RESEARCH REPORT

ENVIRONMENT

Title: Development of methods to measure dust (PM_{10}) and ammonia emissions from Minnesota pig facilities **NPB# 01-074**

Investigator: Larry D. Jacobson

Institution: University of Minnesota

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I. Abstract:

The concentration and emission rate for ammonia, hydrogen sulfide, particulate matter or dust under 10 microns in diameter (PM_{10}), and odor were measured in a representative deep-bedded hoop pig finishing barn and a slatted-floor, curtain-sided pig finishing barn during 2+ week periods in the winter and summer in Minnesota. Ammonia and hydrogen sulfide were continuously measured with gas analyzers in an environmentally controlled instrument trailer while PM_{10} and odor were measured roughly twice during the 2+ week sampling period. Ammonia concentrations inside both barns were quite similar in the winter and summer but the emission of ammonia were higher in the hoop barn on a per pig basis. Hydrogen sulfide (H_2S) concentrations and emissions were lower in the hoop barn compared to the curtain barn during both the winter and summer except for the per pig emissions in the winter which were similar. Fine particle dust (PM_{10}) concentrations and per pig emissions were very similar for both barn types during the winter and summer. Odor concentrations and per pig emissions in the winter were lower in the hoop barn compared to the curtain barn but both levels were similar between the barns in the summer, showing a slight advantage of lower odor emissions in the hoop barn during warm conditions. Although these result are helpful in evaluating the air quality impacts between these different finishing housing systems, it must be remembered that the winter and summer values were not measured simultaneously because of the availability of only one set of gas analyzers, dust collectors, and a single instrument trailer. Also these comparisons are only between single barn types and these specific barns may not exactly represent the general barn type. Considering these limitations, it would seem from the results that the hoop barn has lower hydrogen sulfide and odor concentrations and emissions compared to the more conventional curtain barn. Lower emissions of ammonia exist in the curtain barn than the hoop barn even though concentrations are quite similar. There seems to be no difference in concentrations or per pig emissions of dust, or more specifically PM_{10} which represent the fine diameter particles, between the two barn types.

II. Introduction:

State and federal regulators are beginning to examine the particulate matter (PM) emissions from animal (including pork) production systems. USEPA (1987) replaced the total suspended particulate (TSP) standards with a PM_{10} standard or dust particles with a mass medium diameter of 10 microns or less. This was done to put more emphasis on relatively fine, rather than coarse, dust particles to provide greater human health protection (Sweeten, et al. 2000). The ambient PM_{10} primary and secondary standards were changed to a 150 $\mu g/m^3$ 24-hour average value with no more than one exceeding time allowed per year (USEPA, 1987). Although these proposed standards have not been officially adopted by EPA because of pending litigation (Sweeten, 2000) they remain a major concern for the pork industry.

Ammonia emissions for agricultural sources in the United States have been estimated by Battye et al. (1994) from the European literature. Ammonia emissions are also of concern for both potential watershed (acid rain) impacts as well as possible human health concerns. Ammonia, along with other gases, is likely the primary contributor to $PM_{2.5}$ (particulate matter under 2.5 microns in diameter) formation (Sweeten, et al. 2000). Only a few researchers (Ni et al. 1998 and Stowell et al. 2000) have measured ammonia emissions in the United States and have generally found lower values than reported in the European literature (Sweeten et al. 2000). It is critical that emission data from buildings that are located in Minnesota and operated under our climate conditions be measured and used to determine if air emission standards are exceeded.

III. Objectives:

To determine the dust or particulate matter (PM_{10}), ammonia, hydrogen sulfide, and odor emissions from slatted and deep-bedded pig grow-finishing facilities in Minnesota.

IV. Procedures:

Emission monitoring was conducted at a bedded pig-finishing hoop barn and a conventional deep-pit slatted floor pig-finishing barn in Minnesota during cold and warm weather conditions. Continuous monitoring of ammonia and hydrogen sulfide emissions was done at each site for approximately 2 weeks during the winter and summer (Table 1). Grab samples of dust were taken twice and odor samples collected once during each monitoring period. Sites were chosen based on the lack of other livestock or poultry farms nearby, the cooperators' willingness to participate in the project, and the timing of the animal production cycles. The goal was to monitor barns that were at or near capacity and with near market weight or mature animals, assuming that this would provide the worst case or highest gas and dust emissions.

