Quality Assured Measurements of Livestock Building Emissions: Part 3. Odor Concentrations

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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, multi-state project has initiated field studies in six states to measure emissions of

odor, PM_{10}, TSP, hydrogen sulfide, ammonia, carbon dioxide, methane and nonmethane hydrocarbons from swine and poultry production buildings. This paper will focus on the intermittent measurement of odor concentrations at identical pairs of buildings in each state. Documented principles used in air pollution monitoring at industrial sources were applied in developing the EPA-approved quality assurance project plan for this project. Since the ventilation air exhaust capacity of the mechanically ventilated livestock buildings are divided among 4 to 75 exhaust fans, air is sampled from multiple locations for odor analysis every two weeks over a 15-month sampling period. Air is collected from the pig and poultry barn in small (10 to 50 L) Tedlar bags through the gas sampling system located in the instrument trailer housing the gas and dust analyzers. The samples are analyzed within 24 hours by a dynamic dilution forced-choice olfactometer (a dilution apparatus). The olfactometers (AC'SCENT International Olfactometer, St. Croix Sensory, Stillwater, MN) used by all participating laboratories meets the olfactometry standards in the United States and Europe.[1,2] Eight trained panelists at each laboratory measures detection thresholds along with intensity. This paper will discuss the protocols for collecting and analyzing odor samples to minimize standard variations between samples and laboratories. Preliminary odor emission data from one of the six sites yields values within the reported literature values for swine gestations buildings.

Keywords: air quality, detection threshold, emissions, emission factors, livestock housing, nuisance, odor, olfactometry, quality assurance, sampling.

IMPLICATIONS

The management of air pollutants is the next major manure management issue that U.S. agriculture face. Odor discussed in this article is associated with concentrated animal feeding operations (CAFOs) can create neighborhood nuisance, animal or human health concerns, or non-compliance with state or federal regulations.[3] Currently, an assessment of the true impact of odor is limited by the lack of reliable data on emission rates. The project goal is to determine baseline emission rates for six types of animal confinement buildings and evaluate the differences in emissions due to geographical region, season of year, building design, growth cycle of the animals, and building management. To date,

this study is the most comprehensive study of air quality in livestock buildings in the U.S. Information from this research will provide producers, technical assistance providers, regulators, and compilers of emission inventories with accurate information.

INTRODUCTION

Livestock and poultry producers in the United States are becoming increasingly concerned over the odors and gases that are generated and emitted from their animal operations. Odors and gas emissions from animal production sites are impacting producers in a variety of ways. 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 or enact new air standards to address these odor issues.

Because of these growing concerns there is an urgent need to determine odor, gas, and particulate matter emissions levels from animal production sites, such as the buildings, associated manure storage units, open lots, and on-farm outdoor feed storages areas. Emissions levels need to be known so producers and others can determine which sources/processes 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 components being emitted. Secondly, 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 and the airflow rate from the source. Few researchers and engineers have taken on the task of measuring odor and/or gas emission rates because of these and other difficulties.

Aerial pollutants of particular interest in livestock buildings are ammonia (NH_3), hydrogen sulfide (H_2S), volatile organic compounds (VOC), and particulate matter ($PM_{2.5}$, PM_{10}, and TSP). Odor contributes to nuisance experienced in areas surrounding livestock facilities. Methane (CH_4) and carbon dioxide (CO_2) emissions are considered to

be important greenhouse gases. However, vegetation provides a substantial sink for CO_2 and the primary reason for measuring CO_2 is to assess building ventilation.

In 2002, the U.S. government initiated multi-state collaborative emission studies of aerial pollutants from livestock production. The USDA funded a 6-state project entitled "Aerial Pollutant Emissions from Animal Confinement Buildings" (APECAB) which is quantifying and characterizing baseline emissions of odor, NH_3, H_2S, PM_{10}, and TSP from four types of swine buildings and two types of poultry buildings. The influences of ventilation, animal weight, humidity, temperature, and manure management on these emissions will also be evaluated. The APECAB study (Jacobson and Heber, co-PIs) is a collaboration of land-grant universities in Indiana, Iowa, Minnesota, Illinois, North Carolina, and Texas. The study is utilizing common instrumentation and protocol. At each measurement site, a mobile instrument trailer is stationed between two identical or nearly identical, mechanically ventilated, confined animal production buildings and emission measurements are quasi-continuous. The trailer houses 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 are measured at the air inlets and outlets of each building while simultaneously monitoring total building airflow rates. Odor samples are taken biweekly to determine odor emissions. Emission rates are calculated by multiplying concentration differences between inlet and outlet air by building airflow rates.[4]

