2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 084417

Hydrogen Sulfide and Nonmethane Hydrocarbon Emissions from Broiler Houses in the Southeastern United States

Hong Li[1], Robert T. Burns[1], Hongwei Xin[1], Richard S. Gates[2], Steve Trabue[3], Douglas G. Overhults[2], Lara Moody[1], and John Earnest[2]

[1] Dept. of Agricultural & Biosystems Engineering, Iowa State University, Ames, IA 50011

[2] Dept. of Biosystems & Agricultural Engineering, University of Kentucky, Lexington, KY 40546

[3] National Soil Tilth Laboratory, USDA Agricultural Research Service, Ames, IA 50011

Written for presentation at the
2008 ASABE Annual International Meeting
Sponsored by ASABE
Rhode Island Convention Center
Providence, Rhode Island
June 29 – July 2, 2008

Abstract. *Hydrogen sulfide (H_2S) and nonmethane hydrocarbon (NMHC) emissions from two mechanically ventilated commercial broiler houses located in the southeastern United States were continuously monitored over 12 flocks for a one-year period during 2006-2007 as a joint effort between Iowa State University and the University of Kentucky. H_2S and NMHC concentrations were measured using UV-Fluorescence H_2S analyzers and methane/nonmethane/total hydrocarbon dual flame ionization detector gas chromatographs. Ventilation rates in each house were measured continuously by monitoring building static pressure and operational status of all ventilation fans in conjunction with individual performance curves developed and verified in situ using a Fan Assessment Numeration System (FANS) unit. United States EPA methods TO-15 and TO-17 were used for the nonmethane hydrocarbon compound speciation. The top-25 compounds are presented. The overall mean H_2S and NMHC emission rates for a one-year period were 65.7 ± 42 g/d-house and 0.76 ± 0.43 kg C_3H_8/d-house, respectively. Annual H_2S emission for the two broiler houses (including downtime emissions) averaged 19.2 kg per year per house or 0.147 g per bird marketed when the birds were marketed at 52 days of age with a stocking density of 11.8 bird per m^2 (1.1 bird per ft^2). Annual NMHC emission averaged 231 kg per year per house (510 lb per year per house) or 1.77 g per bird marketed.*

Keywords. Hydrogen sulfide, nonmethane hydrocarbon, emission, broiler, air quality

Introduction

A comprehensive review by the National Academy of Science (NAS, 2003) regarding air emissions data pertaining to U.S. AFOs concluded that such data were lacking for U.S. animal production conditions. The review called for collection of baseline emission data and development of process-based models to predict such air emissions. In response to NAS recommendations, the United States Department of Agriculture (USDA) has made quantification of air emissions from AFOs one of the top priorities in its Initiative for Future Agriculture and Food System (IFAFS) Program and subsequently the National Research Initiative (NRI) Program. As a result, since 2002 great strides have been made toward collection of baseline air emissions from U.S. AFO facilities. Noticeable among the funded studies was the six-state (IA, IN, IL, MN, NC, TX) project on air emissions from cattle and swine facilities, and the three-state (IA, KY and PA) project on ammonia emissions from layers (in Iowa and Pennsylvania; Liang et al., 2005) and broilers (in Kentucky and Pennsylvania; Wheeler et al., 2006). There is a lack of air emissions (except for ammonia) data for broiler housing systems. During this time period, more research findings on ammonia emissions from European broiler houses have been reported (Nicholson et al., 2004). However, information regarding emission rates of particulate matter, hydrogen sulfide (H_2S) and nonmethane hydrocarbons (NMHC) from broiler houses remains meager.

The objective of this study was to determine and report air emissions based on continuous measurement of aerial pollutant concentrations and fan airflow data over a one-year period from two broiler houses representative of commercial broiler production in the southeastern United States. The aerial pollutants quantified in this paper include H_2S and NMHC. The emissions data presented in this report were collected using a continuous monitoring protocol over a 13-month period at two broiler production houses in western Kentucky.

Monitoring System Description

Broiler House Characteristics

Two commercial broiler houses (T-1 and T-2) with dimension of 13.1 m x 155.5 m (43 x 510 ft) in western Kentucky were selected for emissions monitoring. The monitored houses used tunnel ventilation and static pressure controlled box air inlets along the sidewalls. The houses had insulated drop ceilings (about R19), box air inlets (15 x 66 cm or 6 x 26 inch) along the sidewalls (26 per sidewall), 26 pancake brooders (8.8 kW or 30,000 Btu/hr each), three space furnaces (65.9 kW or 225,000 Btu/hr each), four 91-cm (36-in) diameter sidewall exhaust fans spaced about 36.6 m (120 ft) apart, and ten 123-cm (48-in) diameter tunnel fans. The 91-cm (36-in) fan (SW1) for minimum ventilation was located in the brood end of the houses away from the tunnel end. Two 24-m (80-ft) sections of evaporative cooling pads were located in the opposite end from the tunnel fans. The houses were also equipped with foggers for additional cooling, if needed. Rice hulls were used as litter bedding in both houses.

Flock Characteristics

The starting times of the air emission monitoring were Feb 14, 2006 and Feb 20, 2006 for T-1 and T-2, respectively. The ending dates of the monitoring were March 14, 2007 and March 5th, 2007 for T-1 and T-2, respectively. At the ending dates, six full flocks had been monitored from T-1 and the sixth flock was ongoing from T-2. Each house had an initial placement of 25,800 Cobb-Cobb straight-run (mixed sex) broilers in winter and 24,400 in summer. The average grow-out periods were 52 days. A bird scale (Model RSC-2, Rotem, Petach Tikva, Israel) was placed in each house to continuously monitor bird weight. Bird mortality was also recorded, allowing for expression of emission on the basis of per bird or per 500 kg animal unit (AU). Both houses had new litter at the beginning of the monitoring study. During the one-year period, one cleanout of the litter was performed for T-1 on Aug 26, 2006 (after 3 flocks) and new bedding was placed on Aug 29, 2006; T-2 had a litter cleanout after the 5th flock, on Feb 3, 2007 and new bedding was placed on Feb 5, 2007.

Monitoring System

Each broiler house had its own Mobile Air Emissions Monitoring Unit (MAEMU) that housed gaseous concentrations and fan flow monitoring systems, and provided an environment-controlled instrument space as shown in Figure 1. Air sampling lines from the broiler house sampling points (representing the exhaust air streams) to the instrument trailer/analyzers were protected against in-line moisture condensation with insulation and temperature-controlled resistive heating cable.

Air samples were drawn from three locations in each house to account for potential spatial variations. One sampling location was near the primary minimum ventilation (36-in) sidewall fan (SW1) in the brooding half of the house; the second sampling location was near the third sidewall (36-in) exhaust fan (SW3) (non-brooding end); and the third sampling location was near the center of the tunnel end of the house between the first two sets of tunnel fans. Placement of the air sampling ports were as follows: for the two sidewall sampling locations, the sampling ports were located 1.2 m (4 ft) away from the fan in the axial direction, 2.3 m (7.5 ft) in the radial direction, and 1 m (3 ft) above the floor; for the tunnel-end sampling location, the sampling port was located at the center across the house (i.e., 6.55 m or 21.5 ft from each sidewall) and 7.32 m (24 ft) from the end wall. In addition, an outside ambient air sample was taken at 2-hour intervals to provide the background concentration. The ambient sample intake line was located between the inlet boxes opposite of the sidewall with the exhaust fans. The background amount of the gas was subtracted from the exhaust amount in calculating air emissions from the house.