Table 1. Sampling schedule.

Farm	Winter Sampling Dates (Average ambient T, ºF)	# animals (lbs/animal)	Summer Sampling Dates (Average ambient T, ºF)	# animals (lbs/animal)
Hoop	12/6/01-12/27/01 (27º)	180 (180)	06/26/02 - 07/11/02 (75º)	180 (235)
Slatted	11/17/01- 11/29/01	950	07/15/02- 07/30/02	1000

Farm	Winter Sampling Dates (Average ambient T, ºF)	# animals (lbs/animal)	Summer Sampling Dates (Average ambient T, ºF)	# animals (lbs/animal)
	(43º)	(230)	(75º)	(150)

Description of Sites:

The hoop barn site consisted of three 30 ft x 72 ft hoop barns (figure 1) which had their long axis running north and south and were spaced 12 ft apart. Only one barn was sampled for this study. There was a concrete floor at the south end of the barn where the round dry feeders and non-electric waterers were located. The remaining floor area was compacted soil (approximately 50 ft) and was bedded with large bales of wheat straw. Typically this area was bedded every 3 to 4 days with two large (600 to 700 lbs) bales but was determined by the pig's age and weather conditions. Pigs were placed in the barn as "feeder pigs" (50 lbs) and removed at 260 to 270 lbs.

The conventional curtain-sided slatted floor barn site (figure 2) consisted of two 41 ft x 400 ft fully slatted barns with each holding 2000 pigs. Both barns had an 8 ft. deep pit under all of the floor area and were divided into two 1000-head rooms. The barns ran east and west (long axis) and were roughly 100 ft apart. The east room of the north barn was sampled for this study. Pigs were brought in at roughly 50 lbs and were removed at approximately 260 lbs. Barn ventilation is typical for this style of building, with mechanical ventilation used (pit and wall fans) in cold weather and naturally ventilated in the summer by thermostatically controlled sidewall curtains.

Sampling setup for gas measurements:

An equipment trailer was used that was environmentally controlled to provide conditions necessary for proper operation of the measurement equipment. Three, 75 foot Teflon air sampling lines were installed in each of the barns evaluated. Multiple sampling lines were used in order to obtain representative sample concentrations in the barn or room to obtain inlet air conditions or evaluate different exhaust streams. Sampling lines were heated using heat tape and insulated between the barn and the equipment trailer to avoid condensation in the lines. A vacuum pump and solenoid valves in the trailer were used sequentially to draw air from each of the sampling lines into a manifold (ten minutes for each sampling line). Air from the manifold was sampled for carbon dioxide using an infrared gas monitor (Model 3600 Mine Safety Appliance, Pittsburgh, PA), hydrogen sulfide using a Pulsed-fluorescence hydrogen sulfide analyzer, Thermal Environment Instrument Model 45C, Franklin, MA and ammonia using a chemiluminescence nitric oxide (NO) analyzer and a thermal ammonia (NH3) converter (Thermal Environment Instrument Model 17C, Franklin, MA). Data was recorded using a CR 21X data logger (Campbell Scientific, Logan, Utah).

Dust Measurements:

At least two, 24-hour dust measurements were made during each site's sampling period. The dust sampling equipment used in this study was a MiniVol Portable Air Sampler (Airmetrics, Eugene OR) that measures PM_{10} or particles less than 10 microns in aerodynamic diameter. This sampler was selected since it does measure "PM_{10}" which is the particle size generally used in ambient air quality standards. These units were located near the center of each of the barns at heights of 6 ft. above the floor.

