Air Quality Measurements at a Laying Hen House: Ammonia Concentrations and Emissions

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ABSTRACT

Ammonia emissions were measured for six months at a modern 250,000-hen high-rise egg laying house using the chemiluminescence method along with multi-point extractive gas sampling. The ammonia analyzer was sequenced through twelve sampling locations including nine exhaust fans every two hours and calibrated at least weekly with certified calibration gases. Fan operation was monitored along with building static pressure. The average daily means of NH_3 concentrations were 2.4, 16.1, and 43.3 mg m^{-3} for inlet, cage, and exhaust air, respectively, and were much higher during the colder months than then warmer months. The net NH_3 emission rate was 387±25 kg d^{-1} or 509±33 g per day per 500 kg live mass. Relatively lower emission rates were measured in the warmer months even though the ventilations were higher. The NH_3 concentration was also found inversely proportional to inlet temperature, exhaust temperature, and ventilation rate. The ammonia concentration and emission data collected in this test is the most comprehensive study of a single laying house to date.

INTRODUCTION

Large livestock confinement buildings are becoming more common because they effectively reduce unit costs of production, but they can also be significant sources of aerial pollutants. Ammonia (NH_3) has been identified as one of the important noxious gas emitted by large animal facilities, quantification of NH_3 emission from such facilities is thus needed.

Emission rates of NH_3 were measured from a mechanically-ventilated, 112,000-bird laying house in Pennsylvania.[1] The measurement consisted of 18, 24-h sampling days over an eight-month period with outdoor air temperature ranged from 1.2 to 25.2 ^{o}C. Mean NH_3 emission rate ranged from 12.9 to 122.4 mg h^{-1} $bird^{-1}$, and was 66.6 mg h^{-1} $bird^{-}$overall. Ventilated rate did not significantly influence NH_3 emission rate.[1]

Ammonia emissions from laying hens and broilers houses in England, The Netherlands, Denmark and Germany varied between 2.1 and 39.4 mg h^{-1} $bird^{-1}$ or 602 and 10 892 mg h^{-1} AU^{-1} (AU = animal unit, 500 kg live mass).[2] The authors reported large variations of emissions between countries, between commercial houses and between seasons.

A combination of manure drying and composting in a high-rise building was used to minimize odor-causing anaerobic decomposition and transportation costs associated with liquid manure storage.[3] Heating in piles of poultry litter results in temperatures of 30-50°C. Moisture content (MC) was 29 to 49% with the lowest MC observed near the exhaust fans.[3] The manure handling systems had a significant impact on manure characteristics, Lorimor and Xin[4] reported mean MC of 47 in high-rise houses and 30% in buildings with manure boards and scrapers.

While there have been several NH_3 studies conducted previously, a systematic quantification of long term, continuous NH_3 emissions from large U.S. laying houses has not been reported. The objective of this study was to evaluate NH_3 concentrations and emissions at a modern caged-layer house.

