**This page is for on-line indexing purposes and should not be included in your printed version.**


## Author(s)

| First Name | Middle Name | Surname | Role | Email |
| --- | --- | --- | --- | --- |
| Ronald | E | Lacey | Associate Professor | Ron-lacey@tamu.edu |

## Affiliation

| Organization | Address | Country |
| --- | --- | --- |
| Texas A&M University | College Station, TX | USA |

## Author(s)

| First Name | Middle Name | Surname | Role | Email |
| --- | --- | --- | --- | --- |
| Jarah | S. | Redwine | Engineer | |

## Affiliation

| Organization | Address | Country |
| --- | --- | --- |
| CH2M Hill | San Antonio, TX | USA |

## Author(s)

| First Name | Middle Name | Surname | Role | Email |
| --- | --- | --- | --- | --- |
| Calvin | B | Parnell, Jr. | Regents Professor | |

## Affiliation

| Organization | Address | Country |
| --- | --- | --- |
| Texas A&M University | College Station, TX | USA |



## Publication Information

| Pub ID | Pub Date |
| --- | --- |
| 024212 | 2002 ASAE-CIGR Annual Meeting Paper |

**Paper Number: 024212**
**An ASAE Meeting Presentation**

# Emission Factors for Broiler Production Operations: A Stochastic Modeling Approach

**Ronald E. Lacey, Associate Professor**

Texas A&M University, College Station, TX, ron-lacey@tamu.edu

**Jarah S Redwine, Engineer**

CH2M Hill, San Antonio, TX

**Calvin B Parnell, Jr., Regent's Professor**

Texas A&M University, College Station, TX

**Written for presentation at the**
**2002 ASAE Annual International Meeting / CIGR XVth World Congress**
**Sponsored by ASAE and CIGR**
**Hyatt Regency Chicago**
**Chicago, Illinois, USA**
**July 28-July 31, 2002**

**Abstract.** *Emissions data for $PM_{10}$ and $NH_3$ from commercial broiler houses in central Texas were analyzed using multiple linear regressions to develop emission factors for average bird weights and interior building temperatures. The emission factor for $PM_{10}$ was 318 mg $PM_{10}$ $bird^{-1}$ and the emission factor for $NH_3$ was 19.8 g $NH_3$ $bird^{-1}$. These results were compared to published values found in the literature. Under typical management practices (i.e. 638,000 birds $yr^{-1}$) the emission inventory was calculated to be 203.2 kg $PM_{10}$ $year^{-1}$ and 12,630 kg $NH_3$ $year^{-1}$. The methodology used in this paper considered the effect of the size of the birds and the variance in ventilation necessary to maintain the desired interior temperatures, where both factors were shown through multiple linear regressions to be significant. The overall emission factor was calculated from these regressions for an average bird and average building temperature.*

**Keywords.** PM10, ammonia, emission factors, emission inventory, broiler production

## Introduction

Emission factors have long been fundamental tools for air quality management. They are used for developing emission control strategies, determining applicability of permitting and control programs, ascertaining the effects of sources and appropriate mitigation strategies, and a number of other related applications by federal, state, and local agencies, consultants, and industry. Because of their importance, it is imperative that they reflect actual conditions as accurately as possible. The United States Environmental Protection Agency (EPA 1995; EPA 2000) defines an emission factor as:

> *An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e. g., kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i. e., a population average).*

An emission inventory is an estimate of the annual emissions of each contaminant under standard management practices.

Production of broiler chickens in the United States is primarily done within enclosed structures where the floor is covered in an absorbent material (i.e. litter). Conditions within these confinement buildings are managed to optimize bird health and productivity. Factors that affect the interior conditions include seasonal climate and weather conditions; building ventilation, heating and cooling; and factors that effect the litter (e.g. feed factors, flock husbandry, litter management). These factors are interrelated in establishing the composition of the interior air of the building. Because commercial broiler production is usually totally confined, the air in the building contains all of the materials emitted to the atmosphere, some of which are potential contaminants (e.g. ammonia, dust, and odorants). The emission rate from the building for any specific contaminant is the rate at which pollutants are expelled into the surrounding atmosphere in terms of mass per time (e.g. kg/min), and is the product of the concentration of the contaminant inside the building and the ventilation rate. This instantaneous emission rate can be developed into an emission factor for regulatory purposes by considering the variables which control emission rates and the management practices of the grower.

The Environmental Protection Agency (EPA) regulates particulate matter (PM) in the ambient air in the United States (United States Office of the Federal Register 2001) with maximum allowable concentrations for $PM_{10}$ and $PM_{2.5}$. The human respiratory system can filter PM larger than 10 μm in aerodynamic equivalent diameter (AED) and prevent it from reaching the alveoli in the lungs. Thus only particulate matter smaller then 10 μm are considered respirable. Particulate matter larger than 10 μm AED can be inhaled into the respiratory system and can also have detrimental health effects.