A positive pressure gas sampling system (GSS) was designed and used for the MAEMU (fig. 3). Four pairs of 2-way solenoid valves (S1-S8) in the GSS were controlled by the data acquisition (DAQ) and control system to take air samples from the four sampling locations. The air samples from each location were analyzed for 120 sec. Selection of the 120 sec measurement cycles was based on extensive testing of the instrument response time, both in the laboratory and in the field (injecting calibration gases into the most distant in-house air sampling port). If fans at all three in-house sampling locations were running, the time interval of a complete sampling cycle would be 360 s (120 × 3 = 360 s). To account for potential concentration changes during this period, linear interpolation between the two adjacent readings of the same location was performed to determine the concentrations in between sampling events. If SW4 and/or TF1 fans were not operating, sampling of these locations would be skipped, and the sampling would either remain at SW1 or switch to the background air. Fan airflow rates concomitant with the measured concentrations were used in the calculation of the house emission rate. Only the concentrations at the end of the sampling cycle (fourth readings at any given in-house location) were considered as valid measurements and used to calculate emissions. When sampling the ambient air, the measurement cycle lasted for 8 min to ensure stabilization following the large step change from in-house relatively higher concentrations to the lower ambient concentrations. As mentioned above, the outside ambient air sample was taken at 2-hour intervals because of its relatively constant concentration levels. Burns et al. (2006) gave a more detailed description of the MAEMU development and operation.

A microprocessor controlled UV Fluorescence hydrogen sulfide (H_2S) analyzer (Model 101E, Teledyne API, San Diego, CA) was used to determine H_2S concentrations during the study. The 95% response time of the API 101E was less than 100 seconds for H_2S. For each location, the last H_2S readings during 120 sec sampling cycles were used for H_2S emission calculation. The VIG model 200 methane/nonmethane/total hydrocarbon analyzer (Model 200, VIG Industries Inc., Anaheim, CA) used column technology to separate methane and non-methane from total hydrocarbons and uses dual FID (flame ionization detectors) to measure each component in the air sample. The response time of NMHC was 70 seconds and NMHC reading was updated every 3 minutes. Every NMHC reading from the VIG 200 analyzer was identified with the corresponding sampling location and used in the emission calculation.

Ventilation rates of the houses were derived by using *in situ* calibrated fan curves from a state-of-the-art fan assessment numeration system (FANS) (Gates et al., 2004). After the actual airflow curves were established for all of the exhaust fans and their combinations, runtime of each fan was monitored and recorded continuously using an inductive current switch (with analog output) attached to the power supply cord of each fan motor (Muhlbauer et al., 2006). Analog output from the current switches was connected to the compact Fieldpoint modules. Concurrent measurement of the house static pressure was made with two static pressure sensors (Model 264, Setra, Boxborough, MA), each for half of the house. Summation of airflows from the individual fans during each monitoring cycle or sampling interval produced the overall house ventilation rate.

Nonmethane Hydrocarbon Speciation (EPA Method TO-15/17)

The EPA air consent agreement with animal feeding operations (AFO) specified the use of EPA TO-15 for the speciation of nonmethane hydrocarbons (NMHC) emitted from these facilities. Sorbent tube sampling may be a more effective technique in the speciation of NMHCs from AFOs due to its ability to capture both volatile and highly polar compounds. Stainless steel canisters (Entech Instruments, Inc., Simi Valley, CA) were used to collect the air samples from the two broiler houses and GC-MS method was used to identify the NMHC compounds. A solid sorbent method (TO-17) was used simultaneously to collect the air samples by glass sorbent tubes custom made by Supelco, Inc. (Bellafonte, PA) with GS 301 gas sampler (Gerstel, Inc., Baltimore, MD). Two collection and speciation trials were conducted on April 19, 2006 at T-2 (empty house) and Feb 6, 2007 at T-1 (with birds in house). The air samples were collected from nine different locations crossing the whole house and every air sampling location as shown in Figure 3. The top 25 compounds were speciated using both the TO-15 & TO-17 methods.

Emission Rate Determination

Gaseous emission rate (ER) from a broiler house to the atmosphere is the difference between the quantity of gases leaving the house and the quantity of gases entering the house. The relationship of ER to gaseous and particulate matter concentration of inlet and exhaust air and building ventilation rate may be expressed as the following:

$$ER_G = \sum_{e=1}^{3} Q_e \left([G]_e - \frac{\rho_e}{\rho_i}[G]_i \right) \times 10^{-6} \times \frac{w_m}{V_m} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}} \qquad [1]$$

where ER_G = gaseous emission rate for the house (g hr^{-1} $house^{-1}$)

Q_e = ventilation rate of the portion of the house at location “e” (SW1, SW3 or TE) at field temperature and barometric pressure (m^3 hr^{-1} $house^{-1}$)

$[G]_i$ = gaseous concentration of incoming house ventilation air, parts per million by volume (ppm_v)

$[G]_e$ = gaseous concentration of exhaust house ventilation air of the portion of the house at location "e" (ppm_v)

w_m = molar weight of air pollutants, g $mole^{-1}$

V_m = molar volume of pollutant gas at standard temperature (0°C) and pressure (1 atmosphere) (STP), 0.022414 m^3 $mole^{-1}$

T_{std} = standard temperature, 273.15 K

T_a = absolute house temperature, (°C+273.15) K

P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure for the site elevation, kPa

ρ_e = air density at exhaust fan location "e", kg dry air m^{-3} moist air

ρ_i = air density at outside conditions, kg dry air m^{-3} moist air

Results and Discussion

Data Completeness

The starting times of emission monitoring were Feb 14, 2006 and Feb 20, 2006 for T-1 and T-2, respectively. The ending dates of the monitoring were March 14, 2007 and March 5th, 2007 for T-1 and T-2, respectively. By the one-year mark (Feb 13, 2007 for T-1 and Feb 18, 2007 for T-2), five full flocks had been monitored at each site; the 6th flock had been monitored for 23 days for T-1 and eight days for T-2. The weather conditions were collected and are reported in the following table (Table 1). The range of daily average ambient temperatures was -9.9 to 29.9 ^{o}C for the two sites. Figures 4 and 5 show the temperature and ventilation changes throughout one-year period for the two houses.

Table 1. Daily average temperature and relative humidity (RH) summary for T-1 and T-2 over the one-year period from Feb 2006 to March 2007.

	Outside Temp., ^{o}C		Outside RH, %		Inside Temp., ^{o}C		Inside RH, %	
	T-1	T-2	T-1	T-2	T-1	T-2	T-1	T-2
Mean	14.3	13.9	73.3	72.7	22.3	22.8	60.6	62.1
S.D.	9.4	9.7	12.4	11.6	5.2	5.1	10.9	11.5
Max	29.8	29.9	99.7	97.4	38.7	32.1	89	94.7
Min	-9.9	-9.0	37.4	37.3	5.7	4.2	30.8	30.8

Hydrogen sulfide (H_2S): For the 365-d annual emission calculation, the complete data days (CDDs) were 314 out of 365 days (86.0% data completeness) and 260 out of 365 days (71.2% data completeness), respectively, for T-1 and T-2. By the end of the monitoring, the CDDs were 342 out of 394 days (86.8% data completeness) for T-1 and 274 out of 379 days (72.3% data completeness) for T-2. The 616 house-days (12 flocks) emission data were used for the emission rate of daily mean, daily maximum, flock total, and during downtime.

Nonmethane hydrocarbon (NMHC): For the 365-d annual emission calculation, the CDDs were 250 out of 365 days (68.5% data completeness) and 201 out of 365 days (55.1% data completeness), respectively, for T-1 and T-2. By the end of the monitoring, the CDDs were 268 out of 394 days (68.0% data completeness) for T-1 and 203 out of 379 days (53.6% data completeness) for T-2. The 471 house-days (12 flocks) emission data were used for the emission rate of daily mean, daily maximum, flock total, and during downtime.