Odor measurements:

Air samples were collected through Teflon tubes at the gas sampling points for odor analysis in 10 liter Tedlar bags using an SKC vacuum box specially designed for this purpose. Duplicate samples were collected at least twice during each 2-3 week period at each site in the winter and summer. The samples were analyzed for odor using an olfactometer and a panel of eight trained panelists to measure the odor threshold. The olfactometer used is a venturi-type dynamic dilution olfactometer (AC'SCENT® International Olfactometer, St. Croix Sensory, Inc., Stillwater, MN). It can provide 14 different dilutions ratios of charcoal-filtered fresh air with the sample air ranging from 2^3 to 2^{16} (10 to 65,000) nominally. The procedure is in accordance with ASTM Standard E679-91 and proposed European Standard ODC 543.271.2.629.52 (Air Quality Determination of Odor Concentration by Dynamic Olfactometry).

Ventilation measurements:

Ventilation rates are one of the most important yet difficult measurements to make when evaluating emissions from livestock buildings, especially those that are naturally ventilated. For this study, the "carbon dioxide balance method" was used to determine the ventilation rates (Albright, 1990). This method compares the ambient carbon dioxide to the carbon dioxide concentrations in the exhaust air. This difference is related to the amount of carbon dioxide given off by the animals, which is estimated using the number and weight of the animals, and the airflow through the barn. Unfortunately, large variations in carbon dioxide can exist in buildings because of incomplete mixing in the barn and other sources of CO_2 generation (e.g., manure decomposition). A standard ambient air concentration of carbon dioxide of 345 ppm was used in this study due to the difficulty in accurately measuring the ambient CO_2 concentrations on site.

V. Results:

The results of the study are summarized in Tables 2-5 below. Each table lists the bedded hoop and slatted floor barn's mean and standard deviation value for ammonia, hydrogen sulfide, dust (PM_{10}), and odor concentration and emission values. Although this method of presentation shows some comparison between the different housing systems it must be remembered that the winter and summer values were not measured simultaneously because of the availability of only one set of gas analyzers, dust collectors, and only a single instrument trailer. As shown in table 1, data was collected from both barn types as soon as possible, allowing for proper cleanup and required biosecurity time spans.

Ammonia (NH_3):

The mean and standard deviations for the continuous 2+ week measurements of ammonia for both barn types in the winter and summer are listed in Table 2. The ammonia concentrations values are quite similar for both barn types with nearly equal levels in the winter (8 to 9 ppm) and in the summer (5 to 6 ppm). However, when expressed as emissions on a per pig basis as shown in Table 2 the deep-bedded barn's values are about an order of magnitude (10 times) as large as those for the slatted barn in the winter and summer. This is a little surprising since ammonia concentrations are essentially equal but results from the high ventilation rate per animal seen in the year-around natural ventilated hoop barn. Ammonia concentrations and subsequent emissions from the hoop barn are dependent on the amount and frequency of bedding in these facilities. Further examination of the continuous ammonia measurements are needed along with the times that bedding was added to the barn but early indications seem to point to a measurable drop in ammonia immediately after the barn is bedded.

Table 2. Mean and Standard Deviation of Ammonia (NH_3) Concentrations and Emissions for a Deep-bedded Hoop finishing barn and for a slatted floor curtain-sided finishing barn.

Barn Type	**Winter Conc. (SD) Emissions (SD) ppm mg/s/pig**	**Summer Conc.(SD) Emissions (SD) ppm mg/s/pig**
Deep-bedded Hoop barn	9.3 (5.0) 0.39 (0.20)	5.9 (6.0) 0.43 (0.45)
Slatted floor barn	8.5 (3.1) 0.02 (0.006)	5.1 (2.9) 0.06 (0.06)

Hydrogen Sulfide (H_2S):

The mean and standard deviations of the continuous hydrogen sulfide (H_2S) concentration and emission measurements taken from these two barn types are listed in Table 3. The table shows, for the most part, lower concentration and emission values for H_2S from the hoop building compared to the conventional slatted-floor finishing barn. The one exception is the per pig H_2S emissions during the winter which reveals very similar values for both barns (actually a slightly higher level for the hoop barn vs. the slatted floor building). An order of magnitude difference (10 vs. 100+ ppb) exists between the hoop and slatted barn's hydrogen sulfide concentrations. It would seem that the existence of the straw seems to chemically bind the sulfur compounds in the hoop barn. The higher H_2S emissions in the hoop barn during the winter can probably be explained by the much higher ventilation rate per animal during this time period compared to the more controlled ventilation system in the slatted floor barn during cold weather.

