Quality Assured Measurements of Animal Building Emissions: Odor Concentrations

Larry D. Jacobson, Brian P. Hetchler, and David R. Schmidt
Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN

Richard E. Nicolai
Department of Agricultural and Biosystems Engineering, South Dakota State University, Brookings, SD

Albert J. Heber and Ji-Qin Ni
Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, IN

Steven J. Hoff
Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA

Jacek A. Koziel
Department of Biological and Agricultural Engineering, Texas A&M University, Amarillo, TX

Yuanhui Zhang
Department of Agricultural and Biological Engineering, University of Illinois, Urbana, IL

David B. Beasley
Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, NC

David B. Parker
Department of Environmental Science and Engineering, West Texas A&M University, Canyon, TX

ABSTRACT
Standard protocols for sampling and measuring odor emissions from livestock buildings are needed to guide scientists, consultants, regulators, and policy-makers. A federally funded, multistate project has conducted field studies in six states to measure emissions of odor, coarse particulate matter (PM$_{10}$), total suspended particulates, hydrogen sulfide, ammonia, and carbon dioxide from swine and poultry production buildings. The focus of this paper is on the intermittent measurement of odor concentrations at nearly identical pairs of buildings in each state and on protocols to minimize variations in these measurements. Air was collected from pig and poultry barns in small (10 L) Tedlar bags through a gas sampling system located in an instrument trailer housing gas and dust analyzers. The samples were analyzed within 30 hr by a dynamic dilution forced-choice olfactometer (a dilution apparatus). The olfactometers (AC'SCENT International Olfactometer, St. Croix Sensory, Inc.) used by all participating laboratories meet the olfactometry standards (American Society for Testing and Materials and European Committee for Standardization [CEN]) in the United States and Europe. Trained panelists (four to eight) at each laboratory measured odor concentrations (dilution to thresholds [DT]) from the bag samples. Odor emissions were calculated by multiplying odor concentration differences between inlet and outlet air by standardized (20 °C and 1 atm) building airflow rates.

INTRODUCTION
Livestock and poultry producers in the United States are becoming increasingly concerned over the odors, gases,
and particulate matter (PM) that are generated and emitted from their animal operations. Odor, gas, and PM emissions from animal production sites are impacting producers in a variety of ways including concerns over human health. Complaints from neighbors are on the increase. Local units of government (counties and townships) have or are considering the establishment of setback requirements from rural residences and livestock operations to prevent odor and other nuisance complaints. State and federal regulatory agencies have begun to enforce existing and enact new air standards that may directly or indirectly address odor issues.

Because of these growing concerns there is an urgent need to determine air emissions levels from animal production sites, including the buildings that house the animals. Emissions levels need to be known so producers and others can determine which sources are the major contributors. Individuals can then develop an air emission strategy for their operation. Unfortunately, quantifying air emissions from animal agriculture is a complex process. First, the complexity arises from the multitude and variety of individual sources responsible for emissions, the extreme variability of these emissions, and the variety of gaseous and particulate components being emitted. Second, the method(s) used to collect emission data from the variety of sources has not been standardized and involves the measurement of both the concentrations of the contaminant(s) and the airflow rate from the source. Few researchers and engineers have taken on the task of measuring odor, gas, and PM emission rates because of these and other difficulties.

A six-state project entitled “Aerial Pollutant Emissions from Animal Confinement Buildings” or APECAB was directed in 2001 with the overall objective to quantifying and characterizing baseline emissions of ammonia (NH₃), hydrogen sulfide (H₂S), PM, and odor from individual swine, and poultry production buildings. The APECAB study was a collaboration of land-grant universities in Illinois, Indiana, Iowa, Minnesota, North Carolina, and Texas. The study utilized common instrumentation and protocol. At each measurement site, a mobile instrument trailer was stationed between two nearly identical, mechanically ventilated, confined animal production buildings. The trailer housed a gas sampling system (GSS), gas analyzers, environmental instrumentation, a computer, data acquisition system, controller units for the real-time PM monitors, calibration gas cylinders, and supplies and equipment needed for the study. Gas concentrations were measured at the air inlets and outlets of each building whereas airflow rates were simultaneously measured. Grab air samples were regularly collected in Tedlar bags (roughly biweekly) to determine odor concentrations. Emission rates were calculated by multiplying concentration differences between inlet and outlet air by standardized (20 °C and 1 atm) building airflow rates.