Gaseous concentrations

Daily mean H_2S and NMHC concentrations in the two broiler houses are shown in figures 6, 7, 8, and 9. The average H_2S concentrations were 50.5 ppb and 52.8 ppb for T-1 and T-2, respectively. With birds present, the maximum daily mean H_2S concentrations were 204 ppb and 175 ppb for T-1 and T-2 respectively. During the downtime between flocks, the highest H_2S concentration were 443 ppb and 441 ppb for T-1 and T-2, and the average H_2S concentrations were 40.4 ppb and 53.4 ppb for T-1 and T-2, respectively. The maximum concentrations between flocks occurred during periods of no ventilation within the houses.

The average NMHC concentrations were 0.59 ppm and 0.41 ppm for T-1 and T-2, respectively. With birds present, the maximum daily mean NMHC concentrations were 2.8 ppm and 1.7 ppm for T-1 and T-2 respectively. During the downtime, the highest NMHC were 2.2 ppm and 1.7 ppm for T-1 and T-2, and the average NMHC concentrations were 0.3 ppm and 0.2 ppm for T-1 and T-2, respectively. Again, the maximum concentrations between flocks occurred during periods of no ventilation within the houses.

Figures 6 and 7 show the seasonal H_2S concentration changes and changes with bird growth. The flocks started with the lowest in-house H_2S concentrations. With the bird growth, the H_2S concentration increased until the middle of the flock, and then tended to decline. For NMHC, there was strong seasonal and cyclic pattern: the NMHC concentrations were high at the beginning of the flocks during the cooler weather when ventilation was lowest, and the NMHC concentrations gradually decreased with the bird growth and increasing temperature (Figures 8 and 9). Ventilation rate had negative impact on H_2S and NMHC concentration as well. During the first weeks of the flocks with new bedding, the H_2S concentrations were less than 10 ppb which was significantly lower than the flocks with built-up litter.

H_2S Emission

H_2S ER was correlated to the bird age, body weight, and ventilation rate. It was weakly correlated with inside RH, and it was not correlated with outside temperature, outside RH, or inside temperature. Among the variables examined, bird age was found to be the predominant correlate. For the flocks on new bedding, there was no clear bedding effect on H_2S ER. Because of the large mortality in flock 5 at T-1, this flock was not used to predict the ER. The H_2S ER per house or per bird from all data except for the flock 5 ERs at T-1 and T-2, as shown in Figures 10 and 11, could be estimated using the following predictive regression equation:

$$\sqrt{\boldsymbol{H_2S\ ER}} = a + b\,X + c\,X^2 + d\,X^3 \qquad [2]$$

where

H_2S ER = g/d-house;

X= bird age.

Table 2 provides the prediction parameter estimates for the two houses, individually, and overall 11 flocks. The correlation coefficients (r^2) of prediction models vary from 0.72 to 0.78 and show the strongest relationship between ER and bird age.

Table 2. Coefficient Estimates of H_2S ER prediction models for the houses, T-1 and T-2.

House	a (± SE)	b (± SE)	c (± SE)	d (± SE)	r^2
1-5	2.18 (± 0.24)	0.20 (± 0.008)	N/A	N/A	0.72
3-3	1.2 (± 0.31)	0.35 (± 0.027)	$-2.9\ E^{-03}$ ($\pm 4.9\ E^{-04}$)	N/A	0.81
Overall	1.38 (± 0.24)	0.31 (± 0.021)	$-2.2\ E^{-03}$ ($\pm 3.9\ E^{-04}$)	N/A	0.76

Figure 12 provides the daily H_2S ER for the two houses for the entire monitoring period with six full flocks and downtime between flocks. The daily ER (g/d-house) varied from 0 to 259.5 g/d-house. The highest ER was 259.5 and 186.3 g/d-house for T-1 and T-2, respectively. Note that the emissions between the vertical dashed lines in Figure12 represent periods between flocks when no birds were in the houses (i.e., downtime). The flocks with new litter did not show significantly lower ER than those with built-up litter (P=0.013) at α = 0.01. The average ER for T-1 over the six flocks was 63.3 ± 44.7 g/d-house which is not significantly lower (from statistical standpoint) than 70 ± 43.6 g/d-house for T-2 (P=0.49). The average ER of all 12 flocks was 65.7 ± 42 g/d-house.

The H_2S ER during the downtime was tested for the environmental variables effect. However, no significant effect of all variables was found. Ventilation rate (VR) of the houses had a significant impact on the NH_3 ER, but no significant effect on H_2S ER (Figure 13). The average H_2S ER for T-1 and T-2 downtime between flock periods was 10.5 ± 13.4 and 7.3 ± 11.8 g/d-house, respectively. The average ER for the two houses during downtime was 9.0 ± 12.5 g/d-house.

Annual Hydrogen Sulfide Emission

The annual H_2S emission from each house is the accumulation of daily ERs over 365 days. However, some daily emissions were missing due to various reasons (for example, power outage from adverse weather and instrument malfunctions). The missing data were filled with the calculated data derived from Equation 2. When 5.4 flocks were placed with average 52 grow-out days and the average flock cumulative emission rate is 3.42 kg/flock (7.53 lb/flock), the annual emission factor was 19.2 kg/year-house (42.3 lb/year-house). On a per 1,000 birds marketed basis the average H_2S emissions over a year period were 147 g per 1,000 birds marketed.

NMHC Emission

In this paper, the NHMC emission rate is expressed using propane (C_3H_8) as a reference. For instance, the unit of kg-NMHC /d-house represents kg-C_3H_8 per day per house.

NMHC ER was correlated to the bird age, body weight, and ventilation rate, but it was weakly correlated with inside RH and not correlated with outside temperature, RH, or inside temperature. Among the three variables, bird age is predominant. For the flocks on new bedding, there was no clear bedding effect on NMHC ER. Because of the large mortality in flock 5 at T-1, this flock was not used to predict the ER. The NMHC ER per house or per bird from all data except for the flock 5 ERs at T-1 and T-2, as shown in Figures 14 and 15, could be estimated using the following predictive regression equation:

$$\text{NMHC ER} = a + b X + c X^2 + d X^3 \qquad [3]$$

where

NMHC ER = kg d^{-1} $house^{-1}$;

X= bird age.

Table 3 provides the prediction parameter estimates for the two houses, individually, and over all 11 flocks. The correlation coefficients (r^2) of prediction models vary from 0.63 to 0.65 and show the strongest relationship between ER and bird age.

Table 3. Coefficient Estimates of NMHC ER prediction models for the houses, T-1 and T-2.

House	a (± SE)	b (± SE)	c (± SE)	d (± SE)	r^2
1-5	0.10 (± 0.13)	0.06 (± 0.02)	- 2.6 E^{-3} (±7.8 E^{-4})	4.3 E^{-5} (± 1.0 E^{-5})	0.65
3-3	0.30 (± 0.022)	N/A	3.7 E^{-4} (±2.2 E^{-5})	N/A	0.65
Overall	0.18 (± 0.07)	0.035 (± 0.01)	-1.4 E^{-3} (±4.5 E^{-4})	2.6 E^{-5} (± 5.9 E^{-6})	0.63

Figure 16 provides the daily NMHC ER for the two houses for the entire monitoring period with six full flocks and downtime between flocks. The daily ER (lb/d-house) varied from 0 to 2.83 kg/d-house. The highest ER was 2.83 and 1.74 kg (5.24 and 3.84) per d per house for T-1 and T-2, respectively. The average ER for T-1 over the six flocks was 0.84 ± 0.49 kg/d-house (1.86 ± 1.07 lb/d-house) which is not significantly lower (from statistical standpoint) than 0.65 ± 0.31 kg/d-house (1.43 ± 0.69 lb/d-house) for T-2 (P=0.017) at α =0.01. The average ER of all 12 flocks was 0.76 ± 0.43 kg/d-house (1.68 ± 0.94 lb/d-house).

