Gas and PM Emissions Monitoring from Swine Gestation and Farrowing Barns in Central Iowa

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Summary and Implications

This on-going study is continuously monitoring emissions of gases including ammonia, hydrogen sulfide, carbon dioxide, methane and (intermittently) selected odorous volatile organic compounds (VOCs) as well as particulate matter (PM) from a 2500-head sow farm consisting of two gestation barns and one farrowing barn in central Iowa. An on-farm instrumentation shelter houses the equipment for measuring pollutant concentrations at representative barn air inlets and outlets, barn airflows, operational processes and environmental variables. Sampling began in July 2007 with data logged every 15 s and 60 s; sampling will continue for 24 months in total. Data are retrieved with network-connected PC, formatted, and validated for calculations of emission rates. A multipoint air sampling system draws air sequentially from representative locations at the barns and delivers it to a manifold from which on-line gas analyzers draw their subsamples. Different size PM including total suspended particulate (TSP), PM_{10} and $PM_{2.5}$ are measured in real time using tapered element oscillating microbalances (TEOMs) and a Beta Gage PM analyzer. Mechanically-ventilated barn airflows are estimated by continuously measuring fan operational status and building static pressure, in combination with calibrated curves for each fan's airflow. Specific processes that directly or indirectly influence barn emissions, including pig activity, manure management/handling and feeding, are measured. Environmental parameters including inside and outside air temperatures and humidity, wind speed and direction, and solar radiation are also monitored. Feed and water consumption, manure production and removal, swine mortalities, and animal production are recorded. Samples of feed, water, and manure are collected and analyzed for total nitrogen and total sulfur.

Introduction

In recent years, the increased size and consolidation of livestock facilities - including poultry, swine and dairy operations - have been the focus of an increasing number of citizen complaints and concern about possible health impacts[1]. The livestock industry in major production states and regions including U.S., Canada, European Union, Australia and others, have been under increasing pressure to comply with more stringent environmental regulations. Iowa is the number one pork producing state in the U.S. and the top state for pork exports. In 2008, Iowa had 8,300 hog farms, marketed more than 37 million hogs, about 31% of the U.S. pork industry. The Iowa pork industry contributes $12 billion annually in economic impact to the state of Iowa[2].

Most modern swine operations raise hogs in confinement buildings. Concentrated animal feeding operations (CAFOs) are sources of aerial emissions of ammonia (NH_3), hydrogen sulfide (H_2S), odors, volatile organic compounds (VOCs), particulate matter (PM), methane, carbon dioxide (CO_2), and other gases[3]. These air quality and emission issues are of particular concern in swine facilities where manure is stored in an under-floor pit (typically ~2.5 m deep); the slurry storage is separated from the animal and worker areas by concrete slats. Pit fans are often used to address this indoor air quality issue in deep pit barns[4], which are standard for Midwestern U.S. pig nursery and grow-finish facilities. Emissions of NH_3 and H_2S were measured from a 2000-head tunnel-ventilated deep-pit finishing-pig barn for 45 days during August and September 2004 and were partitioned between the pit and wall exhaust streams[5]. Results showed that the pit and wall NH_3 and H_2S emissions were similar.

Due to the health and environmental concerns, the airborne emissions of some of these pollutants (NH_3, H_2S, and PM_{10}) are now regulated by the federal Environmental Protection Agency (EPA) through the notification provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA) plus the Clean Air Act (CAA). However, the U.S. EPA has found it difficult to determine whether CAFOs are in violation of these regulations because of the lack of reliable emissions data. The National Air Emissions Monitoring Study (NAEMS) was initiated to improve the emission database[6].

This on-going study is monitoring emissions of gases including NH_3, H_2S, CO_2, CH_4 and other VOCs as well as TSP, PM_{10}, $PM_{2.5}$ from the 2500-head sow farm consisting of two gestation barns and one farrowing barn in central Iowa, as part of the NAEMS. An on-farm instrumentation shelter (OFIS) houses the equipment for measuring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn airflows, operational processes and environmental variables. The 24-month sampling period started in July 2007. The objective for this project is to quantify aerial pollutant (NH_3, H_2S, PM_{10}, TSP, $PM_{2.5}$) emissions from two tunnel-ventilated deep-pit swine gestation barns and a pull-plug shallow-pit farrowing room in central Iowa over two year period. As

part of the NAEMS, this study is subject to the objectives set forth in the Quality Assurance Project Plan[7], instrument and method-specific standard operating procedures, and a site monitoring plan[8]. The measurement and monitoring of CO_2, CH_4, and odorous VOCs is not target pollutants of the NAEMS because EPA does not regulate them. They are either measured for quality assurance (CO_2), to obtain non-methane VOC (CH_4), or to meet the objectives of another study (odor).