While not regulated under the Federal Clean Air Act, atmospheric nitrogen compounds emitted from livestock operations, primarily in the form of ammonia, have been implicated as causing nitrogen enrichment and eutrophication of surface waters (Aneja *et al.* 1998), as contributing to the formation of acid precipitation (ApSimon *et al.* 1995), and as possible precursors to the formation of particulate material ($PM_{2.5}$) in the form of ammonium nitrate and ammonium sulfate (Barthelmie and Pryor 1998). Additionally, ammonia is an odorant and conditions conducive to the production of ammonia will probably result in the emission of other odorants (e.g. volatile fatty acids, volatile amines, indole, phenol, sulfur-containing compounds). Ammonia is produced from the microbial breakdown of uric acid in poultry manure. The decomposition is dependent on a number of factors including (in decreasing order of importance): litter pH; temperature; and moisture content (Elliott and Collins 1982; Carlile 1984).

## Objectives

The goal of this paper is to estimate emission factors for broiler production facilities based on empirical data and management practices at the facility. Specifically, the objectives are:

1. Use data recorded for the operation of broiler production operations in central Texas to estimate emission factors for $PM_{10}$ and $NH_3$.
2. Compare these emission factors with values published in the literature for broilers on litter.
3. Calculate an emissions inventory for a typical modern broiler production facility in central Texas for $PM_{10}$ and $NH_3$.

## Methods

Data for this study was taken from four commercial tunnel ventilated broiler houses in north Brazos County, Texas. The site contained four identical tunnel ventilated broiler houses with evaporative cooling pads. The houses were 152.4 m x 13.4 m x 2.6 m with the long axis oriented east-west and the center roof height was 4.85 m. The sidewalls had ventilation openings 2.1 m in height that ran the length of the house and were equipped with moveable curtains. The sidewalls of each house contained tunnel ventilation openings, 18.3 m in length that housed the evaporative cooling pads. Six air baffles were spaced evenly down the length of the house at approximately 3 m above the floor level. A schematic of the plan view of the buildings is shown in figure 1. A 24-hour reduced lighting scheme was employed.

Approximately 27,500 birds were placed in the houses immediately after hatching and grown until the market age of 49 days with a final body weight of approximately 2.4 kg. The housing space was divided into each of three sections. Two end sections were 25% of the floor space each and the middle section was 50% of the floor space. During the brooding period (0-18 days) the birds were confined to the middle section of the house. After the brooding period, the birds occupied the entire length of the building at a stocking density of 13.5 birds $m^{-2}$.

Wood shavings were used for litter. After four flocks, the litter in the middle section and one end section of the house is removed and replaced with fresh litter. After the next four flocks, the litter in the middle half and opposite end quarter of the house is removed and replaced. Thus, the litter in the center section would be changed every four flocks and the litter in the end sections every eight flocks.

The broiler houses were ventilated to maintain a temperature to maximize bird performance. The target temperature for the house was 31$^{o}$C on day 1 and was decreased by 0.26$^{o}$C per day until 20$^{o}$C was reached. A programmable controller was used to control ventilation. Three different ventilation schemes were used to maintain the target temperature in the house. They were, in increasing order of ventilation rate, natural ventilation, sidewall ventilation, and tunnel ventilation. The natural ventilation rate was controlled by varying the area of the sidewall openings with the moveable curtains. Sidewall ventilation used five 0.91 m diameter exhaust fans with gravity-controlled shutters mounted on the north sidewall. When the sidewall exhaust fans were in use, the ventilation rate was controlled by operating the fans intermittently and the sidewall curtain on the south side of the building was opened approximately 5 cm. The tunnel ventilation system consisted of eleven 1.2 m diameter tunnel fans with discharge diffuser cones mounted on the west end of the building. Four of the eleven fans were on the west end wall and the remaining seven were mounted on the ends of the north and south sidewalls, three on one side and four on the other. Additionally, eight 0.91 m diameter mixing fans were mounted approximately 2.1 m above the litter directed from the center of the building toward each end of the house. The mixing fans were used for short time periods during sidewall ventilation when the exhaust fans were not running. Variations in tunnel ventilation rate were accomplished by controlling the number of fans in operation (2, 3, 4, 5, or 11). During this study tunnel ventilation was the predominant strategy used with some sidewall ventilation during the data for the winter months. Natural ventilation was never employed. Evaporative cooling pads were placed at the opposite end of the building from the tunnel fans and used during tunnel ventilation to reduce the temperature of the incoming air.