The NMHC ER during the downtime was tested for the environmental variables effect. Ventilation rate (VR) of the houses had a linear relationship with NMHC ER (Figure 17). The average NMHC ER for the two houses during downtime was 0.2 ± 0.29 kg/d-house (0.45 ± 0.64 lb/d-house).

Annual NMHC Emission

The annual NMHC emission from each house is the accumulation of daily ERs over 365 days. When 5.4 flocks were placed with average 52 grow-out days and the average flock cumulative emission rate is 39.7 kg/flock (87.5 lb/flock), the annual emission rate was 231 kg/year-house (510 lb/year-house). On a per 1,000 birds marketed basis the average NMHC emissions over a year period were 3.9 lb per 1,000 birds marketed which is equivalent to 1.77 g/bird-marketed.

NMHC speciation

Ambient background was not sampled for NMHC. It was assumed that background ambient air consists of the same NMHC compounds emitted from the houses. Also, it was assumed that the empty house and occupied house had different speciation of detected compounds, but the speciation would not change during the empty or occupied period. Air samples from the three different sections with empty and occupied houses were collected from the locations as previously indicated in Figure 3 and speciated. Table 4 provides a list of net concentration levels for the combined top 25 NMHCs from the samples that were collected in the empty house and occupied house. This table also includes the mass conversion coefficient for all compounds that were identified and quantified. The emission rate of all the compounds can be calculated by multiplying the NMHC ER with corresponding mass conversion coefficient.

Table 4. Top-25 speciated NMHC concentration levels (ppb) and mass conversion coefficient (kg/kg-C_3H_8) for samples collected in the empty house and occupied house

Compound	Empty house		Occupied house	
	Sample concentration, ppb	Conversion Coefficient, kg/kg·C_3H_8	Sample concentration, ppb	Conversion Coefficient, kg/kg·C_3H_8
2,3-Butanedione	4.2	0.009	238.7	0.498
2-Pentanone	5.3	0.015	5.9	0.015
2-Butanone	N/A	N/A	13.7	0.024
2-Methyl-3-Pentanone	N/A	N/A	11.2	0.041
3-Hydroxy-2-Butanone	3.2	0.007	13.4	0.029
3-Methylindole	1.6	0.013	N/A	N/A
3-Methyl butanoic acid	N/A	N/A	5.8	0.018
4-Ethylphenol	1.6	0.010	N/A	N/A
4-Methylphenol	6.5	0.032	N/A	N/A
Acetamide	N/A	N/A	8.2	0.006
Acetic acid	61.9	0.048	288.7	0.210
Acetone	27.5	0.031	37.4	0.039
Benzalaldehyde	9.8	0.047	N/A	N/A
Benzoic acid	7.5	0.042	N/A	N/A
Butanoic acid	3.0	0.007	15.8	0.034
Butanol	275.8	0.531	36.0	0.065
Dimethyl disulfide	6.6	0.008	13.6	0.015
Dimethyl sulfone	6.3	0.008	4.0	0.005
Ethanol	26.2	0.016	109.9	0.061
Hexane	20.7	0.070	9.3	0.029
Indole	N/A	N/A	3.2	0.018
Isoprene	7.6	0.017	N/A	N/A
Methanol	58.4	0.012	146.9	0.029
Pentane	N/A	N/A	7.4	0.016
Pentanoic acid	N/A	N/A	3.3	0.010
Phenol	16.7	0.061	N/A	N/A
Propanoic acid	5.1	0.007	12.0	0.016
Propanol	5.1	0.006	14.2	0.016
Propene	N/A	N/A	10.0	0.008
Sulfolane	1.6	0.005	N/A	N/A
Tetra methyl pyrazine	N/A	N/A	2.7	0.025
Toluene	46.0	0.193	N/A	N/A
Triethyl citrate	12.8	0.277	N/A	N/A
Trimethyl oxazalone	N/A	N/A	4.4	0.018
Trimethyl propanoic acid	N/A	N/A	8.6	0.006
Unknown compound	46.4	0.040	N/A	N/A

Conclusions

Gaseous emissions of H_2S and NMHC from two representative broiler houses in western Kentucky were continuously measured for 13 months, involving a total of 12 grow-out flocks (6 flocks per house). Each house had 5.4 flocks per year and averaged 24,200 marketed birds per flock. The following conclusions were drawn.

- Regression equations are presented to relate H_2S and NMHCs emission rates to broiler age.
- The overall mean H_2S emission rate (mean ± S.D.) for the 12 flocks was 65.7 ± 42 g/d-house, and during downtime (empty house between flocks) it was 9.0 ± 12.5 g/d-house. Annual H_2S emission for the two broiler houses (including downtime emissions) averaged 19.2 kg per year per house (42.3 lb per year per house) or 0.147 g per bird marketed for birds marketed at 52 days of age and stocked at a density of 11.8 bird per m^2 (1.1 bird per ft^2).
- The overall mean NMHC emission rate (mean ± S.D.) for the 12 flocks was 0.76 ± 0.43 kg C_3H_8/d-house, and during downtime (empty house between flocks) it was 0.20 ± 0.29 kg/d-house. Annual NMHC emission for the two broiler houses (including downtime emissions) averaged 231 kg per year per house (510 lb per year per house) or 1.77 g per bird marketed for birds marketed at 52 days of age and stocked at a density of 11.8 bird per m^2 (1.1 bird per ft^2).

Acknowledgements

Financial support of the study was provided by Tyson Foods, Inc. The authors wish to sincerely thank the growers and workers at the commercial broiler operation for their cooperation throughout the study.

References

Burns, R.T., H. Xin, H. Li, S. Hoff, L. Moody, R. Gates, D. Overhults and J. Earnest. 2007. Tyson Broiler Ammonia Emission Monitoring Project: Final Report.

Burns, R.T., H. Xin, H. Li, S. Hoff, L. Moody, R. Gates, D. Overhults and J. Earnest. 2006. Monitoring system design for the southeastern broiler gaseous and particulate matter air emissions monitoring project. *Proceedings of the Symposium on Air Quality Measurement Methods and Technology*, 9-11 May, Durham NC. AWMA.

Burns, R., H. Xin, R. Gates, H. Li, S. Hoff, L. Moody, D. Overhults and J. Earnest. 2006. Monitoring system design for the southeastern broiler gaseous and particulate matter air emissions monitoring project. *Presented at: Workshop on Agricultural Air Quality: State of the Science*, Bolger Conference Center, Potomac MD. 5-8 June. ESA.

Casey, K.D., R.S. Gates, E.F. Wheeler and H. Xin. 2006. Comparison of measured estimates of annual ammonia emissions from poultry production facilities with mass balance modeling approaches. Presented at: *Workshop on Agricultural Air Quality: State of the Science*, Bolger Conference Center, Potomac MD. 5-8 June. ESA.

Casey, K.D., R.S. Gates, A. Singh, A.J. Pescatore, E.F. Wheeler, H. Xin, Y. Liang. 2006. Managing Litter to Reduce Ammonia Emissions from Broiler Chicken Houses in the U.S.A. In *Proceedings of Poultry Information Exchange 2006, Surfers Paradise, Gold Coast, Australia*, April 2-4.: PIX Association Inc.