The 15-month sampling duration for the APECAB project assures that long-term emissions and annual emission factors can be fully characterized. Long-term measurements allow the recording of variations in emissions due to seasonal effects, animal growth cycles, and diurnal variations. The purpose of this four-part series is to describe how well-established principles of quality control and quality assurance were applied to emission measurements at livestock buildings to develop a common protocol. Parts 1-4 address gas, particulate matter, and odor concentrations, and airflow rate, respectively. This paper addresses odor concentration measurements.

MATERIALS AND METHODS

The Sense of Smell

The sense of smell is complex. The basic anatomy of the human nose and olfactory system is well understood. Odorous compounds are detected in a small region known as the olfactory epithelium located high and in the rear of the nasal cavity. The olfactory epithelium contains millions of neurons, the signaling cells of sensory systems, with hair like sensors called cilia. The cilia extend outward and are in direct contact with the nearby air. In turn each neuron is connected to the olfactory bulb through fibers called axons. The olfactory bulb connects to the olfactory cortex and other parts of the brain.[5]

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 becoming available, illustrates how important smells can be to people. The power, complexity, and our limited understanding of the sense of smell make olfaction a challenging field.

Most odors are a mixture of many different gases at extremely low concentrations. The composition and concentrations of the gas mixtures affects the perceived odor. To completely measure an odor, each gas would need to be measured. Some odorous gases can be detected (smelled) by humans at very low concentrations (Table 1). The fact that most odors are made up of many different gases at extremely low concentrations makes it very difficult and expensive to determine the exact composition of the ambient odor.

Odor Measurements

There are two general approaches used to measure odor, either measure individual gas concentrations or use a sensory method such as olfactometry. Both approaches have strengths and weaknesses. Future developments will hopefully close the gap between the two approaches. The specific individual gaseous compounds in an air sample can be identified and measured using a variety of sensors and techniques. The results can be used to compare different air samples. With good sensors and proper techniques, valuable

information about the gases that emanate from a source can be collected and evaluated. Gas emission rates and control techniques can be compared rigorously. Regulations can be established to limit individual gas concentrations. However, the gas measurement approach has some weaknesses when used to measure and control odors. The greatest weakness of the gas measurement approach is that there is no known relationship between the specific gas concentrations in a mixture and its perceived odor.[6] 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 of a source.

Some scientists have proposed using "indicator" gases to quantify livestock odors. Hydrogen sulfide and ammonia are among the most common chemicals proposed. Unfortunately, hydrogen sulfide and ammonia concentrations are not correlated to livestock odor. [7-11] Yashuhara (1980) found that a mixture of eleven compounds strongly resembled the quality of solid swine manure.[12] Livestock odors consist of many gases at extremely low concentrations, which are very difficult and expensive to measure. Measuring some of the gases may not be enough to describe the odor. Research and development of new, better, lower cost sensors is ongoing. Electronic noses, which use electronic sensors to measure a select number of chemical compounds, are being used in some industries for quality control. Most studies indicate that the output of electronic noses does not correlate with livestock odors however one study suggests that technological developments may make it possible in the future.[13-16]

Olfactometry, the most common 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 analyses the complete gas mixture so that contribution of each compound in the sample is included in the analysis. There are different olfactometry techniques. Data collected by different techniques can be neither combined nor directly compared.