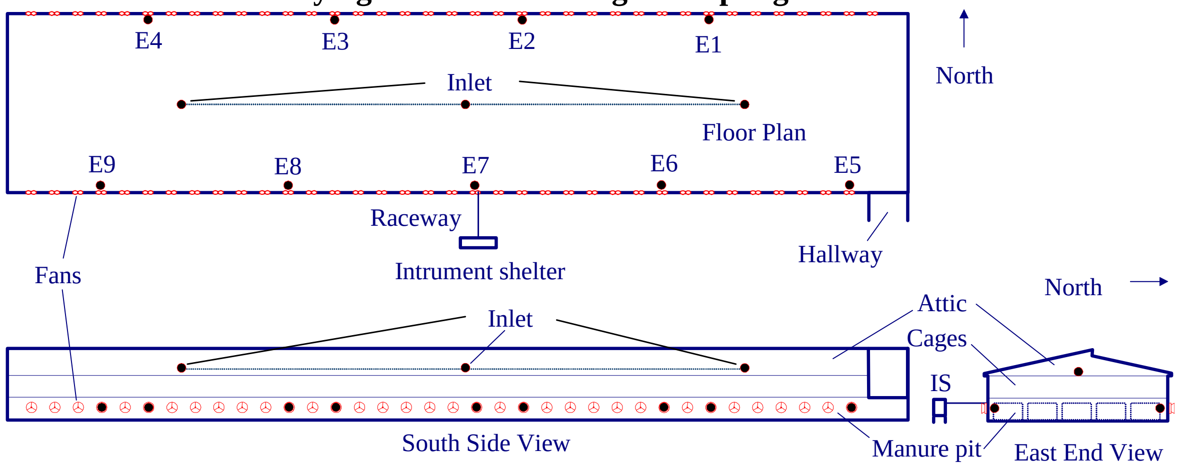
MATERIALS AND METHODS

Concentrations of NH_3 along with many other environmental variables were collected from December 1, 2001 to June 15, 2002. The technique used for measuring these variables in this research is extensively described by Heber et al.[5]

Experimental Barns

The caged-hen layer house was a one-year old 250,000-hen high-rise building, located at a 14-barn egg-laying facility in north-central Indiana. The 36.6 m wide and 182.9 m long building had ten 177-m long rows of cages in the 3.7-m high upper floor. Manure was scraped daily into the first floor, a 3.2-m deep manure storage pit. Automatically-adjusted baffled ceiling air inlets admitted fresh air from the attic over each row of cages. Manure drying on the first floor was enhanced with twenty-five 92-cm dia. circulation fans (Model 40404-36, Choretime-Brock, Milford, IN). Seventy-three, 1.23-m dia. belted exhaust fans (Model 38233-4, Choretime-Brock) were distributed along the sidewalls of the first floor (Fig. 1), and were grouped into eight fan stages for temperature-based control. Ventilation air flowed through the slots into the pit as a result of under pressure created by these exhaust fans. The lights in the second floor were shut off automatically between 20:00 and 04:00 h.

Figure 1. Floor plan (top), side view (bottom left), and cross section (bottom right) of the laying house with some gas sampling locations.



Automatic measurements of building pressure, ventilation fan operation, temperatures (T), relative humidity (RH), and gas concentrations at building inlets and exhausts were conducted at this building.[5] Instruments were housed in an on-farm instrument shelter parked along the south sidewall near the 17th fan from the east end. Air was continuously sampled by a multi-point gas sampling system (GSS) in the shelter.[5] Air was drawn sequentially from several locations in the building into the shelter for gas analysis. Sampling location groups (SLG) were used for ventilation inlet air, cage locations (animal exposure), and the exhaust locations.[6]

The nine exhaust locations were distributed among four, continuous, stage-1 fans (SLG's 1, 3, 7 and 9) and the five stage-2 fans (SLG's 2, 4, 5, 6, and 8) (fig. 1). The three ceiling inlet locations were sampled individually but grouped together after the animal exposure group was added on February 21. Since the opening of baffled inlet was controlled based on temperature instead of pressure, the inlets sometimes allowed warm contaminated air to rise into the attic especially during colder weather, causing errors in the background measurement. Thus, background measurement locations should be moved to a location that is less vulnerable to errors.

Ammonia Concentration Measurement and Calibration

Ammonia concentrations were measured with a 0-200 ppm (0-141 mg m^{-3}) chemiluminescence NH_3 analyzer (TEI Model 17C) after conversion to NO, as described by Ni et al.[7] The analyzer sampled at a flow rate of 0.6 L min^{-1} with an external vacuum pump (Model PU426, KNF Neuberger, Trenton, NJ). The NH_3 analyzer was calibrated with zero and 27.0-ppm (19.1-mg m^{-3}) certified calibration gases (BOC Gases, Murray Hill, NJ) at least once per week for a total of 44 times. A new tank of 24.6-ppm (17.4-mg m^{-3}) calibration gas was used after April 12. The calibration gases were much lower than winter exhaust concentrations (50 to 150 ppm), but similar to warm weather concentrations of 15 to 30 ppm. Although the nominal range of the NH_3 analyzer was 100 ppm, it was increased to 200 ppm by reducing instrument sensitivity by 50%.