## Results and Discussion

Emission rates were calculated from ventilation rates times the corresponding concentration data and divided by the number of birds in the building. All values were adjusted to standard temperature and pressure. These results have been presented elsewhere (Redwine and Lacey 2001) and summaries of the data are shown in figures 1 and 2 for $PM_{10}$, and $NH_3$, respectively. The particle size distribution (PSD) of the PM was measured by a particle size analyzer (Multisizer, Beckman Coulter Inc.) and was described by a log-normal distribution with a mass median diameter (MMD) of 25 μm and a GSD of 1.6 (Redwine 2001). The fraction of TSP that was $PM_{10}$ was 5.94 % and $PM_{10}$ emissions were calculated as the product of TSP emissions and this fraction.

The age and weight of the birds and the ventilation rate were the two primary causes which determined the specific emissions of $PM_{10}$ and $NH_3$ from the facilities. As the birds grew they excreted more uric acid, the primary source of $NH_3$ (Carlile 1984). Poultry house PM is composed of feather and skin debris, feed, litter, and fecal material (Koon *et al.* 1963; Madelin and Wathes 1989). The larger birds consumed more feed, excreted more waste, imparted more energy to the litter, and had a greater surface area of skin and feathers. Larger birds also produced more sensible and latent heat and thus increased the ventilation requirements. The minimum ventilation rate was determined as that necessary to maintain the interior relative humidity between 40% and 80% (ASAE 1999) but conditions requiring minimum ventilation were not observed during this study. The building temperature and relative humidity ranges for the data in this study are shown in figures 3 and 4, respectively.

Bird weights were estimated from broiler growth equations (Flood *et al.* 1992) where the 49-day weight was equal to the market weight of 2.4 kg for the birds in this study. The average weight of a broiler during the 49-day growth cycle was 1.03 kg. The typical production cycle is seven weeks of production followed by 2 weeks of idle time for an average of 5.8 flocks per year. This varies with market demand and processing capacity but would represent the overall production goal of the facility. The site used in this study had four identical buildings housing a total of 110,000 birds per flock or a total of 638,000 birds per year.

### $PM_{10}$ Emission Factor and Emission Inventory

A multiple linear regression was performed on the data for $PM_{10}$ as the dependent variable with bird weight (g) and interior temperature ($^oC$) as the independent variables. Relative humidity was also tested as an independent variable but the t-values were not significant. The results of that regression are shown in Table 1.

**Table 1 Multiple regression analysis of $PM_{10}$ for bird weight (g) and interior building temperature ($^oC$).**

| Parameter | Value | Error | t-Value | Prob>\|t\| |
|---|---|---|---|---|
| Y-Intercept | -0.076 | 0.011 | -6.803 | <0.0001 |
| T | 0.002 | 3.62E-4 | 6.172 | <0.0001 |
| Wt | 3.17E-5 | 1.706E-6 | 18.581 | <0.0001 |
| R-Square(COD) | Adj. R-Square | Root-MSE(SD) | | |
| 0.786 | 0.781 | 0.011 | | |

| ANOVA Table: | | | | |
|---|---|---|---|---|
| Item | Degrees of Freedom | Sum of Squares | Mean Square | F Statistic |
| Model | 2 | 0.042 | 0.021 | 176.132 |
| Error | 96 | 0.011 | 1.187E-4 | |

For the temperature profile reported above, the average interior temperature during the 49-day production cycle was 24.9$^{o}$C. Combined with an average bird weight of 1.03 kg, the average $PM_{10}$ emissions were calculated from the multiple regression coefficients to be 6.5 mg day$^{-1}$ bird$^{-1}$. Thus, the emission factor for broilers was 318 mg $PM_{10}$ bird$^{-1}$. For typical production conditions, the emissions inventory for $PM_{10}$ from this facility was 203.2 kg $PM_{10}$ year$^{-1}$.

Table 2 shows PM emissions data reported in the literature. The $PM_{10}$ emissions rate in this study can be converted to 131.5 mg hr$^{-1}$ 500 kg$^{-1}$ liveweight for an average weight bird. Note that the methodology and terminology common in European studies do not readily translate to USEPA requirements as stated in 40CFR50 (United States Office of the Federal Register 2001).