Casey, K.D., J.R. Bicudo, D.R. Schmidt, A. Singh, S.W. Gay, R.S. Gates, L.D. Jacobson and S.J. Hoff. 2006. Air quality and emissions from livestock and poultry production/waste management systems. Pp 1-40 in: *Animal Agriculture and the Environment: National Center for Manure and Animal Waste Management White Papers*. J.M. Rice, D.F. Caldwell, F.J. Humenik, eds. ASABE: St. Joseph MI.

Gates, R.S., K.D. Casey, E.F. Wheeler and H. Xin. 2006. Estimating annual ammonia emissions from U.S. broiler facilities. Presented at: *Workshop on Agricultural Air Quality: State of the Science, Bolger Conference Center*, Potomac MD. 5-8 June. ESA.

Gates, R.S., K.D. Casey, E.F. Wheeler, H. Xin and A.J. Pescatore. 2007. U.S. broiler ammonia emissions inventory model. *Atmospheric Environment*. Accepted for publication.

Li, H., R. T. Burns, H. Xin, L. B. Moody, R. Gates, D. Overhults, and J. Earnest. 2006. Development of a Continuous NH_3 Emissions Monitoring System for Commercial Broiler Houses. *Proceedings of the Annual Air and Waste Management Association Conference.*

Liang, Y., H. Xin, E.F. Wheeler, R. S. Gates, H. Li, J.S. Zajaczkowski, P. Topper, K.D. Casey, B.R. Behrends, D.J. Burnham and F.J. Zajaczkowski. 2005. Ammonia emissions from U.S. laying hen houses in Iowa and Pennsylvania. *Transactions of ASAE* 48(5):1927-1941.

Moody, L., H. Li, R. Burns, H. Xin and R. Gates. 2006. Quality Assurance Project Plan (QAPP) implementation for the southeastern broiler gaseous and particulate matter air emissions monitoring project. Presented at: *Workshop on Agricultural Air Quality: State of the Science*, Bolger Conference Center, Potomac MD. 5-8 June. ESA.

Muhlbauer, R. V., T. A. Shepherd, H. Li, R. T. Burns, H. Xin. 2006. Development and Testing of a Fan Monitoring System Using Induction Operated Current Switches. *ASABE Paper #064159*. St. Joseph, MI: ASABE.

Nicholson, F. A., B. J. Chambers, and A. W. Walker. 2004. Ammonia emissions from broiler litter and laying hen manure management systems. Biosystems Eng. 89(2): 175-185.

U.S. Environmental Protection Agency, National Emission Inventory – Ammonia Emissions from Animal Husbandry Operations. See http://www.epa.gov/ttnchie1/ap42/ch09/related/nh3inventorydraft_jan2004.pdf (accessed March, 2005).

Wheeler, E. F., K. D. Casey, R. S. Gates, H. Xin, J. L. Zajaczkowski, P. A. Topper, Y. Liang, A. J. Pescatore. 2006. Ammonia emissions from twelve U.S. broiler chicken houses. *Trans. ASABE* 49(5): 1495−1512

Figure 1. Environmentally-controlled Mobile Air Emissions Monitoring Units (MAEMU).

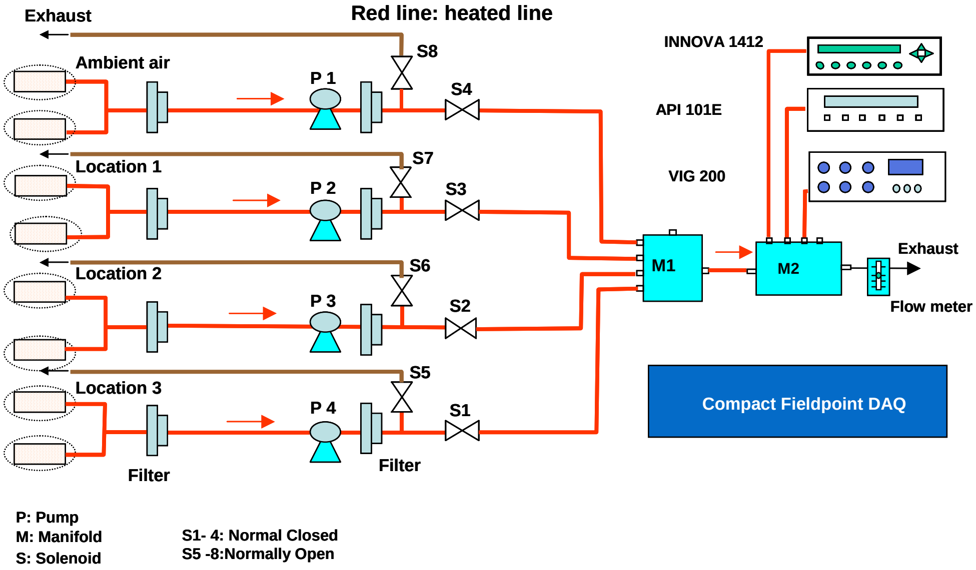

Figure 2. Schematic representation of the positive pressure gas sampling system (PP-GSS) used in the MAEMU for measurement of broiler house air emissions.

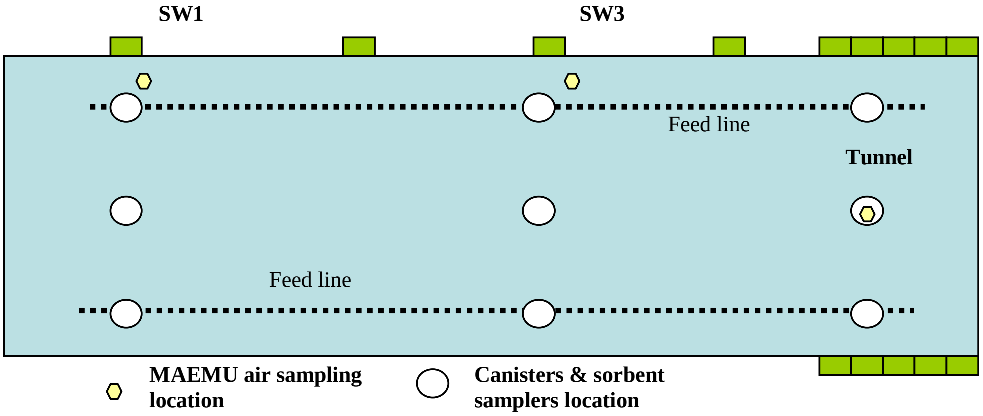

Figure 3. Schematic of air sampling locations for NMHC speciation.