The objective of this paper is to describe how air samples from the APECAB project were collected, transported, and analyzed for odor concentrations and how odor emissions were then calculated for the animal buildings monitored in the study.

**BACKGROUND**

**Odor Measurements**

Odors evoke a wide range of physiological and emotional reactions. Different people can have very different reactions to the same odor. Odors can be either energizing or calming. They can stimulate very strong positive or negative reactions and memories. Aromatherapy, which is used in human medicine, illustrates how important smells can be to people. The power, complexity, and our limited understanding of the sense of smell make olfactometry a challenging field. There are two general approaches used to measure odor, either indirectly by measuring individual gas concentrations in an air mixture or directly by using a human sensory method such as olfactometry. Both approaches have strengths and weaknesses.

The main advantage of measuring specific individual gas compounds in an air sample is that they can be identified and measured using a variety of sensors and techniques. Electronic noses, which use electronic sensors to measure a select number of chemical compounds, are being used in some industries for assessing odor. In the livestock industry, odors often consist of many (>300) gases at extremely low concentrations, thus making the gas measurement methods very difficult and expensive.

The greatest weakness of the gas measurement approaches is that there is no known relationship between the specific gas concentrations in a mixture and its perceived odor. As a result, regulations based on gas concentrations may reduce specific gas emissions and concentrations but not adequately address the odors sensed by people downwind from a source.

Olfactometry, the most common human sensory method, uses trained individuals and standardized procedures to measure odor levels and describe odors. The key advantage of olfactometry is the direct correlation with odor and its use of the human’s highly sensitive sense of smell. Olfactometry also has the advantage that it analyzes the complete gas mixture so that the contribution of each compound in the sample is included in the analysis. McFarland reviewed many of the current olfactometry techniques being used for odor measurement and concluded that dynamic forced-choice olfactometry appears to be the most accepted method. This method presents a diluted odor sample and one or two blank samples (if two blank samples then referred to as a triangular system) to a panelist and they must choose which sample contains the odor even if it is a guess (forced-choice). If the choice was a guess or an incorrect detect, the panelist is presented with another set of samples but the odor sample’s concentration is two times higher than the previous one. This process is continued until the panelist makes two correct detect selections in a row. This increasing level of sample presentation is called “ascending concentration series”.

The selection described above is referred to as dilutions to thresholds (DT), and is the non-odorous airflow rate divided by the odorous airflow rate when a panelist correctly detects which airstream was different. DT is dimensionless and commonly reported as odor units (OU). Most researchers have expressed DT or odor concentration as OU per cubic meter (OU/m³). If this convention is followed, then odor emission rates (OU/sec) from a livestock building are the product of the ventilation airflow.
rate (m$^3$/sec) through the barn and the odor concentration (OU/m$^3$) in the exhaust air. However, the European Committee for Standardization (CEN)\textsuperscript{15} defines a European OU (designated as OUE) as the amount of odor that 123 \mu g of n-butanol (C$_4$H$_{10}$O), which when evaporated into 1 m$^3$ of neutral air at standard conditions elicits a DT response of 1. Odor concentration using the CEN standard is expressed as OUE/m$^3$ and odor emission rates, from a source such as livestock buildings, is the product of the airflow rate and concentration, or OUE/sec.

**EXPERIMENTAL METHODS**

The six states in the APECAB project used similar dynamic, triangular, forced-choice olfactometers (AC'SCENT International Olfactometer, St. Croix Sensory, Inc.), shown in Figure 1, to determine DT or odor concentrations. The precision of dynamic olfactometry depends on variations in factors such as the operation of the olfactometer (including accuracy of instrument’s airflow rate, the environment in the room housing the olfactometer, and the panel leader), panelist selection and training, sample collection, transportation, storage, and the data processing method. Each of these error-producing factors in odor measurements for this project will be discussed.