**Table 2 Particulate matter emission rates (mg hr$^{-1}$ 500 kg$^{-1}$ liveweight) reported in the literature and from this study for broilers on litter.**

| Reference | Inhalable Particulate Matter[1] Emission Rate (mg hr$^{-1}$ 500 kg$^{-1}$ liveweight) | Respirable Particulate Matter[2] Emission Rate (mg hr$^{-1}$ 500 kg$^{-1}$ liveweight) | TSP Emission Rate (mg hr$^{-1}$ 500 kg$^{-1}$ liveweight) | $PM_{10}$ Emission Rate[3] (mg hr$^{-1}$ 500 kg$^{-1}$ liveweight) | Notes |
|---|---|---|---|---|---|
| (Wathes *et al.* 1997) | 5000 | 600 | | | Winter conditions |
| | 8500 | 850 | | | Summer conditions |
| (Takai *et al.* 1998) | 6218 | 706 | | | Data from England |
| | 4984 | 725 | | | Data from The Netherlands |
| | 1856 | 245 | | | Data from Denmark |
| | 2805 | 394 | | | Data from Germany |
| Lacey *et al.* | | | 2214 | 131.5 | This study |

[1] Determined by IOM (Institute of Occupational Medicine, Edinburgh) dust samplers
[2] Determined by cyclone dust samplers (SKC Ltd., Blandford Forum, UK)
[3] Calculated from measured TSP and measured particle size distribution for actual PM less than or equal 10 µm aerodynamic equivalent diameter.

Both the IOM and cyclone samplers used in the European studies were originally designed for personal monitoring and have been adapted to measurements in broiler houses and other agricultural structures. The IOM sampler results are reported as inhalable PM and the cyclone sampler results as respirable PM. Inhalable PM is defined as the percentage $E_1$ of airborne particles of aerodynamic equivalent diameter (AED) D (μm) are given by equation 1 (ISO 7708 1995):

$$E1 = 50 \, [1 + \exp(-0.06 \, D)] \qquad [1]$$

This means that 50% of the particles with an AED of 100 μm would be captured by the sampler. The HI-Volume TSP sampler used in this study had a nominal cut-point of 25 to 50 μm AED depending on the ambient wind speed (United States Office of the Federal Register 2001Appendix B). The air velocity during sampling the data in figures 1 and 2 ranged from 0.8 m $sec^{-1}$ to 2.6 m $sec^{-1}$, which was less than the 4.6 m $sec^{-1}$ used to determine the sampler performance (Wedding *et al.* 1977). Therefore, the sampler cut-point was nearer 50 μm and the TSP emissions reported for this study are comparable with the inhalable emissions reported in the literature.

Respirable PM for a target population of healthy adults is defined as the percentage given by a cumulative log-normal distribution with a median diameter of 4.5 μm and a geometric standard deviation of 1.5 (ISO 7708 1995). The $PM_{10}$ emissions reported in this study are less than those in the literature for respirable PM (table 2). Since $PM_{10}$ is by definition larger than respirable PM this result does not at first seem reasonable. However, it has been shown that aerosol samplers which utilize a preseparator will over-sample in environments where the PSD is greater than the values used in the preseparator design (Buser *et al.* 2002). For the PSD of the PM in this study, the SKC cyclone sampler used to collect the respirable data would be expected to over-sample the ambient PM by a factor of 7.6 to 18.9, depending on the flow rate through the sampler, where the sampler cut-point is dependent on sampler flow rate (Harper *et al.* 1998). If the SKC sampler was used to capture PM with characteristics similar to this study (i.e MMD = 25 μm and GSD = 1.6) then the true respirable PM should vary from 13 to 112 mg $hr^{-1}$ 500 $kg^{-1}$ liveweight. These values are more consistent with the data reported in this study.

## $NH_3$ Emission Factor and Emission Inventory

A multiple linear regression was also performed on the data for $NH_3$ as the dependent variable with bird weight (g) and interior building temperature ($^oC$) as the independent variables. Relative humidity was also tested as an independent variable but the t-values were not as significant and inclusion of relative humidity did not improve the regression model. The results of the regression are shown in table 3.

**Table 3 Multiple linear regression results of $NH_3$ for bird weight (g) and interior building temperature ($^oC$).**

| Parameter | Value | Error | t-Value | Prob>\|t\| |
|---|---|---|---|---|
| Y-Intercept | -1.094 | 0.283 | -3.859 | 1.909E-4 |
| T | 0.031 | 0.009 | 3.531 | 6.022E-4 |
| Wt | 7.02E-4 | 4.443E-5 | 15.799 | <0.0001 |
| R-Square(COD) | Adj. R-Square | Root-MSE(SD) | | |
| 0.691 | 0.685 | 0.304 | | |
| ANOVA Table: | | | | |
| Item | Degrees of Freedom | Sum of Squares | Mean Square | F Statistic |

| | | | | |
|---|---|---|---|---|
| Model | 2 | 23.185 | 11.592 | 125.179 |
| Error | 112 | 10.372 | 0.093 | |
| Total | 114 | 33.557 | | |

The average $NH_3$ emissions were calculated from the multiple regression coefficients to be 404 mg $day^{-1}$ $bird^{-1}$ for an average bird weight of 1.03 kg and interior temperature of 24.9°C. Over a 49-day production cycle the $NH_3$ emission factor was 19.8 g $bird^{-1}$. Based on the management parameters and facility size given earlier, the $NH_3$ emission inventory for this facility was 12,630 kg $NH_3$ $year^{-1}$.