Ventilation Airflow and Emission Rates

The operating status of each fan stage was monitored via auxiliary contacts of fan motor control relays. Since dust build-up, belt wear, and shutter degradation causes less airflow than predicted by published fan performance curves, fan airflow capacities were measured in the field with a portable fan tester consisting of multiple traversing impellers.[8] The fan tester was calibrated with an accuracy of ±2% at the University of Illinois Bioenvironmental Systems and Simulations (BESS) Laboratory with two fans temporarily removed from the laying house. Adjustment factors were assigned to each fan stage based on field tests of 22 fans conducted between May 17 and June 7. The minute airflow rates of each SLG were calculated based on the number of fans operated, percent time of operation, adjustment factors to each stage, and the BESS-calibrated fan curve using measured static pressure. Total building ventilation rate was the summation of adjusted airflows from each SLG.

Net emission rate (E) was determined by multiplying the total ventilation airflow ($m^3\ s^{-1}$) by the increase in concentration between the inlet (C_I) and the exhaust (C_{EX}).[9]

$$E = Q\,(C_I - C_{EX}) \qquad [1]$$

where Q is the volumetric rate of ventilation airflow ($m^3\ s^{-1}$). Gross emission rate was the direct multiplication of ventilation rate and exhaust concentration, neglecting the inlet concentration. Emission rates were specified to the total live mass of the birds by dividing building emission rate by the number of animal unit to allow comparison with other studies.[10]

Data Acquisition and Other Measured Variables

A commercial data acquisition (DAQ) software (Labview for Windows, National Instruments, Austin, TX) was used with the DAQ hardware described by Heber et al. (2001). Blocks of data collected at 1 Hz were averaged and stored every 60 s.

Temperatures (T) at all gas sampling locations were measured with semiconductor sensors (Model AD592, Computer Boards, Mansfield, MA). Attic air T and relative humidity (RH) were measured continuously with precisions of ±0.6 °C and ±3%, respectively (Model 50Y, Vaisala, Woburn, MA). Static pressure differences (±0.5 Pa) across each sidewall were monitored with differential pressure sensors (Model 267, Setra, Boxborough, MA).

Forty surface samples were collected from the top 5 cm of the stored litter on March 14, April 15 and May 16 at randomly selected locations, and analyzed for moisture content (MC) and pH. Moisture content was analyzed gravimetrically at 90-95 °C in duplicate. A KCl electrode was used to determine pH.

Data Processing

The sampling interval of all sampling locations was 10 min but was decreased to 5 min after May 2. Since the analyzer was measuring air samples drawn from different locations with different concentrations, there was a need to wait for equilibrium of the analyzers. The equilibrium and stabilizing times were seven and four minutes for the 10- and 5-min sampling intervals, respectively.

Custom data processing software was used to handle the large set of data.[11,12] During cold days only one fan stage operated, thus the SLG's associated with stage 2 (SLGs 2, 4, 5, 6, and 8) were excluded since sampled air from these did not represent exhaust air. The data completeness criterion for validating exhaust concentrations were that the fan sampled must have operated for more than 50% of the time during that same minute. This condition must also hold for each of the last six previous 60-s readings.

Since one analyzer was used for multiple sampling locations, there were only about three and one valid minute data points for each sampling cycle for the 10- and 5-min sampling intervals, respectively. For analysis purposes, concentration values were linearly interpolated based on the mean valid data, the interpolated data was then used for emission calculation. When there were multiple valid minute data, the mean values were then used for interpolation. Interpolation was performed only when no more than one cycle of data was invalid, which means when there were two or more consecutive invalid or missing cycle data, there would be no interpolation of concentrations.

The mean concentration of the nearest two or three SLG values was substituted for an SLG that did not have valid or interpolated data. Several days were characterized by incomplete data, because of problems with some software and hardware components. Only days with 80% data completeness were used in calculating gas emission rates. These days were referred to as "complete" days. Some complete days had one to two hours of missing data because of analyzer calibrations.

RESULTS AND DISCUSSION

All measured variables are summarized in Table 1. A total of 176 complete days (based on T and RH) of data were collected, during which 125 d had 80% or more complete net emission means. The barn inventory was 249,077 and 243,265 hens on December 1 and June 15, respectively, with an average body mass of 1.54 kg and mean total live mass of 761 AU. The exhaust air temperature was relatively stable with a mean of 19.5±0.5 ^{o}C. The means of monthly RH means were also relatively stable for the entire measurement period.