McFarland (1995) 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.[17] Olfactometry suffers from a lack of precision

compared to some of the sophisticated chemical sensors available. The lack of precision in olfactometry is due in part to the variability in each person's sense of smell and their reaction to an odor. Also, olfactometry does not identify the individual compounds that make up the odor. Even though olfactometry has limitations it still is the best technique available for directly measuring odors at this time. Progress is being made to model population responses to odor concentrations.[18]

Dynamic, Triangular, Forced-Choice Olfactometer

The six states in the APECAB project will use a dynamic, triangular, forced-choice olfactometer in their odor laboratory to determine detection threshold concentrations. The unit being used was developed in cooperation with consultants with extensive olfactometry laboratory experience. It is designed to be operated in accordance with ASTM Standard E679-91 and proposed European Standard ODC 543.271.2:628.52.[2,17] . A chemical calibration of the olfactometer's airflow rate is done at least once at all odor laboratories using several concentrations of isobutylene and a PhotoVac^{TM} model #2020 PID detector.

Standardized procedures and 4 hours of panelist training are used to achieve repeatable olfactometer results. Panelists are required to follow the rules listed in Table 2. The standard procedures and panelist rules help panelist's use their sense of smell to obtain consistent results and develop a professional attitude to their work. Odor panel sessions are limited to approximately 3 hours to avoid odor fatigue and help keep the panelists focused on proper sniffing technique. Panelists are trained to use proper sniffing (breathing) techniques to increase the contact between the air sample and their olfactory epithelium. A dynamic, triangular, forced-choice olfactometer presents three air streams to the trained panelists. One of the air streams is a mixture of non-odorous air and an extremely small amount of odorous air from a sample bag. The other two air streams have only non-odorous air. Panelists sniff each air stream and are forced to identify which air stream is different (i.e., has some odor) than the other two non-odorous air streams. Initially panelists must guess which air stream is different because the amount of odorous air added is below the detection threshold. In steps, the amount of odorous air added is doubled until the panelist correctly recognizes which air stream is

different. The detection threshold is the non-odorous airflow rate divided by the odorous airflow rate when the panelist correctly recognizes which air stream is different. A panel of 8 trained people is normally used to analyze each odor sample. The panel's average (geometric mean) concentration is reported and used in statistical analysis.

Panelists are screened to find people with a "normal" sense of smell. Even with training and a normal sense of smell panelists have a great deal of variability in their ability to determine the detection threshold of an air sample. It is known that sense of smell is normally distribution in the general population. A small percentage of individuals are either hypersensitive (able to detect odors at very low concentrations) or anosmic (unable to detect odors). A majority of people falls in the "normal" range and people from this group are selected as panelists. To ensure panelists maintain their sensitivity, the detection threshold of a n-butanol sample that is presented to the panelist during each odor session must be within the range of 20 to 80 ppmv.

One European odor unit (EOU) is defined as the amount of odorant at the panel detection threshold (DT) and is dimensionless. However, the DT of a sample is often expressed as odor units per cubic meter (OU/m^3) for calculation convenience of odor emission.[2] If this convention is followed, then odor emission rates (OU/sec) from a livestock building is the product of the ventilation airflow rate (m^3/s) through the barn and the odor concentration (OU/m^3) in the exhaust air.

Odor Emissions from Livestock Buildings

Klarenbeek (1985) measured odor emissions from pig facilities in The Netherlands.[21] The measured values ranged from 1.01 OU/pig place/sec in a partially slatted pig barn (70% solid floor?) to 11.15 OU/ pig place/sec in a fully slatted floor barn with pit ventilation. Emissions were found to be seasonal with levels during winter significantly lower than in summer. Verdoes and Ogink (1997) also measured odor from "low ammonia emitting pig barns" in The Netherlands.[22] Using a calibration fan, they found emission rates were between 9 and 12 OU/pig place/sec for dry sows, 31 and 40 OU/pig place/sec for farrowing sows, 3 to 8 OU/pig place/sec for weaners, and 12 to 16 OU/pig place/sec for finishers under a low pH food (?) ration. Hartung *et al*. (1998) measured odor emission rates in a gestating sow and a finishing barn in Germany and found that

they varied from 16 to 495 OU/livestock unit/sec.[23] A distinct diurnal variation was observed in the odor emission that was probably due to the changing ventilation rates during the day. Jiang and Sands (1998) found odor emission levels from several Australian naturally ventilated broiler facilities ranging from 3.1 to 9.6 OU/m^3/ m^2/sec.[24]