There have been reported emission factors for $NH_3$ from broilers on litter. These values are given in table 4.

**Table 4 Annual ammonia emission factors reported in the literature and from this study for broilers on litter.**

| Reference | Emission Factor (kg $bird^{-1}$) |
|---|---|
| (Battye *et al.* 1994) | 0.179 |
| (Misselbrook *et al.* 2000) | 0.19 |
| (Hutchings *et al.* 2001) | 0.2 |
| Lacey *et al.* | 0.02 |

Note that 0.02 kg $bird^{-1}$ found in this study is an order of magnitude less that other reported emission factors for $NH_3$ from broiler houses. Misselbrook *et al.* (2000) and Hutchings *et al.* (2001) report similar methodologies used to determine their emission factors. The total N excreted by the animal, given as 0.8 kg N $bird^{-1}$ $yr^{-1}$ or 0.5 kg N $bird^{-1}$ $yr^{-1}$, respectively, was multiplied by the fraction of N that is emitted as $NH_3$. However, ASAE Standard D384.1 gives the total amount of N excreted by a broiler as 1.1 kg 1000 $kg^{-1}$ live animal mass $day^{-1}$ (ASAE 1999). Thus for an average bird of 1.03 kg, the total nitrogen excreted per bird over the 49-day growth cycle was calculated to be 55.5 g N $bird^{-1}$ which is an order of magnitude lower than the values used by Misselbrook *et al.*. (2000) or Hutchings *et al.*. (2001). For the fraction nitrogen converted to $NH_3$ were 0.24, as reported by Misselbrook *et al.* (2000) the total amount of $NH_3$ emitted would be 13.3 g $NH_3$ $bird^{-1}$. If the fraction of nitrogen converted to $NH_3$ were 0.4, as reported by Hutchings *et al.* (2001) the total $NH_3$ emissions would be 22.2 g $NH_3$ $bird^{-1}$. These values bracket the results of this study, which was 19.8 g $NH_3$ $bird^{-1}$. The discrepancy in the values in table 4 results from the value used for the total amount of nitrogen excreted by the birds but neither study gives sufficient detail to determine where these values originated. The data from Battye *et al*. (1994) was presented without sufficient information to determine its derivation.

Emission rates of $NH_3$ for broilers as reported in the literature are summarized in table 5. For comparison, the emission factor of 19.8 g $bird^{-1}$, determined in this study, was converted to 16.8 mg $NH_3$ $hour^{-1}$ $bird^{-1}$ or 8.2 g $NH_3$ 500 $kg^{-1}$ liveweight $hour^{-1}$ based on an average bird weight of 1.03 kg per bird and a market cycle of 49 days. These values are larger than those most reported from the European studies noted in table 5. The warmer climate in Texas versus the northern European locations cited in the literature would promote increased $NH_3$ emissions. There may also be differences in bird weights that account for the greater $NH_3$ emissions. The study by Groot Koerkamp *et al.* (1998), reported values for broiler chickens in two sets of units as noted in table 5. The data reported in mg $hr^{-1}$ $bird^{-1}$ were divided by the data in g $hr^{-1}$ 500 $kg^{-1}$ liveweight, with appropriate unit conversion, which resulted in estimated bird weights that ranged from 0.50 kg to 0.84 kg, which are smaller that the 1.03 kg per bird average weight used in this study.

**Table 5 Ammonia emission rates (g hr$^{-1}$ 500 kg$^{-1}$ liveweight) reported in the literature and from this study for broilers on litter.**

| Reference | Emission Rate[4] (g hr$^{-1}$ 500 kg$^{-1}$ liveweight) | Emission Rate (mg hr$^{-1}$ bird$^{-1}$) | Estimated Average Bird Weight (kg) | Notes. |
|---|---|---|---|---|
| (Sneath *et al.* 1996) | 7.4 | | | Stocking density was 20.8-23.4 birds m$^{-2}$ |
| (Wathes *et al.* 1997) | 8.5 | | | Stocking density was 20.8-23.4 birds m$^{-2}$ |
| (Groot Koerkamp *et al.* 1998) | 8.3 | 19.8 | 0.84 | Data from England |
| | 4.2 | 11.2 | 0.75 | Data from the Netherlands |
| | 2.2 | 8.9 | 0.50 | Data from Denmark |
| | 7.5 | 18.5 | 0.81 | Data from Germany |
| (Demmers *et al.* 1999) | 1.9 | | | |
| (Misselbrook *et al.* 2000) | 6.2 | | | |
| Lacey *et al.* | 8.2 | 16.8 | 1.03 | Stocking density was 13.5 birds m$^{-2}$ |