Average spot measurements of fan airflows were 5% lower than that estimated by measured static pressure and the BESS-calibrated fan curve, and generally indicated that fans had lower actual capacity at lower fan stages, which operated more frequently. Adjustments to BESS calibrations based on in-field tests ranged from 0.858 for stage 1 to

1.024 for stage 8. The overall mean building ventilation rate during the air sampling events reported in this paper was 151±15.7 m^{-3} s^{-1}.

Table 1. Means of measurement variables.

Variables\Period	Dec	Jan	Feb	Mar.	April	May	June	Mean
Inventory, birds	248,662	247,986	247,181	246,197	245,367	244,342	243,516	246,384
Animal units, AU	749	757	751	766	768	765	780	761
Ventilation, m^3 s^{-1}	103	91	105	126	186	192	354	151
Temperatures, °C								
Ambient			-0.5	2.4	10.9	18.9	21.5	11.2
Inlet	3.2	2.0	2.1	4.1	12.1	15.0	22.3	7.4
Exhaust	16.6	16.8	17.7	18.8	21.6	22.6	26.4	19.5
Relative humidity, %								
Ambient			81.0	78.8	76.8	74.7	76.9	77.5
Inlet	77.4	70.0	69.4	70.3	68.6	65.8	69.1	70.2
Exhaust	76.3	78.9	78.5					77.7
Concentrations, mg m^{-3}								
Inlet	3.1	3.1	2.6	2.4	1.5	1.9	2.4	2.4
Cage			30.5	35.5	14.5	9.5	3.9	16.1
Exhaust	45.4	61.4	61.0	59.6	31.2	22.1	10.8	43.3
Emission rates								
Gross, kg d^{-1}	414	472	530	575	401	293	252	415
Net, kg d^{-1}	382	446	506	550	378	263	195	387
Net, g d^{-1} AU^{-1}	510	588	673	718	493	344	251	509
Number of days*	10	20	19	13	26	27	10	125

* Number of days with 80% or more complete net emission rate

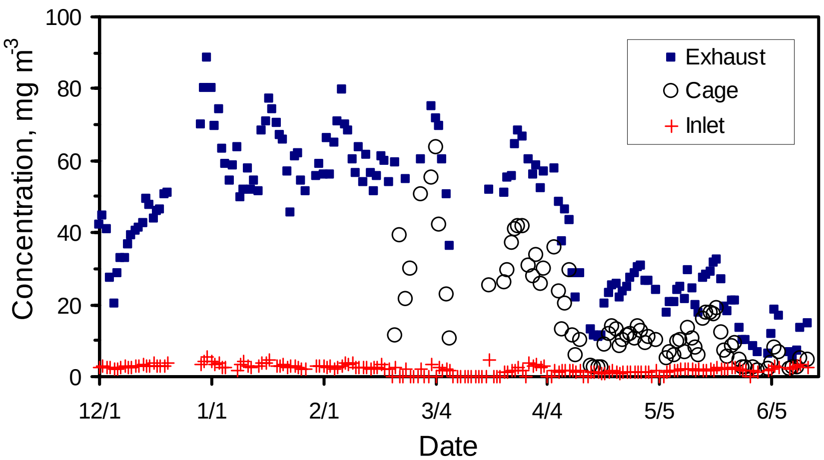
The mean MC of the surface litter samples were 36.4±6.2%, 26.0±4.2%, and 25.0±5.6% and mean pH was 8.38±0.12, 8.26±0.14, and 8.29±0.15 for the March, April, and May samples, respectively. The wide variation in MC among 40 samples was due to large spatial differences in drying caused by nonuniform surface air speeds created by circulation fans in the manure pit. The decrease in MC with time was apparently due to extra drying caused by increased ventilation rate associated with warmer weather. Although the circulation fans promoted surface drying year-round, the bulk mean MC may have been greater than the surface samples.