In the United States, Lim et al., (2001) reported the overall mean emission rate of 34 OU/animal unit/sec (1.8 OU/m2/sec).[25] Heber *et al*. (1999) reported odor emissions of 5.3 to 36.2 OU/min/animal unit (0.8 to 5.4 OU/m^2/sec) from pig finishing barns with shallow gutters that were recharged with lagoon water.[26] Heber *et al*. (2002) reported the average odor flux emissions of 1.72 OU/m^2/sec from a facultative swine lagoon stratified by surface aeration.[27] Jacobson *et al*. (1999) reported on odor emissions from a variety of animal production facilities in Minnesota.[28] The variation in building emission rates ranged from 1 to 30 OU/m^2/sec. Also in Minnesota, Zhu *et al*. (2000) reported on daylong monitoring of odor from different poultry and livestock facilities.[29] A pig nursery barn had the highest one time odor emission rate (48 OU/m^2/sec) while other pig production facilities monitored (gestation, farrowing and finishing) as well as a broiler building had emission rates lower than 10 OU/m^2/sec for most of the day. Stowell et al. (2002) reported lower (by approximately 28 OU/m^2/sec) odor emissions from a prototype high-rise™ compared to a more conventional deep-pit finishing swine facilities in Ohio.[30]

APECAB Odor Measurement Protocols

For determining emission factors for the APECAB project, odor samples are collected from the ventilation inlet (or ambient air) and outlet locations from each building. Samples are taken directly from the sampling manifold exhaust system in the trailer. Samples are collected using 0.05 mm thick, 10-L to 50-L Tedlar bags equipped with single polypropylene fittings. New bags are used for each sample collection on biweekly basis.

The Tedlar bags are attached to a port immediately downstream of the sampling pump (Figure 1) and allowed to fill under the pressure created by the sampling pump. During odor sampling the automatic sampling of the data acquisition (DAQ) system is interrupted but gas monitoring of the selected location (sample line) continues. The location in the building are manually selected using the LabView® data program. The

Tedlar bag is filled 1/3 full for preconditioning after at few minutes of equilibrium time at a given location. The preconditioning of Tedlar bag with the sampled air minimizes the affects of adsorption to bag walls and increases the sample recovery. The equilibrium time is used to assure that a representative sample is collected from a given sampling line. The bag is then emptied and filled. Duplicate samples are taken at an inlet location (background) and in triplicate at two exhaust locations (one per building) for a total of 8 samples at each state research sites.

These samples will be evaluated for detection threshold (DT) within 30 hours of collection using the same type of olfactometer (AC'SCENT® International Olfactometer, St. Croix Sensory, Inc., MN) in the respective states. All machines meet the CEN performance standard for precision and accuracy using a revised protocol for the St. Croix Sensory olfactometer. In addition to dilutions to threshold concentrations, panelists also determine intensity at full strength.

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 are significant, decisions must be made on when to take odor samples. In the cases 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. Currently no “time of odor sampling” criterion is being used. As the project develops and more emission data from the other gases is determined efforts will be made to collect both the “peak” and “average” odor emissions based on “peak” and “average” emissions of the other gases. Timing of odor sampling to attain this information will be varied among sites. Collecting the air samples in the trailer through the air measuring lines reduces the risk of sampling and human error due to working outside the exhaust fans in potential weather extremes. Collecting samples from inside the building is not advisable because of animal disturbance, which would probably increase the odor emission.

RESULTS AND DISCUSSION

The 2.5 year APECAB project was begun in the fall of 2001 with the initial year dedicated to equipment purchases and setup, protocol development, quality assurance and control, and startup. Data collection at the six different sites began in the fall and early winter of 2002. Odor collection and analysis is being done on a biweekly basis.

Preliminary Results from the Minnesota Gestation Barns

The collection of gas, particulate matter, and odor concentrations and emission data from the swine gestation site shown schematically in Figure 2 was started in late September of 2002 in Minnesota. The buildings are oriented N-S and spaced 30 ft (22.9 m) apart. The roofs of the buildings have a 4:12 slope. Each building is 254 ft × 48 ft. (186.0 m × 30.2 m) and will house about 630 sows in six rows of crates. Manure is collected in a shallow pull-plug pits beneath the slatted floor for one week. Each week the pull plug is removed and liquid manure is allowed to flow to the first stage storage basin. The shallow pits are recharged with liquid from the second stage manure storage unit after the weekly manure removal.