## Conclusions

Emissions data for $PM_{10}$ and $NH_3$ from commercial broiler houses in central Texas were analyzed using multiple linear regressions to develop emission factors for average bird weights and interior building temperatures. The facility was typical of newer operations in the region and would house a total of 638,000 birds yr$^{-1}$ on litter. The buildings were cooled by mechanical ventilation, usually operated in a tunnel mode. Natural ventilation was available but not used during these studies.

The emission factor for $PM_{10}$ was 318 mg $PM_{10}$ bird$^{-1}$. Evaluation of these results against the data on PM emissions in the literature found that these values agreed with the previous work when comparing the TSP emission rate with inhalable PM emission rates. However, the $PM_{10}$ emission rate was less than reported respirable PM emissions. This was attributed to over sampling by the PM preseparator used in the respirable PM sampler. The emissions inventory for $PM_{10}$ from this facility was 203.2 kg $PM_{10}$ year$^{-1}$.

The emission factor determined for $NH_3$ was 19.8 g $NH_3$ bird$^{-1}$. The $NH_3$ emission rate found in this study was comparable to reported $NH_3$ rates. However, the $NH_3$ emission factor was an order of magnitude less than reported values. This was attributed to values used for the total nitrogen excreted by broilers that

[4] In some cases the units were converted from a different time base, e.g. day- or year$^{-1}$.

greatly exceeded that recommended by ASAE Standard D384.1 (1999). The $NH_3$ emission inventory from this facility was 12,630 kg $NH_3$ $year^{-1}$

The methodology used in this paper considered the effect of the size of the birds and the variance in ventilation necessary to maintain the desired interior temperatures, where both factors were shown through multiple linear regressions to be significant. The overall emission factor was calculated from these regressions for an average bird and average building temperature assuming that the ventilation system can meet the target temperatures. A future study will address the actual temperature profile within broiler houses in this region to determine how well the buildings can perform against the target values.

### *Acknowledgements*

The authors would like to express appreciation for the cooperation of Sanderson Farms and Parks Poultry in collecting the data used in this study. Funding was provided by a grant from the Texas State Legislature for a research initiative into *Agricultural Air Quality*. Additional funding was from a contract with the Texas Natural Resource Conservation Commission for a *Study of Odor and Arsenic Emissions from Poultry Growing Operations*.

## References

Aneja, V. P., G. C. Murray and J. Southerland 1998. Atmospheric nitrogen compounds: Emissions, transport, transformation, deposition, and assessment. *EM*: 22-25.

ApSimon, H. M., S. Couling, D. Cowell and R. F. Warren 1995. Reducing the contribution of ammonia to nitrogen deposition across Europe. Acid Reign '95, Proceedings of the 5th International Conference on Acidic Deposition: Science and Policy, Goteborg, Sweden, Kluwer Academic Publishers.

ASAE 1999. D384.1. Manure production and characteristics. *ASAE Standards*. St Joseph, MI, ASAE**:** 663 - 665.

ASAE 1999. Design of ventilation systems for poultry and livestock shelters. *ASAE Standards 1999*. St. Joseph, Michigan, ASAE**:** 606-623.

Barthelmie, R. J. and S. C. Pryor 1998. Implications of ammonia emissions for fine aerosol formation and visibility impairment - a case study from the lower fraser valley, British Columbia. *Atmospheric Environment* **32**(3): 345-352.

Battye, R., W. Battye, C. Overcash and S. Fudge 1994. Development and selection of ammonia emission factors. Durham, NC, EC/R Incorp.**:** 2-1 to 2-20.

Buser, M. D., C. B. Parnell, R. E. Lacey and B. W. Shaw 2002. PM10 sampler errors due to the interaction of particle size and sampler performance characteristics. Beltwide Cotton Conference, Atlanta, Georgia.

Carlile, F. S. 1984. Ammonia in poultry houses: A literature review. *World's Poultry Science Journal* **40**: 99-113.

Demmers, T. G. M., L. R. Burgess, J. L. Short, V. R. Phillips, J. A. Clark and C. M. Wathes 1999. Ammonia emissions from two mechanically ventilated UK livestock buildings. *Atmospheric Environment* **33**(2): 217-227.

Elliott, H. A. and N. E. Collins 1982. Factors affecting ammonia release in broiler houses. *Transactions of the ASAE* **25**(2): 413-424.