**Olfactometer Factors**

The St. Croix sensory olfactometer was designed to operate in accordance with American Society for Testing and Materials (ASTM) standard E679-97\textsuperscript{15} and critical segments of the CEN standard.\textsuperscript{16} The CEN standard suggested a primary airflow rate of 20 L/min at the sniffing port that was followed by all olfactometers used in the study. Clanton et al.\textsuperscript{17} suggested that variation in odor DTs would be reduced if each level (14 in the St. Croix Sensory olfactometer) was measured before each laboratory run and used in that session’s DT calculation. The odor labs for this project followed this procedure in most cases. Another procedure, completed in this project to improve the accuracy of the odor DT values from each olfactometer, included a chemical calibration of the olfactometer’s airflow rate using several concentrations of isobutylene and a PhotoVac model no. 2020 photoionization (PID) detector. The procedure followed is outlined in Section 6.5 of the CEN standard.\textsuperscript{15} This was done for each olfactometer and was mostly successful (only the very low levels failed to be within a 5% range) for all cooperating laboratories. The probable reason for not obtaining a 100% success rate of the chemical calibration was that the PID detector used did not seem to react fast enough at these very low levels, thus resulting in an initial spike response and then a sharp decay that was not sufficiently near the expected value. Finally, inlet air into the room that housed the olfactometers was charcoal filtered and had a positive pressure ventilation system that prevented odors from nearby rooms and hallways from entering into this space. This design maintained an odor-free space for the panelist to reside during odor sessions.

**Panelist Selection and Training**

It is known that sense of smell is normally distributed in human populations. A small percentage of individuals are either hypersensitive (able to detect odors at very low concentrations) or anosmic (unable to detect odors). Before participating in any measurement sessions for this project, panelists were screened to see if they had a “normal” sense of smell. After being screened, panelists were trained to use proper sniffing and breathing techniques to increase the contact between the air sample and their olfactory senses. A standardized procedure that included several hours of training was used to achieve repeatable olfactometry results for each individual. Odor panelists were also required to meet and follow the criteria and

![Figure 1. AC'SCENT International olfactometer that was used by all six states in this APECAB study to measure odor concentrations.](image-url)
rules listed in Table 1 before participating in any odor sessions for this project. These operational rules (including only having nonsmokers as panelists, eating no spicy food at least 6 hr before the lab, and the need to be fragrance free) assisted in panelists maintaining their odor-sensing ability during the sessions.

Even with training and a normal sense of smell, panelists exhibit a great deal of variability in their ability to determine the DT of an air sample. To ensure panelists maintained their sensitivity, the DT of a nominal 40 ppm (reference) n-butanol sample, which was presented to all panelists during each odor session, was recorded and compared with the allowable range of 20–80 ppm. The running average of the 20 most recent levels for each person’s reference n-butanol DT results was kept on file and if the average fell outside of the 20–80 ppm n-butanol allowable range that individual was removed from the panelist pool. This protocol of determining the ongoing sensitivity of the panelist is outlined in Section 6.7 of the CEN standard.

A panel of eight trained people was normally used to analyze each odor sample at the various sites. At some laboratories, four panelists were used twice for a total of eight separate evaluations. The odor panel sessions were limited to approximately 3 hr to avoid odor fatigue and help keep the panelists focused on proper sniffing technique.

**Sample Collection, Transportation, and Storage**

For this project, odor samples were collected from the ventilation inlet (background) and the primary exhaust fan (outlet) locations for each building sampled (each site sampled two adjacent buildings). Samples were collected from the sampling manifold exhaust system of the custom-built GSS inside the instrument trailer. During odor sampling, the automatic sampling of the data acquisition (DAQ) system’s sampling cycle was interrupted and the specific locations (inlet or outlet) in each building were manually selected using the LabView data program. Collection of the odor samples in the trailer through the regular gas sampling lines rather than directly at the exhaust fans and inlets reduced the risk of sampling and human error.

Odor samples were collected in 0.05 mm thick, 10-L Tedlar bags with polypropylene fittings. Depending on the site, the Tedlar bags were either purchased commercially or manufactured by the particular university from stock material and these same bag sources were used consistently throughout the project. New bags (n unbaked) were used for each sample collection to minimize any adsorption of odorous compounds onto bag surfaces. The Tedlar bags were filled one-third full with sample air from the GSS port for preconditioning after an equilibrium sample line time (typically 5 min) was reached at a given barn location. The bags were then removed from the port and manually emptied. After reattaching the bags to the GSS port they were refilled to a transportable capacity of approximately 8 L in about a 3-min time span. Three bag samples were collected at each building’s exhaust (outlet) location whereas two bag samples were taken at the barn’s inlet (background) for a total of eight samples. Samples were generally collected every 2 weeks at each of the six sites. Bag samples were transported in plastic tote containers to avoid direct sunlight and kept in as cool of an environment as possible until analyzed at the olfactometry laboratories. No cross-laboratory odor measurements were done during this study although comparison of results between some of the odor laboratories had previously been done.