The barn is tunnel-ventilated. Minimum ventilation air enters the room from the attic through evenly spaced gravity baffled ceiling air inlets. Mild and summer ventilation air flows through evaporative cooling cells in the south end wall opposite the fans. There are five 48-in diameter and one 36-in diameter Aerovent™ belt-driven exhaust fans in the north end wall. The one 36-in fan operates continuously and the 48-in fans are staged to operate as room temperature increases.

The two gestation barns are part of a 1400 sow farrowing operation that produces weaned piglets. Sows from the farrowing barn are brought into the west breeding/gestation barn for breeding purposes. Some sows are relocated into the east barn to remain during their 115-day gestation cycle before returning to the farrowing barn. Feed rations during the gestation cycle remain constant. Feed consumption by each sow is managed individually depending on her physical body condition.

Odor data collection started during the last week of September, 2002 at the Minnesota site. As described previously, samples were collected during the day (Tuesday) and analyzed at the University of Minnesota Olfactometry laboratory the next

day (Wednesday). Table 3 lists preliminary odor concentration and emission data that were collected at this site on Oct. 8, 2002 and Nov 5, 2002. The two barns, identified as gestation and breeding (Figure 2), are of similar same size but the breeding barn houses about 110 less animals. The ventilation rates in both barns decreased from the October to the November sampling period since the outside temperatures dropped and the exhaust fans are temperature-controlled. Odor concentrations were lower in the October compared to the November levels since airflow rates were higher. Even though odor concentrations inside barns increased in November, the odor emissions were smaller then the October emission rates due to the reduction in the ventilation airflow rates in the barns. These preliminary emission rates fall within the previously stated ranges of odor emissions for other pig facilities. This project will produce concentration and emission values over a full year of operation, covering seasonal and other variations seen in animal production whereas previous studies only looked at emission over a shorter time span.

CONCLUSIONS

The results of the APECAB research study will provide animal producers, regulators, animal building designers and consultants with much needed data on the emissions of important air pollutants such as odor, that are emitted 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, gas, and dust emissions from these facilities as well as building consultants and air dispersion modelers to reduce the impact these sources have on neighbors and the environment.

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TABLES

Table 1. Odor threshold for select chemicals often found in livestock odors.

Chemical	Odor Threshold (ppbv)
Aldehydes	
Acetaldehyde	210
Propionaldehyde	9.5
Volatile Fatty Acids	
Acetic acid	1000
Propionic acid	20000
Butyric acid	1
Nitrogen containing	
Methylamine	21
Dimethylamine	47
Trimethylamine	0.21
Skatole	19
Ammonia	46800
Sulfur containing	
Methanethiol	2.1
Ethanethiol	1
Propanethiol	0. 74
t-Butythiol	0.09
Dimethy sulfide	1
Hydrogen sulfide	7.2

Adapted from[4].

Table 2. Rules for odor panelists as part of quality assurance and quality control.

#	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 one hour prior to odor panel work.
4	Must not eat spicy foods for at least six hours prior to odor panel work.
5	Must be "fragrance-free" by not using perfume, cologne, deodorant or scented aftershave, shampoo, or hand lotion the day of odor panel work.
6	Must not consume alcohol for at least six hours prior to odor panel work.
7	May drink only bottled water during odor panel work.
8	Must not discuss their odor selections and answers with other panel members or public.
9	Must attend a training session and recertification each year
10	Must demonstrate “professional behavior” at all times.
11	Must sign attendance sheet at the beginning of each session.