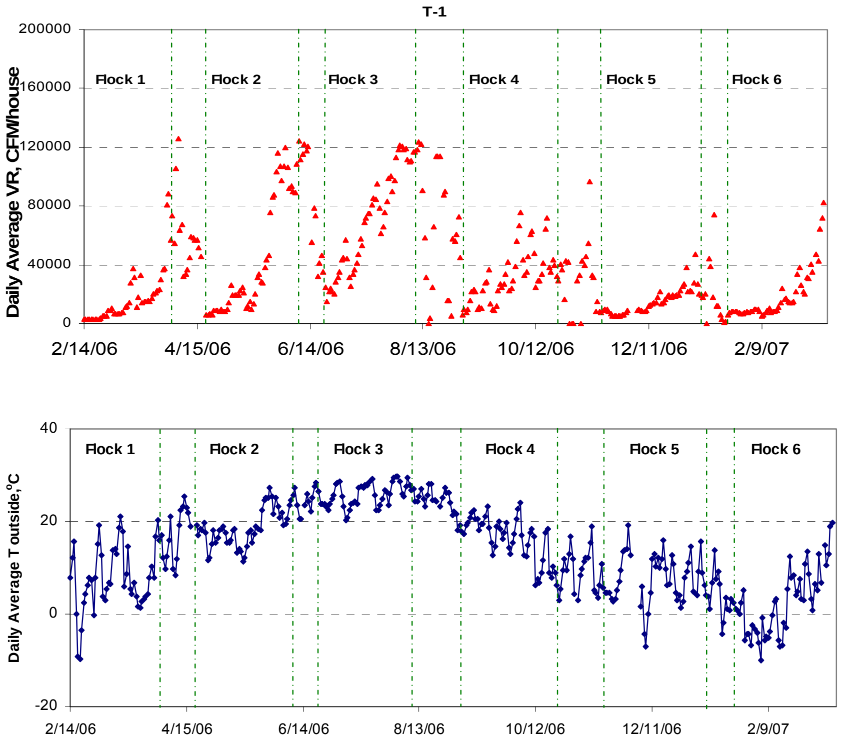

Figure 4. The daily mean ventilation rate and outside temperature for T-1. (1 CFM=1.7 m^3/HR)

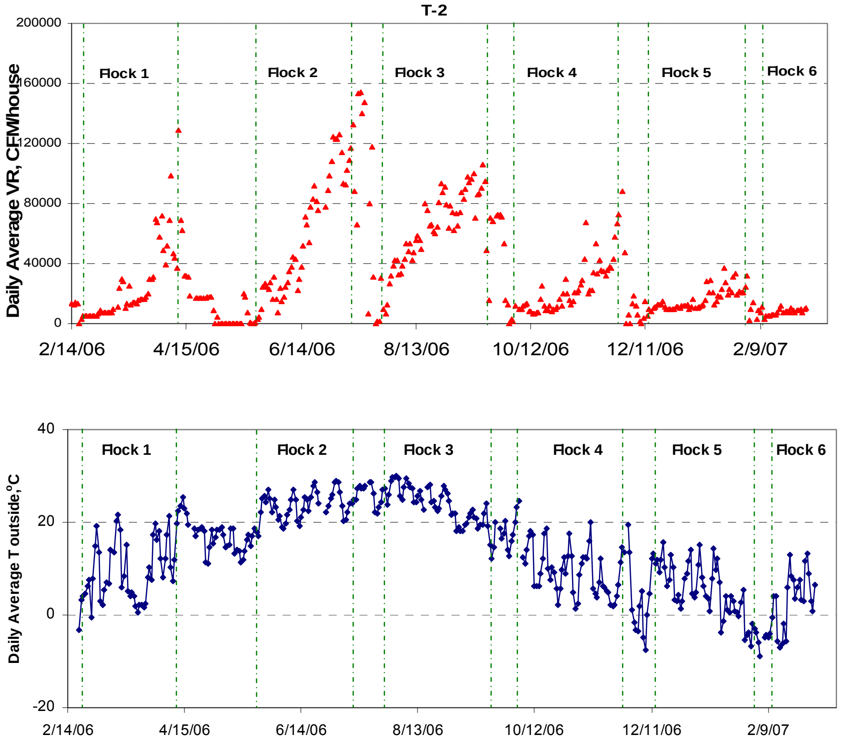

Figure 5. The daily mean ventilation rate and outside temperature for T-2. (1 CFM=1.7 m^3/HR)

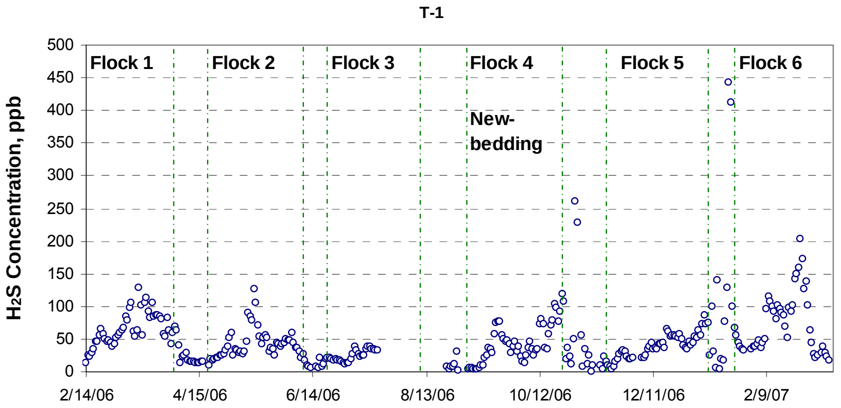
T-1

Figure 6. The daily mean H_2S concentration from T-1.

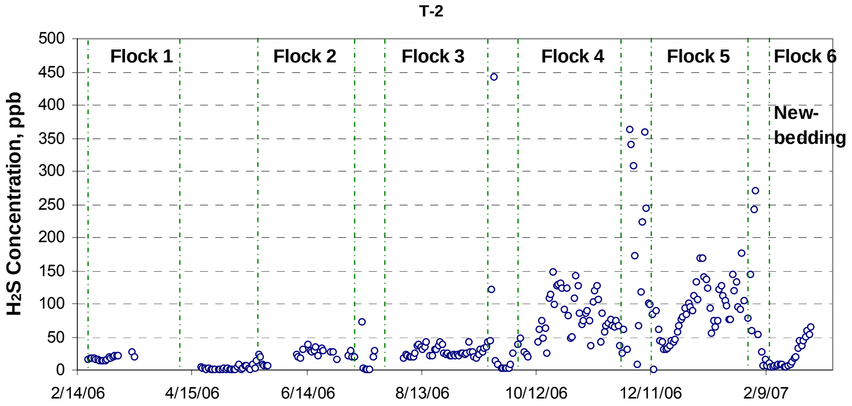
T-2

Figure 7. The daily mean H_2S concentration from T-2.

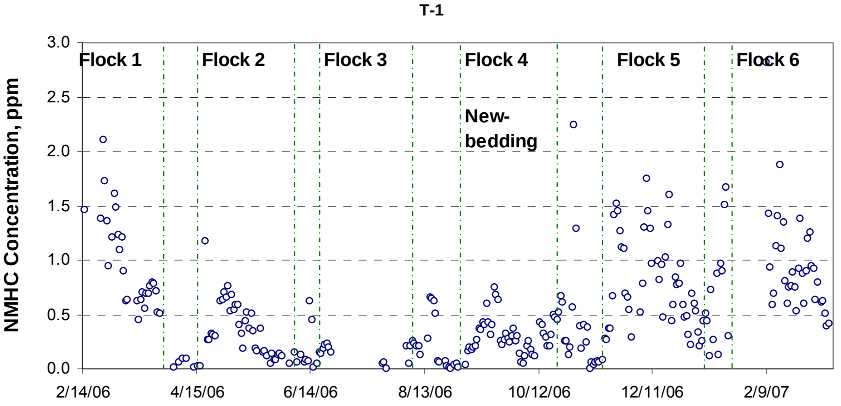
T-1

Figure 8. The daily mean NMHC concentration from T-1.