Table 3. Mean and Standard Deviation of Hydrogen Sulfide (H_2S) Concentrations and Emissions for a Deep-bedded Hoop finishing barn and for a slatted floor curtain-sided finishing barn.

Barn Type	**Winter Conc.(SD) Emissions (SD) ppb micrograms/s/pig**	**Summer Conc.(SD) Emissions (SD) ppb micrograms/s/pig**
Deep-bedded Hoop barn	10.1 (11.6) 0.39 (0.37)	8.7 (14.4) 0.55 (0.79)
Slatted floor barn	97 (55) 0.21 (0.10)	149 (98) 1.93 (2.18)

Dust (PM_{10}):

The dust or more specifically particulate matter with an aerodynamic diameter less than 10 microns (PM_{10}) generated and released in these two types of pig finishing barns are listed in Table 4. PM_{10} concentrations are greater in the winter compared to the summer values for both barns but emissions are 2 to 4 times larger in the summer than the winter as a result of the increase ventilation rates for both barns in the summer. Also the higher variations for the summer emission values are the result of large variations in ventilation rates as calculated from carbon dioxide concentrations in these warm weather naturally ventilated facilities. One needs to be reminded that PM_{10} is only the relatively fine to very small particles. Total dust concentrations and emissions for these barns would be considerably greater since large particles, although fewer in number, contributes significantly in weight (or mass). As indicated earlier, PM_{10} was measured for this study since this parameter is being used in many ambient air quality standards. PM_{10} is used for these standards since the smaller particles are inhalable and represent a greater impact to both animal and human health.

Table 4. Mean and Standard Deviation of Dust (PM_{10}) Concentrations and Emissions for a Deep-bedded Hoop finishing barn and for a slatted floor curtain-sided finishing barn.

Barn Type	**Winter Conc.(SD) Emissions (SD) mg/m^3 mg/hr/pig**	**Summer Conc.(SD) Emissions (SD) mg/m^3 mg/hr/pig**
Deep-bedded Hoop barn	0.28 (0.09) 8.60 (1.40)	0.12 (0.06) 37.0 (40.8)
Slatted floor barn	0.51 (0.06) 7.31 (1.36)	0.09 (0.03) 11.2 (6.80)

Odor:

The geomeans of the intermittent odor measurements made in these two types of finishing barns are listed in Table 5. Typically, two separate odor measurements were taken during the two + week sampling period. Odor samples were collected over only a 3 to 4 minute period so it represents the odor present during this short span of time. Also odor concentrations are log values so if the numbers are of the same order of magnitude or power of ten they are quite similar. The deep-bedded barn had odor concentrations and emissions that were lower than the odor levels from the slatted floor barn. The one exception to this was during the summer where both barns had essentially similar odor concentrations but with the slatted barn's higher ventilation rates during this period, its odor emissions exceeded that of the deep-bedded hoop barn by a factor of two. Thus it would seem between these two particular barns, the conventional slatted-floor curtain-sided barn does emit more odors compared to the deep-bedded hoop barn on a per pig basis. As mentioned in the ammonia discussion above and as expected, the amount and frequency of bedding in the hoop barn seems to have an effect on the magnitude of odor concentrations and emissions.

Table 5. Geomean and Standard Deviation of Odor Concentrations and Emissions for a Deep-bedded Hoop finishing barn and for a slatted floor curtain-sided finishing barn.

Barn Type	**Winter** **Conc.(SD)** **OU**	**Emissions (SD)** **OU/s/pig**	**Summer** **Conc.(SD)** **OU**	**Emissions (SD)** **OU/s/pig**
Deep-bedded Hoop barn	148 (97)	1.75 (0.25)	117 (0)	11.67 (0)
Slatted floor barn	1358 (1515)	4.74 (5.21)	74.4 (92)	24.00 (32.80)

References:

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Figure 1. Instrument trailer at deep-bedded hoop finishing barn site.

Figure 2. Instrument trailer at curtain-sided, slatted floor finishing barn site.