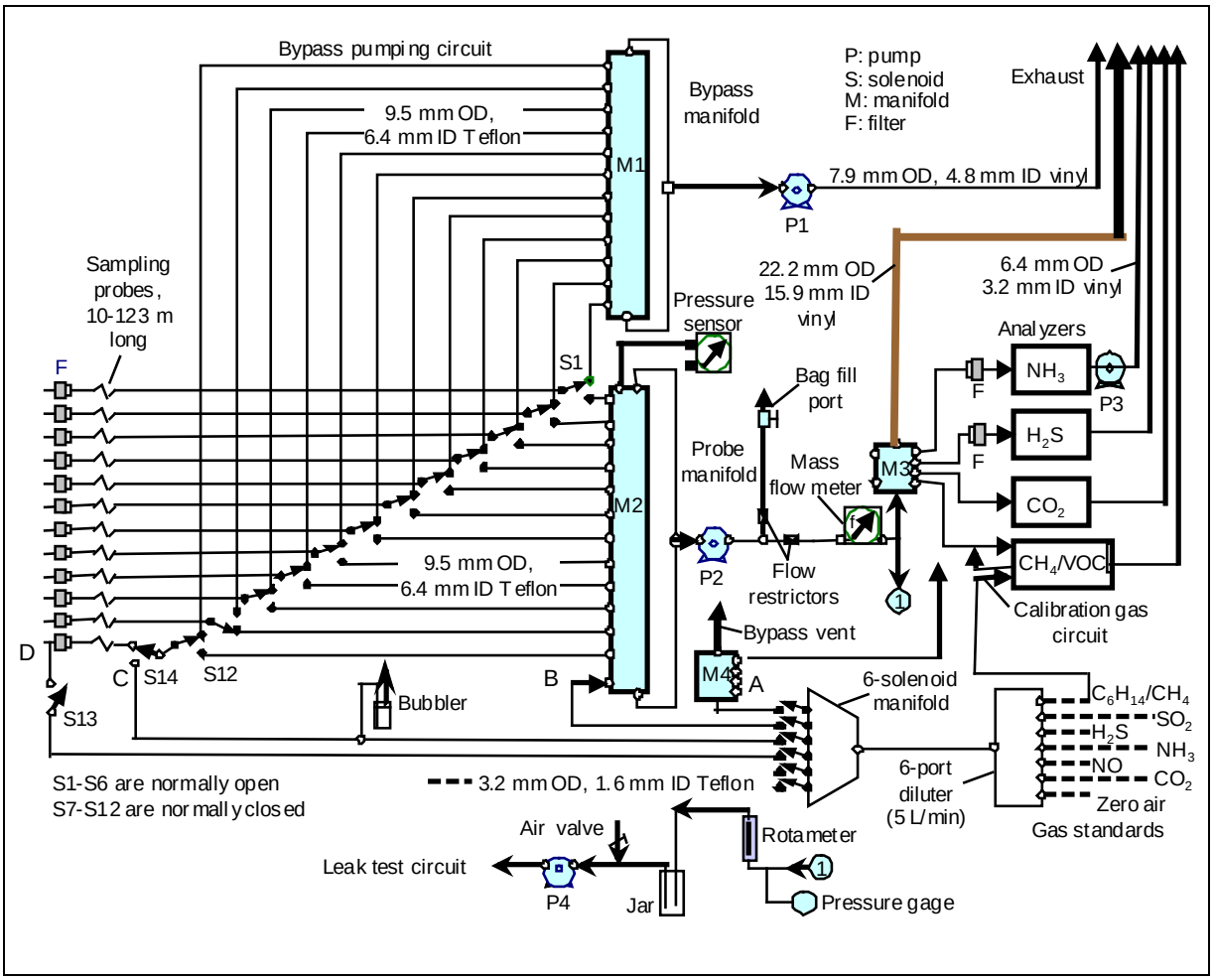
Table 3. Odor concentrations and emissions from Minnesota APECAB site – fall, 2002.

Barn type - date	Odor Concentration (OU)	Barn Airflow (m^3/s)	Barn Area (m^2)	Odor Emissions ($OU/m^2/s$)
Gestation - 10/8/2002	829	15.4	5620	2.27
Breeding - 10/8/2002	536	15.4	5620	1.46
Gestation - 11/5/2002	1483	5.3	5620	1.40
Breeding - 11/5/2002	846	5.3	5620	0.80

FIGURES

Figure 1. Gas sampling system (GSS) for the APECAB project. The odor bag fill port is shown downstream from pump P2.