The goal of this paper is to describe the monitoring plan to meet the objectives mentioned above.

Description of the Site

The 2500-head sow farm consists of two larger gestation barns, a farrowing building with 16 rooms, a small isolation barn, and a small office building. Construction of the barns was completed in 1998.

The farm has a capacity of 1100 breeding and gestation sows in each gestation barn, and 384 farrowing sows in the farrowing barn. The gestation barn is 86 m long × 25 m wide with a 3.3 m ceiling height; and the farrowing barn is 106 m long × 21 m wide. The two gestation barns are separated by the long axis of the farrowing barn, and are thus 113 m apart. The gestation barns have concrete slatted floors with 3m deep pits for manure storage. They have two 20 cm thick pit walls under the floor that essentially separate the entire pit into three pits. However, four 0.3 m × 1.2 m equalizing holes at the bottom of the walls allow manure to flow between them. Manure is stored in the 25 m × 86 m × 3 m deep pit for about six months. When hauling manure out of the gestation barns, the producer agitates the pits after opening the 56 cm wide curtains on each sidewall. However, about 30 to 45 cm of slurry usually remains in the pit after pump out. Power washing is supplied by a central system.

Each of the two gestation barns has 9 pit fans and 11 wall fans. The gestation barns' pit fans have wind diverters . Ventilation air enters through three rows of ceiling air inlets, 10 inlets in each row. The ceiling ventilation inlets are typically open with exceptions of those situated in the vicinity of the wall fans and are manually adjusted from October through March. Ceiling ventilation inlets are closed in the warm season, when tunnel ventilation is used, as fresh air enters through evaporative cooling cells in the W, N, and S walls. Emergency curtains are 56 cm wide, and run the entire length of both sides of gestation barns (S and N walls). There are six 46-cm, 1725-rpm pit fans and four 61-cm, 1100-rpm pit fans in each gestation barn. These large 122-cm diameter wall fans are shut off and the gestation barns are ventilated by the pit fans only during the winter. Fan stages and cool cells are controlled by an integrated controller. The curtain opening on the outside of evaporative cooling cells is controlled by the barn static pressure. There are six gas heaters, controlled in two stages, to provide supplemental heating.

The farrowing barn has a combination iron/plastic/concrete floor over a 61-cm shallow pit divided into two cells for short-term manure storage. Stored manure in the farrowing barn is transferred via gravity flow once every 21 to 24 d into the easternmost deep pit of the nearest gestation barn. Manure on the walkways is scraped or swept into the pit five times weekly (M-F).

The farrowing barn consists of 16 individual 6.5 × 19.5 m rooms. Each room has three fans: one 3300-rpm, 0.25-cm pit fan, one 1100-rpm, 61-cm wall fan, and one 1150-rpm, 61-cm wall fan. Each room is ventilated in three ventilation stages. A 1.2-m wide hallway located at the E side of the farrowing barn is heated with five 225,000 Btu/h gas heaters. Ventilation air enters the room from the attic via six ceiling air inlets and from the hallway via four wall inlets. There is a gas heater in each farrowing room. All of the ventilation fans and controllers were manufactured by Automated Production Systems. The ventilation and pit fans are backed up by generator when there is a power failure or emergency. All fans use single-phase motors.

All feed brought to the site is weighed on a state-inspected and certified truck scale. The gestation sows are fed twice daily. Feed is delivered by an automated flex auger system. A concrete bunker at the south end of the facility is used for composting piglet mortalities. The farm is located in rolling agricultural land. There are no obvious sources of potential contaminants, other than fields that occasionally receive manure, within about 1.8 km of the site.