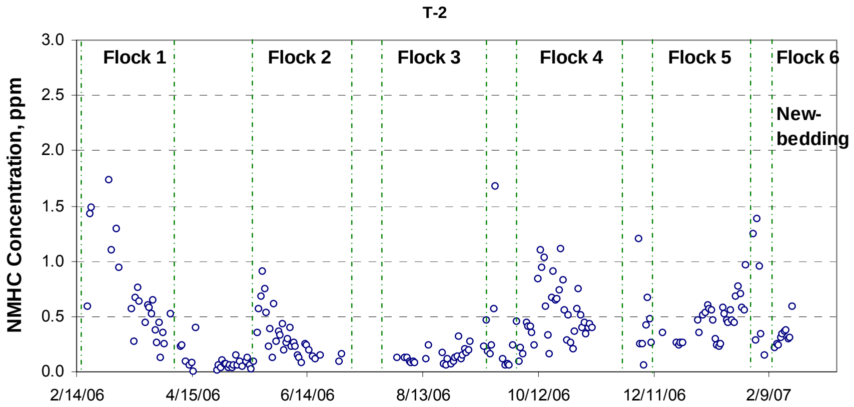

Figure 9. The daily mean NMHC concentration from T-2.

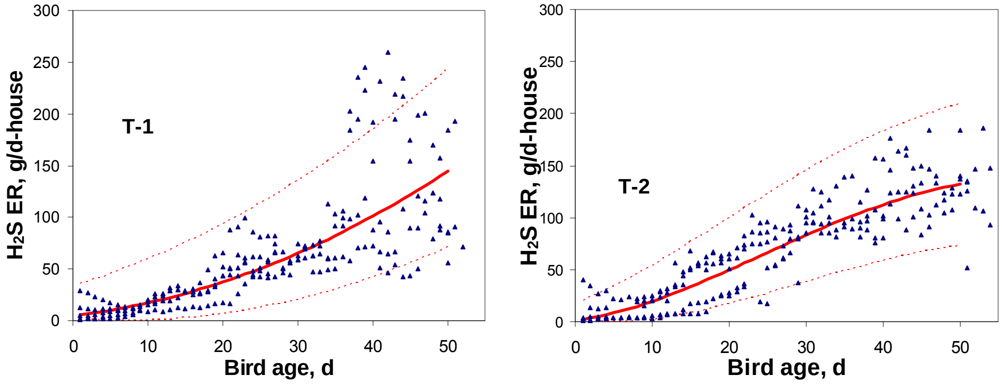

Figure 10. Relationship between H_2S ER per house vs. bird age for T-1 and T-2. The solid line is the regression line; dash lines are 95% prediction limit.

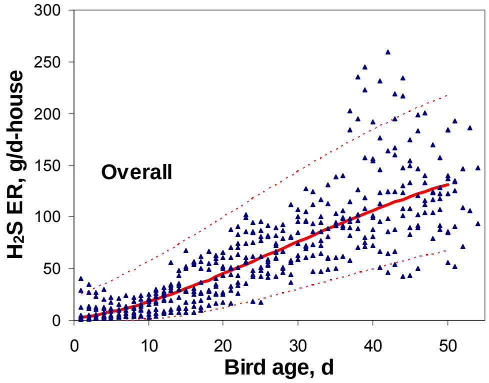

Figure 11. Relationship between H_2S ER per house vs. bird age. The solid line is the regression line; dash lines are 95% prediction limit.

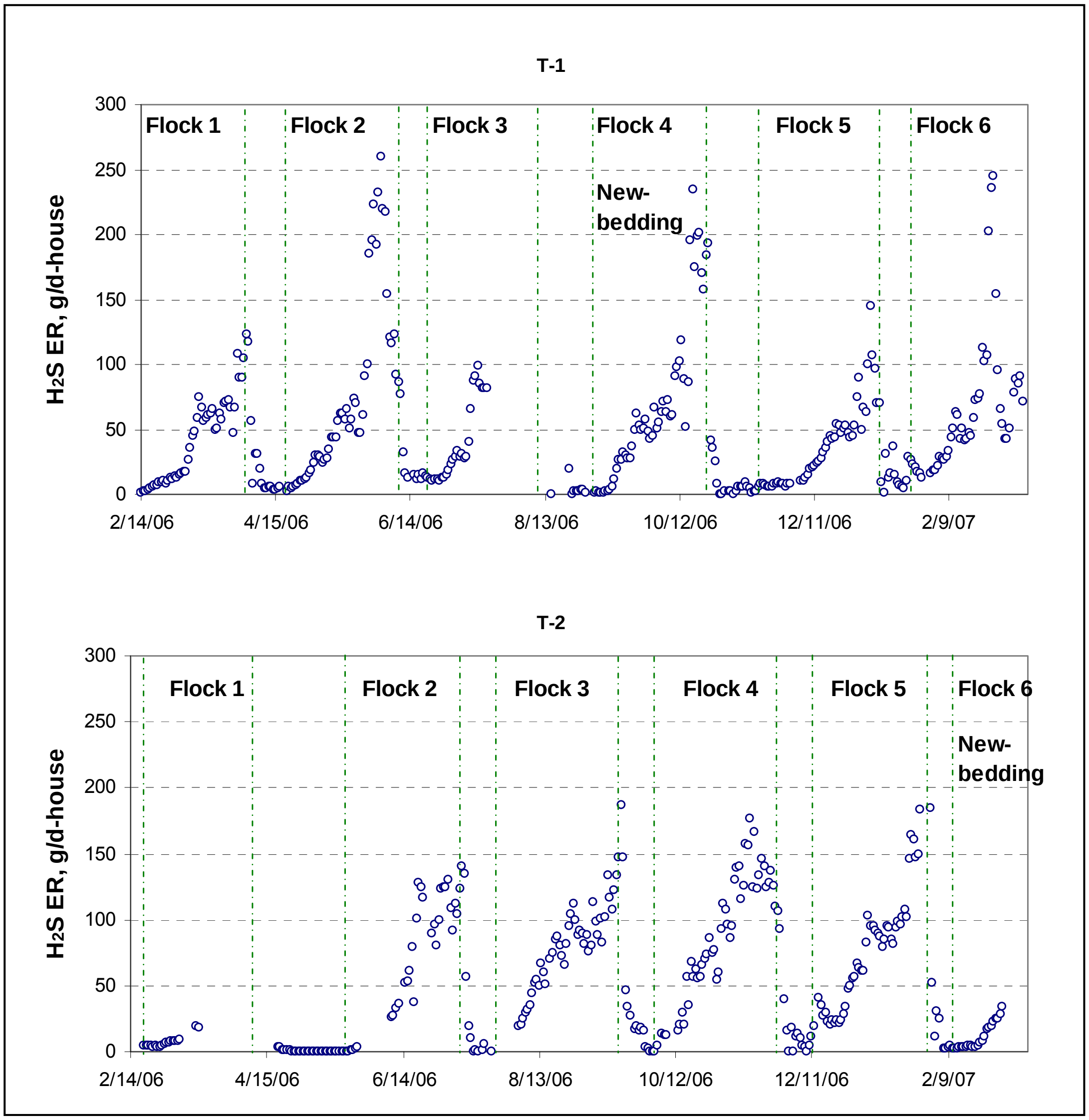

Figure 12. Daily H_2S emission rate over the six flocks for T-1 and T-2.

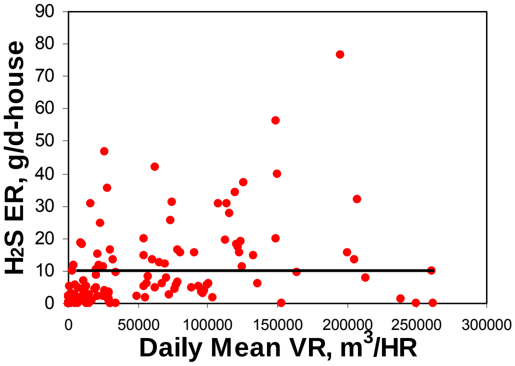

Figure 13. H_2S emission rate(ER) vs. ventilation rate (VR) during downtime.