The inlet to the sampling lines in the GSS system used to collect odor samples were filtered with a 1 μm filter. Therefore the air inside the Tedlar bags did not contain airborne particulates that are typically present in livestock buildings. However, even in odor sampling systems that do not filter the air before it is collected in the Tedlar bags, the olfactometer’s plumbing system filters the air before the air enters the panelist sniffing ports and thus odors that are attached to dust particles are not measured. In this study the odor sample was filtered a second time with a 0.3-μm line filter that was inserted between the Tedlar sample bag and olfactometer inlet.

Limited information is available on the diurnal patterns of odorous gas emissions. Because odor emissions cannot be measured continuously and the cost of odor measurements is significant, decisions must be made on when to take odor samples. In the case of other gas emissions the key element is the average emissions over the course of a day or year. In the case of odor, it is unclear if measurements should be taken to assess the average or peak emissions. For this project, there were no “time of odor sampling” criteria used.

**Odor Data Processing**

Odor samples were evaluated for DT within 30 hr of collection. The panel’s average (geometric mean) concentration was used along with the time-specific airflow rate for the appropriate building in the following equation to determine the odor emissions:

\[
E = Q \times (C_{\text{exhaust}} - C_{\text{inlet}})
\]

where \(E\) is the odor emission from the appropriate barns (OU/sec), \(Q\) is the barn airflow rate at the specific time of sample collection (m3/sec), \(C_{\text{exhaust}}\) is the average (of three samples) concentration of odor at the barn exhaust fan (OU/m3), and \(C_{\text{inlet}}\) is the average (of two samples) concentration of odor at the barn inlet (OU/m3).

**Table 1. Odor panel rules.**

1. Must be free of colds or other physical conditions affecting the sense of smell.
2. Must not smoke or use smokeless tobacco.
3. Must not chew gum, eat, or consume coffee, tea, or beverages for at least 1 hr prior to odor panel work.
4. Must not eat spicy foods for at least 6 hr prior to odor panel work.
5. Must be “fragrance-free” by not using perfume, cologne, deodorant, or scented after shave, shampoo, or hand lotion the day of odor panel work.
6. Must not consume alcohol for at least 6 hr prior to odor panel work.
7. Must attend a training session and recertification each year.
8. Must not discuss their odor selections and answers with other panel members or public.
9. May drink only bottled water during odor panel work.
10. Must not consume alcohol for at least 6 hr prior to odor panel work.
11. Must not chew gum, eat, or consume coffee, tea, or beverages for at least 1 hr prior to odor panel work.
A critical variable in the odor emission calculation is the airflow rate as expressed above. All six universities in this study utilized a portable fan tester called the Fan Assessment Numeration System (FANS) unit that accurately measured the airflow rate of all exhaust fans in the buildings as a function of the barn’s static pressure. Static pressure was continuously measured in all buildings using pressure transducers, and fan-running time was measured using a variety of techniques. Also, as the above odor emission calculation shows, the odor concentration used in the analysis was the difference between what was leaving minus that entering the buildings. This procedure eliminated the need of Tedlar bag blanks that are often used to determine the contribution of odor from the bags themselves.

### Measurement Example of Odor Concentrations and Calculated Emissions
As an example of the type of odor information collected during this project, the mean and maximum odor concentration and emission data over the monitoring period for the two dry sow barns in Minnesota are listed in Table 2. Values are listed both per barn and per animal unit (AU = 500 kg of animal mass). The seasonal odor emission trend for these two sow barns is displayed in Figure 2. These values represent an average of three samples collected instantaneously per barn every 2 weeks during the monitoring period. The increase in odor emissions during the summer compared with the winter probably occurred because of the increased ventilation rates during the summer, warmer ambient and manure temperatures, and the management of the manure handling. The elevated odor emission rate during the summer is a concern because it may create nuisance issues for neighbors living near swine production facilities similar to this farm. Similar data from the other five sites were collected and will be reported in a later paper.

### CONCLUSIONS
This paper describes how established standards and the proper use of odor measuring (olfactometry) equipment can be implemented to measure odor concentrations and emissions from pig and poultry buildings. The methodology for odor measurement described in this APECAB research study will provide animal producers, regulators, animal building designers, and consultants with much needed data on odor emissions from swine and poultry confinement buildings. These findings will extend current research emission data to include seasonal, animal weight, manure management, and geographic effects. This information will be useful to government officials in developing science-based regulations for odor emissions from these facilities and also to building consultants and air dispersion modelers to reduce the impact these sources have on neighbors and the environment.

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