NH_3 Concentration and Emissions

The average daily means (ADM) of NH_3 concentrations were 2.4, 16.1, and 43.3 mg m^{-3} for inlet, cage, and exhaust air, respectively (Table 1). The mean inlet, cage, and exhaust concentrations ranged from 2.4 to 5.4, 11.2 to 63.9, and 47.0 to 88.5 mg m^{-3} (Fig. 2), respectively. It is apparent that NH_3 concentrations were much higher during the colder months than then warmer months. The ADM NH_3 concentrations of January through March was 153% higher than of April through June 15.

The higher NH_3 concentrations measured during the colder days were most probably due to greater NH_3 emitted from manure with higher MC. Our manure sample results indicated that the mean MC decreased from 36% in April to 25% in May. These values confirmed the findings of Nishina et al., who measured 41, 33 and 63% (MC) in stored litter of a laying house during summer, autumn and winter, respectively. However, there were only three groups of manure samples taken in a relatively short time period, and larger variations existed among the samples (especially for a large facility).

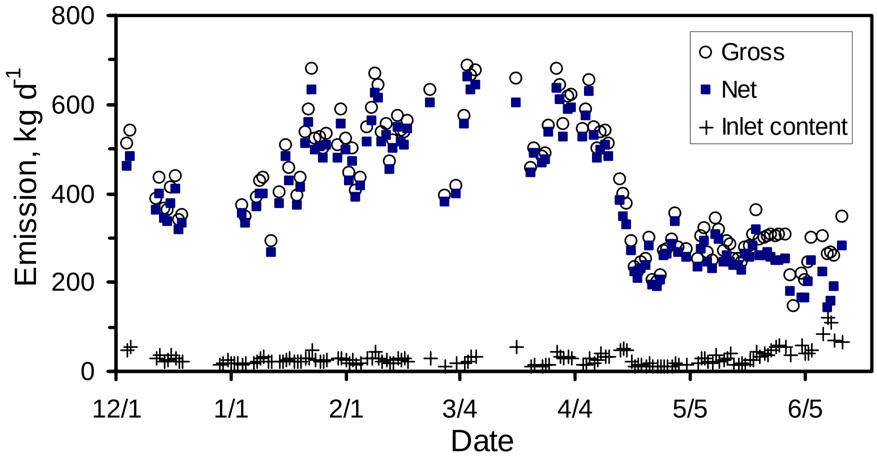
Figure 2. Daily mean ammonia concentrations of various locations.



The ADM net NH_3 emission rate was 387±25 kg d^{-1} or 509±33 g d^{-1} AU^{-1} (Table 1). Based on statistical and census data and several studies, a factor of 132 g d^{-1} AU^{-1} was reported for the UK and Irish caged layers.[13,14] The NH_3 emission rate reported in this study is also two to three times higher than those reported by Groot Koerkamo et al.[2], which were 7392, 9455, 10892 mg d^{-1} AU^{-1} (or 177, 227, 267 g d^{-1} AU^{-1}) for layhing hens with deep litter/perchery in UK, the Netherlands, and Denmark, respectively. However, the mean NH_3 emission rate of a US commercial laying hen house was 66.6 mg h^{-1} bird[1], and was similar to this study (65.5 mg h^{-1} bird).

The ADM NH_3 emissions for January through March was 67% higher than emissions between April 1 and June 15 (Fig. 3). Relatively lower emission rates were measured in the warmer months even though the ventilation were higher, which were mainly due to the much lower NH_3 concentrations. The ADM NH_3 concentrations and ventilation rates of January through March were 153% higher and 51% lower than of April through June 15, respectively. The large variations of emissions between between seasons confirm the findings of previous research[2].

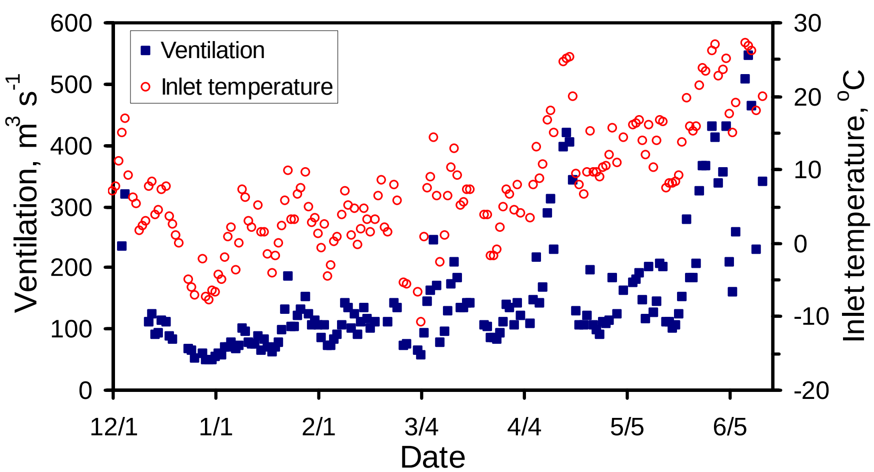
Figure 3. Daily mean gross and net emission rates and inlet.