EPA 1995. Compilation of air pollutant emission factors, AP-42, fifth edition, volume i: Stationary point and area sources. Research Triangle Park, NC, U.S. Environmental Protection Agency.

EPA 2000. Supplements to the compilation of air pollutant emission factors AP-42, fifth edition, volume i: Stationary point and area sources. Research Triangle Park, NC, U.S. Environmental Protection Agency.

Flood, C. A., J. L. Koon, R. D. Trumbull and R. N. Brewer 1992. Broiler growth data: 1986-1991. *Transactions of the ASAE* **35**(2): 703-709.

Groot Koerkamp, P. W. G., J. H. M. Metz, G. H. Uenk, V. R. Phillips, M. R. Holden, R. W. Sneath, J. L. Short, R. P. White, J. Hartung, J. Seedorf, M. Schroder, K. H. Linkert, S. Pederson, H. Takai, J. O. Johnsen and C. M. Wathes 1998. Concentrations and emissions of ammonia in livestock buildings in northern Europe. *Journal of Agricultural Engineering Research* **70**(1): 79-95.

Harper, M., C.-P. Fang, D. L. Bartley and B. S. Cohen 1998. Calibration of the skc, inc aluminum cyclone for operation in accordance with ISO/CEN/ACGIH respirable aerosol sampling criteria. *Journal of Aerosol Science* **29**(1): 347-348.

Hutchings, N. J., S. G. Sommer, J. M. Andersen and W. A. H. Asman 2001. A detailed ammonia emission inventory for Denmark. *Atmospheric Environment* **35**(11): 1959-1968.

ISO 7708 1995. Air quality - particle size fraction definations for health-related sampling. Switzerland, International Standards Organization**:** 9.

Koon, J., J. R. Howes, W. Grub and C. A. Rollo 1963. Poultry dust: Origin and composition. *Agricultural Engineering*(November): 608-609, 611.

Madelin, T. M. and C. M. Wathes 1989. Air hygiene in a broiler house: Comparison of deep litter with raised netting floors. *British Poultry Science* **30**: 23-37.

Misselbrook, T. H., T. J. Van Der Weerden, B. F. Pain, S. C. Jarvis, B. J. Chambers, K. A. Smith, V. R. Phillips and T. G. M. Demmers 2000. Ammonia emission factors for UK agriculture. *Atmospheric Environment* **34**(6): 871-880.

Redwine, J. S. 2001. *Emission factors for ammonia and particulate matter from broiler houses*. Master of Science Thesis: 110 pages. Biological and Agricultural Engineering. Texas A&M University, College Station

Redwine, J. S. and R. E. Lacey 2001. Concentration and emissions of ammonia and particulate matter in tunnel ventilated broiler houses under summer conditions in Texas. ASAE Annual International Meeting, Sacramento, California, USA.

Sneath, R. W., M. R. Holden, V. R. Phillips, R. P. White and C. M. Wathes 1996. An inventory of emissions of aerial pollutants from poultry buildings in the UK. International Conference on Air Pollution from Agricultural Operations, Kansas City, Missouri, MidWest Plan Service.

Takai, H., S. Pederson, J. O. Johnsen, J. H. M. Metz, P. Koerkamp, G. H. Uenk, V. R. Phillips, M. R. Holden, R. W. Sneath, J. L. Short, R. P. White, J. Hartung, J. Seedorf, M. Schroder, K. H. Linkert and C. M. Wathes 1998. Concentrations and emissions of airborne dust in livestock buildings in northern Europe. *Journal of Agricultural Engineering Research* **70**(1): 59-77.

United States Office of the Federal Register 2001. Code of federal regulations. Title 40. Protection of environment. *Part 50--National primary and secondary ambient air quality standards*. Washington, Office of the Federal Register National Archives and Records Service General Services Administration.

Wathes, C. M., M. R. Holden, R. W. Sneath, R. P. White and V. R. Phillips 1997. Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in uk broiler and layer houses. *British Poultry Science* **38**(1): 14-28.

Wedding, J. B., A. R. McFarland and J. E. Cermak 1977. Large particle collection characteristics of ambient aerosol samplers. *Environmental Science & Technology* **11**: 387-390.