Results and Discussion

Continuous aerial emissions monitoring is conducted in all three barns (i.e., two gestation barns and room #9 in the farrowing barn). Schematics of the monitoring plan are provided in Figure 1, The OFIS is located by the farm office near the east side of the farrowing barn. A short heated raceway, about 3 m in length, connects the OFIS with the farrowing barn and protects the sampling lines and electrical cables from damage. It also prevents condensation in the sample lines during cold weather. Sampling lines from the two breeding/gestation barns pass through the farrowing barn to the raceway location, and then to the OFIS. Sections of the sampling lines running through the farrowing barn are heated to prevent condensation in these lines that might arise due to temperature/humidity differences between the two barns and typically colder air in the corridor.

Exhaust gas in each gestation barn is sampled at the inlet of the stage-2 wall fan, and from three sets of composited pit fan gas sampling location groups (GSLGs), each consisting of two 46-cm stage-one fans (Figure 1). The two air-sampling points in the farrowing barn are both located at the south end of room 9. The stage-1 pit fan and stage-2 wall fan are each sampled in this room. Sampling probes are located about 0.5 m directly in front of the wall fans, at the same height as the fan hub. For the pit fans,

sampling probes are located in close proximity to the fan opening, underneath the slatted or wire-mesh floors.

There are a total of 11 gas-sampling locations at the site. One inlet gas concentration is sampled near the south end of the OFIS, and approximately 3 m away from the air inlet of the farrowing barn's east sidewall. This inlet location is judged to be fairly representative of the inlet air to all three barns, since most of the inlets for each barn are downwind of at least one set of exhaust fans during most of the year, based on prevailing winds. There is no outdoor manure storage or lagoon to contribute to inlet contaminant concentrations.

All gas-sampling locations are connected with Teflon tubing to a gas sampling system (GSS) in the OFIS that sequences through all 11 locations to deliver selected gas streams to an analyzer manifold (M_a). Instruments that draw subsamples from the M_a include a fluorescence-based H_2S analyzer (Model 450C, Thermo Environmental Instruments, Waltham, MA) and a photoacoustic IR multi-gas monitor (Model 1412, Innova AirTech Instruments, Ballerup, Denmark) for NH_3, CO_2 and CH_4. Periodic odorous VOC samples are collected from the GSS using stainless steel tubes packed with Tenax TA sorbent and subsequently analyzed by multidimensional GC-MS-Olfactometry at the Iowa State University Atmospheric Air Quality lab.

A beta attenuation PM monitor (Beta Gage Model FH62C14, Thermo Fisher Corp., Franklin, MA) is located on top of the OFIS for measurement of continuous inlet PM concentrations (Fig. 1). The sampling location of the ambient PM monitor is very close to the ventilation inlet air that enters barns through the side curtain and ridges, and the possible contaminant sources (the exhaust fans) are either at the other side of the barn (in the case of the farrowing barn), or more than 45 m away (in the case of the gestation barns). Tapered element oscillating microbalances (TEOM Model 1400a, Thermo Environmental Instruments, Waltham, MA) are used for continuous PM monitoring of the barn exhaust air. Each barn/room has one fan denoted as the primary representative exhaust fan (PREF) for its respective barn. In the farrowing room, the TEOM is located to the side of the center hallway and near the Stage 2 fan. In the gestation barns, the PREF is at the stage three wall fans (Figs. 1). One easternmost sow stall was vacated in the north gestation barn for the TEOM. In the south gestation barn, where there are pens near the wall fans, a part of the stall is also used for the TEOM.

The PM_{10} inlet heads on the TEOMs and Beta-Gage are replaced with $PM_{2.5}$ heads for two two-week periods (warm and cold seasons) over the course of the study. The first of these was in February 5-20, 2008 and the second was in August 15-30, 2008. TSP inlet heads are placed on the TEOMs and Beta-Gage for one week every two months.

Capacitance-type relative humidity and temperature probes (NOVUS RHT-WM, Novus Electronics, Rio Grande do Sul, Brazil) are located at the PREF's. Thermocouples (Type T) measure temperatures at four positions along the length of each gestation barn at the center of the farrowing room, at each gas sampling point that does not have the RH/T probe, inside the heated raceways, and in the OFIS. A solar radiation-shielded RH/T probe, a wind anemometer and wind vane are attached to the roof weather tower mounted on the farrowing barn.

Differential static pressure sensors (Model 260, Setra Inc., Boxborough, MA) are used to measure pressure across each wall with fans (the N, E, and S walls of the gestation barns, and the W wall of the farrowing barn) (Figure 1). Static pressure in the OFIS is also measured to ensure that positive pressure is maintained.