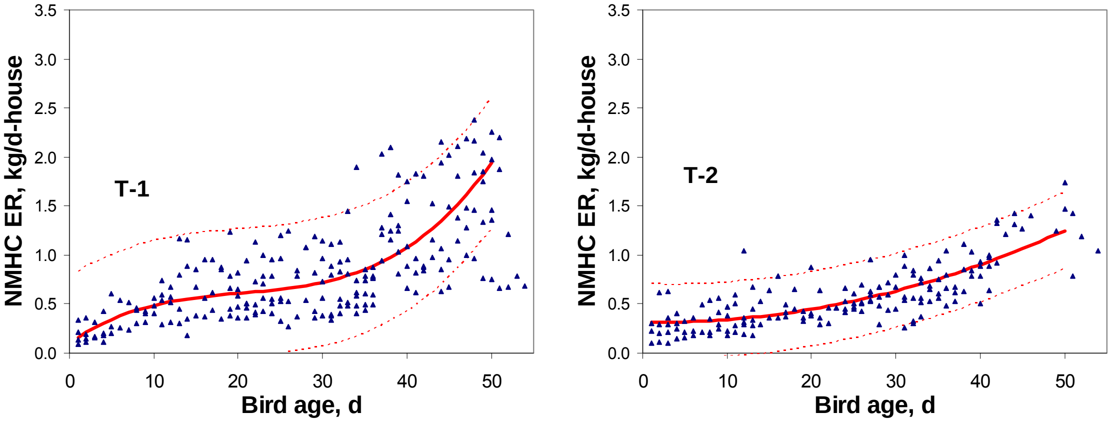

Figure 14. Relationship between NMHC ER per house vs. bird age for T-1 and T-2. The solid line is the regression line; dash lines are 95% prediction limit.

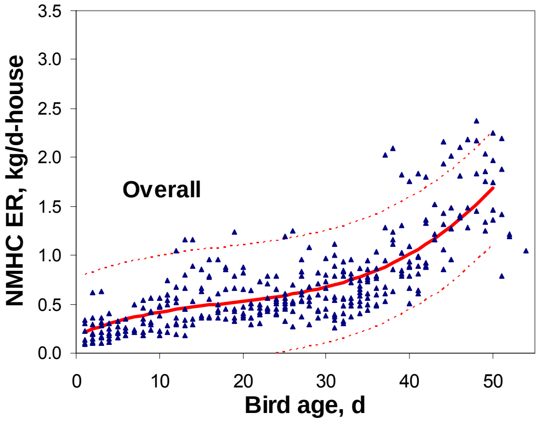

Figure 15. Relationship between NMHC ER per house vs. bird age. The solid line is the regression line; dash lines are 95% prediction limit.

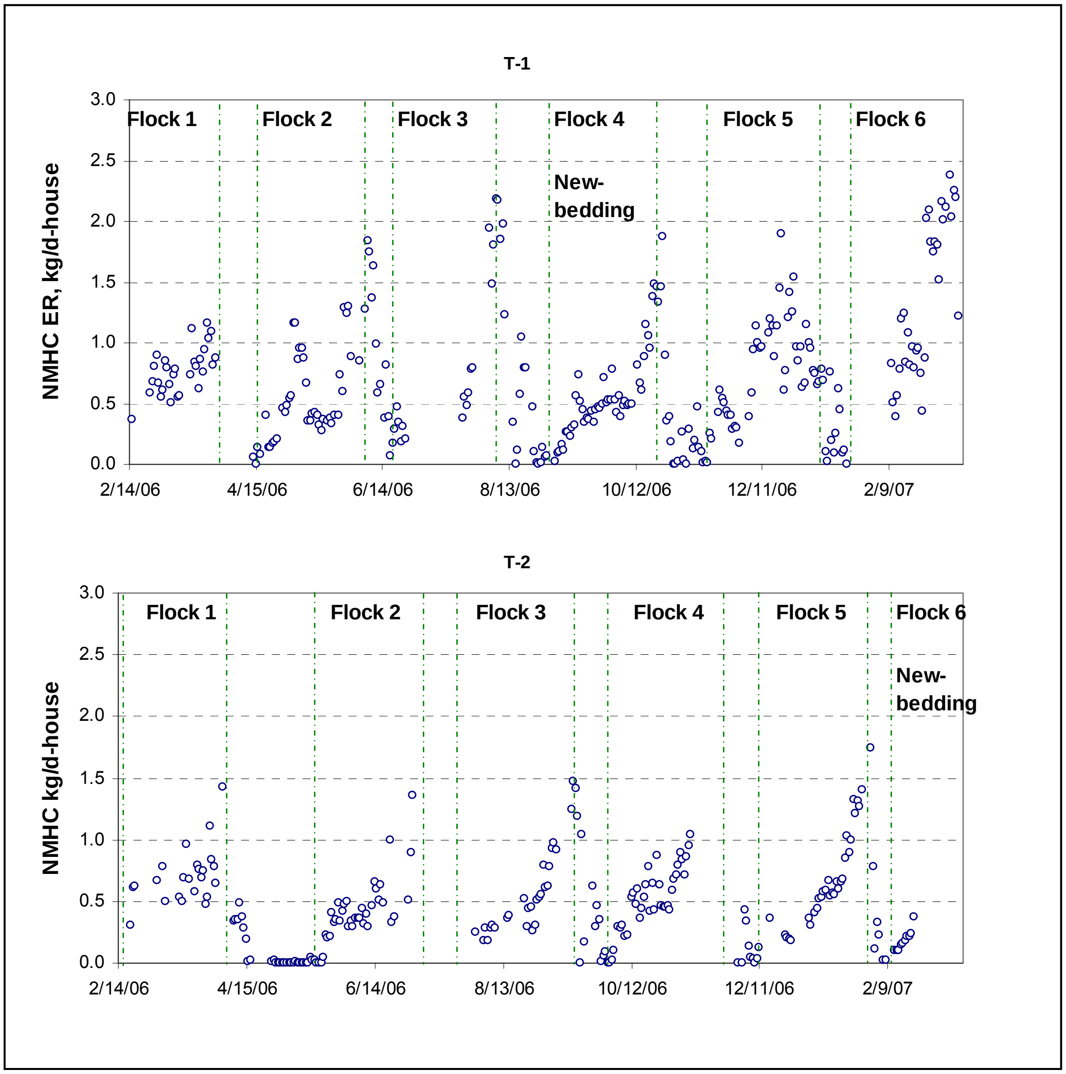

Figure 16. Daily NMHC emission rate over the six flocks for T-1 and T-2.

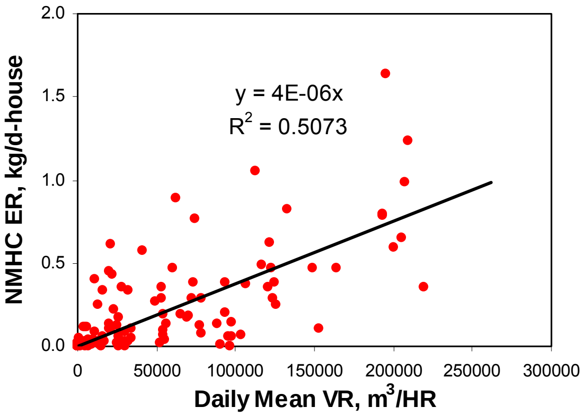

Figure 17. NMHC emission rate(ER) vs. ventilation rate (VR) during downtime.