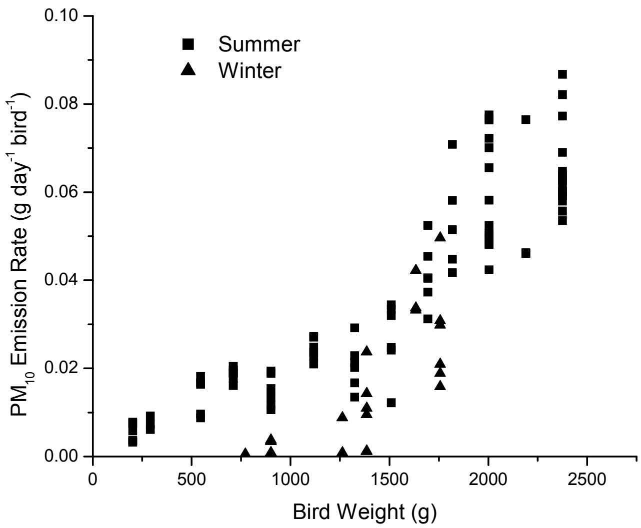


**Figure 1 Emission rates for PM10 versus the age of the birds for four broiler houses in central Texas.**

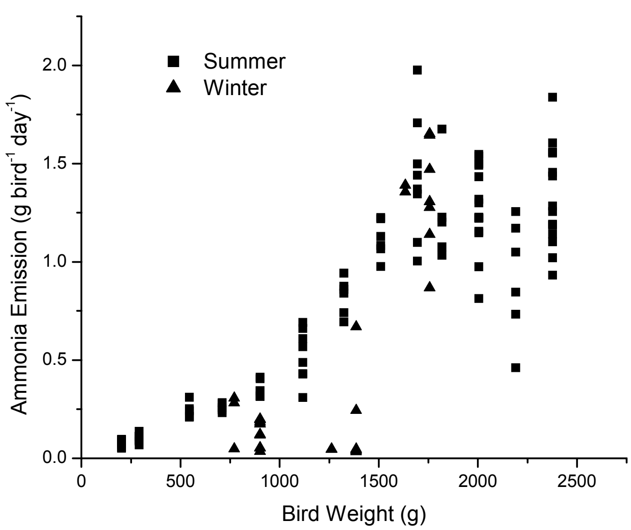


**Figure 2 Emission rates for PM10 versus the age of the birds for four broiler houses in central Texas.**

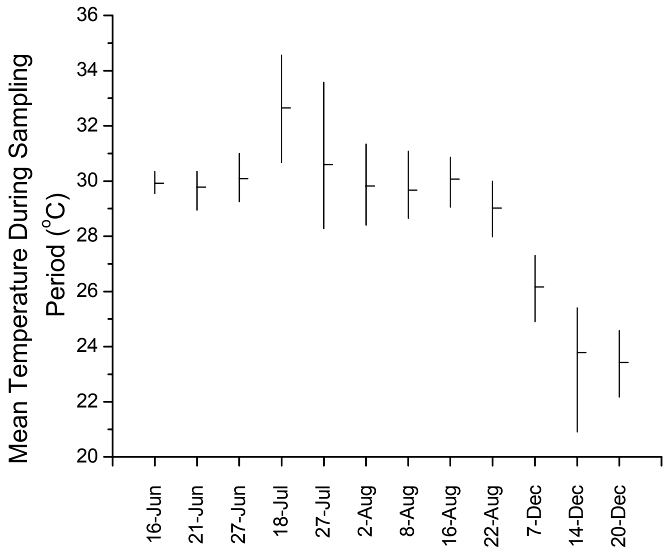


**Figure 3 Mean temperature and temperature range in the buildings during data collection of PM and ammonia emissions from commercial broiler houses in central Texas.**

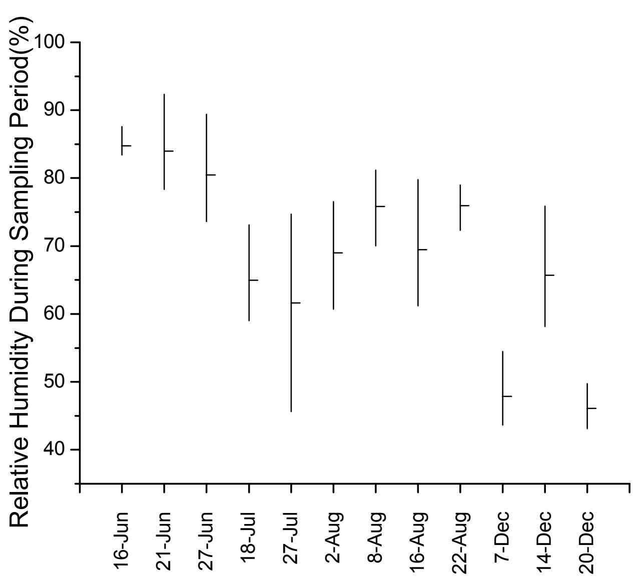


**Figure 4 Mean relative humidity and relative humidity range in the buildings during data collection of PM and ammonia emissions from commercial broiler houses in central Texas.**