Factors Affecting NH_3 Concentration and Emission

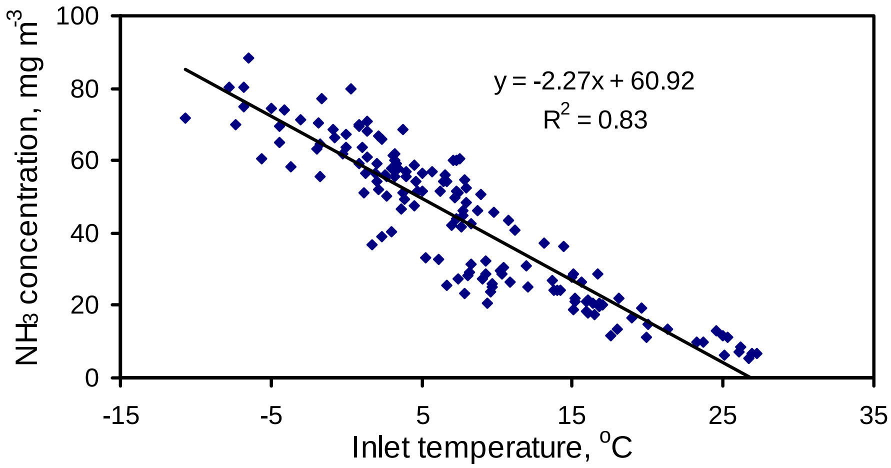
Lower NH_3 concentrations, emissions, and MC in the warmer months were most probably caused by the higher ventilation rates. Ventilation rate was found proportional to inlet (similar to outdoor) temperature (correlation coefficient = 0.89, $P<0.001$), Figure 4. Groop Koerkamp[15] concluded that NH_3 emissions of battery systems with manure belts underneath the cages are lower than housing systems with composting, because of lower MC and regular removal of manure. A higher dry matter content of litter slows down the volatilization of ammonia, forced drying of manure seems the only effective and acceptable way for temporary control of NH_3 emissions inside housing systems. [15]

Figure 4. Daily mean ventilation rates and inlet temperatures.



The correlation coefficients were -0.91, -0.85, and -0.74 ($P<0.001$) for ADM NH_3 exhaust concentration and ADM inlet temperature, exhaust temperature, and ventilation rate, respectively. It is apparent that higher ventilation rates had removed more moisture from the manure piles thus reducing the concentrations and emissions (Fig. 5). However, Maghirang and Manbeck[1] reported that indoor and outdoor temperatures, and ventilation rate did not significantly influence NH_3 emissions. The more frequent measurement of this research and other factors such as building design, management could have caused the difference. The correlation coefficients were 0.73, and -0.33 (P<0.001) for ADM NH_3 net emission rate and ADM exhaust NH_3 concentration and ventilation rate, respectively.

Figure 5. Daily mean exhaust NH3 concentration and inlet temperatures.



CONCLUSIONS

1. Mean NH_3 concentrations of inlets, cages, and exhaust air were 2.4, 16.1, and 43.3 mg m^{-3}, respectively.
2. The ADM NH_3 concentration was inversely proportional to inlet and building exhaust air temperatures, and building ventilation rate.
3. The ADM of net NH_3 emission rate was 387±25 kg d^{-1} or 509±33 g d^{-1} AU^{-1}.
4. The ADM NH_3 emission was proportional to building exhaust concentration, and inversely proportional to building ventilation rate.

KEYWORDS

Livestock
Airflow
Emission
Ammonia
Poultry

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