Figure 2. Schematic drawing of swine gestation building layout for Minnesota site.



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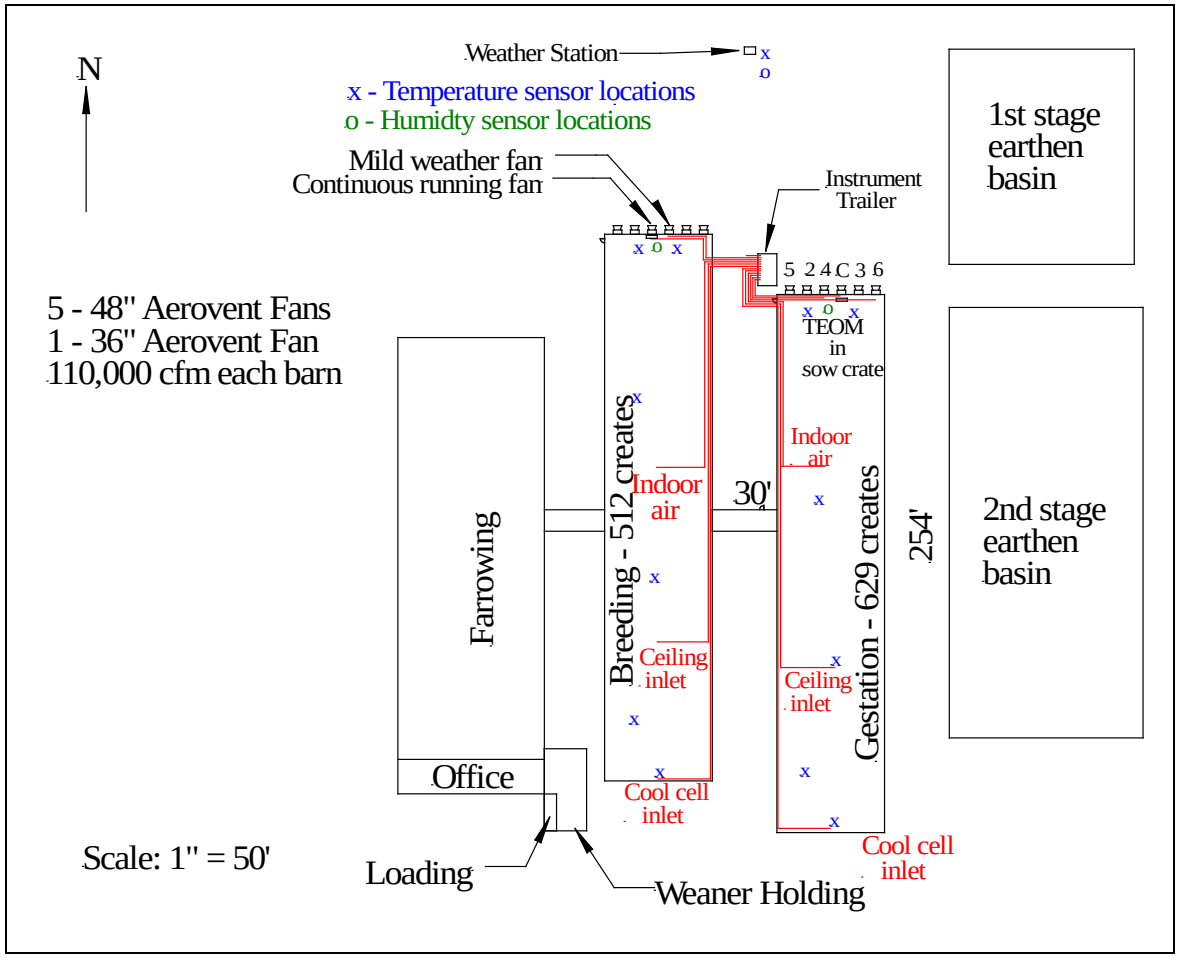

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Larry, please consider changing font to Arial 12 pt. to make this figure sharper. The use of color is probably not needed. Also, please change the dimensions to metric.