Fan operation is monitored using two methods. In the first year, geartooth sensors (Model GS1007, Cherry Electrical Products, Pleasant Prairie, WI) monitored the fan rotational speed of each fan, however, the sensor were susceptible to problems related to power supply instabilities. In the middle of the study, most of the geartooth sensors were replaced with current switches (CR9380-NPN, CR Magnetics, St. Louis, MO) to avoid the loss of fan operation data. Also, impeller anemometers (Model 27106RS propeller anemometer, R.M. Young Company, MI) are placed downstream of each barn's PREF (fan 16 in each of the gestation barns, fan 1 in the farrowing room), and fan 6 and fan 9 in the north gestation barn (Figure 1). Placement at these two latter fans ensures that at least one fan of each type has an anemometer, so that the data from these can be correlated with geartooth sensor data (prior to July 2008) for all types of fans.

The FANS[9] (Fan Assessment Numeration System, FANS, Biosystems and Agricultural Engineering Department, University of Kentucky, Lexington, KY) is used to periodically calibrate airflow for fans with continuously measured differential static pressures in the south gestation barn. The traverse anemometer method is used for the north gestation barn as well as all the pit fans. Animal activity sensors (SRN-2000N, Visonic, Ltd., Bloomfield, CT) are located to monitor movement of animals and workers in the barn (Figure 1), and researchers in the OFIS.

Manure samples are collected bimonthly from the barns to determine pH, ammoniacal N and total solids content. During each sampling period, 12 and four samples are collected from distinct, randomly-selected locations in the pits of the gestation barns and farrowing room, respectively. These samples will be used to model the effect of these manure parameters on barn emissions.

The bimonthly manure sampling is timed to coincide with emptying of the shallow pit under the farrowing barn. At each sampling, a total of four samples of manure leaving the farrowing barn are collected. Similarly, when the deep pits under the gestation barns are emptied, 24 samples are taken from the mixed manure leaving each of these barns. These samples (those leaving the under barn pits) are analyzed for pH, solids content, total N, and ammoniacal N. The volume of manure discharged from the farrowing and

gestation barns at each emptying are assessed to facilitate nitrogen mass balance calculations. Additionally, feed and water consumption rates and animal inventory and weight are provided by the producer, and animal inventories are verified weekly by the study personnel. Feed samples are also collected and analyzed for feed N content. Water is evaluated with several samples of the water provided to the animals. All manure, feed and water samples are analyzed by an independent lab. The producer records daily mortalities. Nitrogen content of the animals themselves (mortalities, piglets removed from the site, and weight added by the sows) will be taken from the literature.

Summary

The Iowa gestation barn monitoring site has been operating for more than two years. Concentrations of NH_3, H_2S, CO_2, CH_4, PM_{10}, $PM_{2.5}$, and TSP, as well as ventilation rate and supporting parameters are monitored continuously. There are 148 variables collected for use in emission calculations. Data from the site is checked on a near-daily basis.

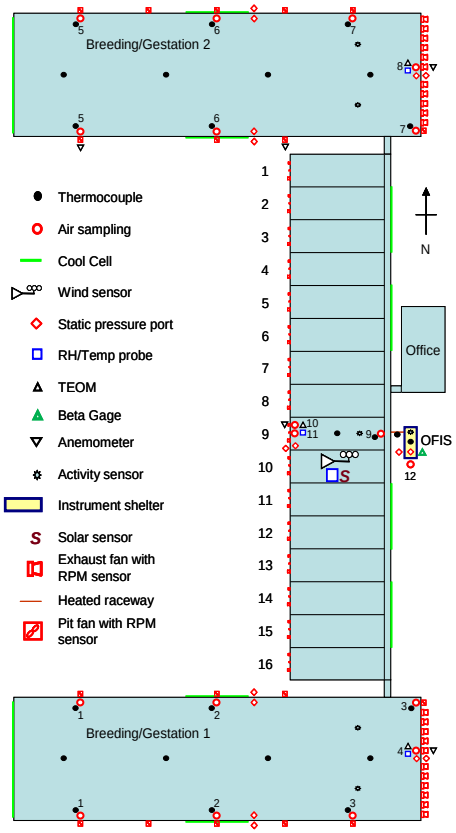

Figure 1. Floor plan of the barns, showing the layout of the site and the sampling and measurement locations.