fig. 2.a, b, c & d Trends in H_2S, NH_3 and CH_4 concentration downwind from one lagoon site from 10/4/2008 to 10/05/2008

The potential for NH_3 emissions from the lagoon surface is generally a function of physical and chemical factors. The chemical effect, the partial pressure of NH_3 at the lagoon surface [$p(NH_3)$], may be explained as a function of Henry's law and the dissociation relationship of NH_3 and NH_4^+: where $[NH_4^+]$ is the lagoon NH_4^+ concentration (µg g^{-1}), $[H^+]$ is the hydrogen (H) ion concentration ($[H^+] = 1 \times 10^{-pH}$ of the lagoon solution, R is the gas constant, and T is the solution temperature (K). The physical effect is the ability of the wind turbulence to remove NH_3 from the water surface–atmospheric boundary layer. For a soluble gas, such as NH_3, the rate-limiting boundary layer is the diffusive air boundary layer and the removal of NH_3 from this boundary layer is a function of the atmospheric turbulence (wind speed) and atmospheric stability [12].

$$p_{(NH_3)} = RT\left(10^{1.6 - \frac{4207.6}{T}}\right)\frac{[NH_4^+]}{[H^+]} \quad (1)$$

Several previous studies of animal waste emissions have observed temperature to be a strong factor controlling the release of NH_3 into the atmosphere. Studies have also found that lagoon pH played an important role in the potential for NH_3 volatilization. In a lagoon, $[NH_3]$ will be in solution with $[NH_4+]$ according to following equilibrium reaction:

$$NH_3(aq) + H_2O(aq) \leftrightarrow NH_4^+(aq) + OH^-(aq) \quad (2)$$

The pH controls the direction of equilibrium in (2). Increasing the pH implies that the concentration of hydroxyl ions ([OH-]) increases, thereby shifting the equilibrium to the left, and subsequently more NH_3 is liberated. Likewise, increasing the water content of the lagoon, e.g. precipitation events, shifts the equilibrium slightly towards the right, causing the NH_3 to be more tightly bound in solution [10].

Table III summarizes lagoon chemistry (temperature, pH and ORP) during the fall of 2008, and highlights some of the differences in the lagoons included in the study. Lagoon chemistry characterizations were not done at sites 1 & 10 (lagoons are always dry/crusted or frozen), 2 (a basin), 5 (a corral) and 9 (monitoring did not start).

TABLE III
LAGOON CHEMISTRY DURING FALL OF 2008

Site	Measurement Period	Temp (ºC)	pH (pH units)	ORP (mV)	Normalized NH3 concentration (ppb/animal)
3	5/8/08 to 5/29/08	19.5	7.8	-489	0.17
4	4/25/08 to 5/6/08	14.8	8.8	-462	0.076
6	3/5/08 to 3/26/08	17.1	7.5	-507	0.083
7	4/2/08 to 4/16/08	17.6	7.7	-515	0.096
8	5/14/08 to 5/31/08	17.2	7.1	-424	0.16

From the data obtained so far lagoon temperature has a positive relationship with NH_3 concentration except at Site 8. At a specific lagoon pH has a very narrow range; thus, no significant relationship is seen between NH_3 and pH. ORP shows entirely different values as compared to previous studies [13], it shows higher reduction in lagoon.

IV. CONCLUSION

In absence of complete data we cannot make any definitive conclusions but the preliminary observations suggest a higher level of all these pollutants and their levels effects on seasonal variation. A long term database of pollutants levels around open sources in USA will be useful to sate and federal regulatory agencies, the livestock's industry, researchers, consultants, and the general public, and will help decision makers formulate and implement policies to manage and control environmental pollution.

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