Assessment of Environmental Factors Affecting PM Emission from Turkey Barn

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Abstract. Concentrations and emissions of particulate matters (PM₁₀ and PM₂.₅) were continuously measured in a mechanically ventilated turkey grow-out house over one-year period. The PM concentrations were measured using tapered element oscillating microbalances (TEOMs), and the building ventilation rate (VR) was measured by monitoring the operation time of calibrated ventilation fans. Bird activities (BA) were monitored with a passive infrared detector (PID). This paper describes the effects of bird age, BA, VR, air temperature, and indoor relative humidity (RH) on the PM emission rate (ER) based on three flocks (bird age of 35 - 140 d) data collected during the one-year monitoring. Considerable diurnal variations were observed in BA, PM concentration and PM ER of the turkey barn. The PM concentration and ER were positively related to BA but negatively related to indoor RH. VR was negatively related to PM concentration but positively related to ER.

Keywords. Particulate matter, emissions, turkey, environmental factors
Introduction

Particulate matter (PM) creates ambient air quality concerns when they are released to the atmosphere. PM is one of the most prominent air pollutants associated with animal feeding operations (AFOs). In 2005 an Air Compliance Agreement (ACA) was reached between EPA and certain sectors of the U.S. livestock and poultry industries, namely, broiler, egg, swine, and dairy industries. The ACA studies will yield more baseline data on air emissions from U.S. AFOs. However, turkey industry was not a part of the ACA and there had been no study that continually quantifies air emissions from U.S. turkey facilities. During 2007 to 2008, a turkey air emissions monitoring study, funded by the USDA-NRI Air Quality Program, was conducted and a tom turkey in Iowa and a hen turkey barn in Minnesota were continuously monitored for one year (Li et al., 2009). As a part of this study, the PM emissions from turkey houses were quantified and the environmental conditions in the turkey houses were monitored.

To control animal-exposure PM level and emissions from the emitting sources, it is important to understand and characterize the factors that influence the PM generation and emission. These factors include, but not limited to, indoor climatic conditions, building ventilation rate (VR), heating and cooling schemes, animal type and age, feed type and feeding schemes, litter or manure conditions, and lighting programs. In mechanically ventilated facilities, high VR in summer results in lower indoor PM concentration due to more air dilution but may increase PM emission rate (ER) (Takai et al., 1998; Haeussermann et al., 2008). Animal activity is the predominant factor that influences airborne particle concentrations (Dawson, 1990; Pedersen et al, 1995; Perkins et al, 1997). However, there were few studies that actually characterize or quantify the impact of animal activity on PM concentrations and emissions (Perkins et al., 1997; Haeussermann et al., 2008). Information is particularly meager concerning animal activity and environmental factors and their impacts on PM emission in poultry operations.

The objective of this paper was to assess the effects of bird activity (BA), VR, indoor air temperature and relative humidity (RH) on PM$_{10}$ (particulate matter with aerodynamic diameters $\leq 10 \, \mu m$) and PM$_{2.5}$ (particulate matter with aerodynamic diameters $\leq 2.5 \, \mu m$) concentration and ER of a commercial grow-out tom turkey barn.

Materials and Methods

A commercial tom turkey barn in central Iowa was continuously monitored for NH$_3$, PM$_{10}$, and PM$_{2.5}$ emissions for 16-month period (May 2007 – August 2008, Table 1). The east-west oriented turkey barn (18.3 x 102 m; 60 x 335 ft) used combined cross and tunnel ventilation and static pressure controlled curtain inlets (fig. 1). Four space furnaces (73.2 kW or 250,000 Btu/hr each) were distributed in the barn (21.3 m or 70 ft apart) to provide space heating in cold weather. The barn had a wooden sidewall on the north and a 1.5 m (5 ft) permeable Nylon curtain on the south. The barn had five 61-cm (24-in) diameter sidewall fans spaced at 18.3 m (60 ft) apart, one 123-cm (48-in) and six 132-cm (52-in) diameter tunnel fans. The sidewall fans were used for cold weather ventilation and the tunnel fans used for warm weather ventilation. At five weeks of age, the Hybrid tom turkeys were transferred from the brooder barn to the grow-out barn where they were raised till market age of 20-21 weeks. Standard commercial diets were fed ad lib to the birds during the study. Prior to onset of the monitoring, the barn was cleaned, disinfected and bedded with rye hulls. Top dressing of 14,000 kg (15.4 U.S. ton) rye hulls was applied after each flock and 409 kg (900 lb) aluminum sulfate (Alum, 50 lb/1000 ft$^2$) was applied on top of the new bedding. Continuous light was used.
Tapered element oscillation microbalances (TEOMs) (model 1400a, Thermo Environmental Instruments Inc., Franklin, MA) were used with different heads to measure PM$_{10}$ and PM$_{2.5}$ concentrations. One set of (two) TEOMs placed at the sidewall location and another set near the tunnel end. For the ambient (background) location, the PM$_{10}$ and PM$_{2.5}$ TEOMs were collocated at the ambient air sampling location near the air inlet. VR of the barn was derived by using in situ calibrated fan curves from a fan assessment numeration system (FANS) (Gates et al., 2004). After the actual airflow curves were established for all the exhaust fans individually and in stage combinations, runtime of each fan was monitored and recorded continuously using an inductive current switch attached to the power supply cord of each fan motor (Muhlbauer et al., 2006). Analog output from each current switch was connected to the compact Fieldpoint modules. Concurrent measurement of the barn static pressure (SP) was made with two SP 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 yielded the overall barn VR. Two RH sensors (HMP 61U, Vaisala Inc., Woburn, MA) located near the TEOMs at sidewall and tunnel location were used to continuously monitor RH. Type T (copper-constantan) thermocouples were used for temperature measurement. Two passive infrared detectors (PIDs) (SRN-2000, Visonic Inc., Bloomfield, CT, USA) were mounted 2 m (6 ft) above the floor: one at the tunnel end and the other in the middle of the house. The PID motion detection sensors were equipped with a #100 lens that had a 90 degree and 18 m radius coverage (fig. 2). The original AC signals from the PIDs were converted to DC signals using a full-wave rectification. The converted DC signals were then amplified and smoothed for the final processing. Dielectric moisture sensors (Model EC5, Decagon Devices, Pullman, WA) were calibrated (Mendes et al., 2008) and used for measuring of litter/bedding moisture content weekly during the flocks (September, 2007 to April, 2008). Fifteen locations were randomly selected and litter moisture contents were measured during each trip.

The relationship of the dynamic PM ER to PM concentrations of inlet and exhaust air and building VR can be expressed as following:

\[
[ER_{PM}]_t = \sum_{c=1}^{2} [Q_e]_t \left( \frac{\rho_e}{\rho_i} [PM]_i \right) \times 10^{-6} \times \frac{T_{std}}{T_t} \times \frac{P_a}{P_{std}}
\]

where
- \( [ER_{PM}]_t \) = PM emission rate of the house (g house$^{-1}$ t$^{-1}$)
- \( [Q_e]_t \) = Average VR of the house during sample integration time t under field temperature and barometric pressure (m$^3$ house$^{-1}$ t$^{-1}$)
- \( [PM]_i \) = PM concentration of incoming ventilation air (ug m$^{-3}$)
- \( [PM]_e \) = PM concentration of exhaust ventilation air (ug m$^{-3}$)
- \( T_{std} \) = standard temperature, 273.15 K
- \( T_t \) = 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
- \( \rho_i, \rho_e \) = air density of incoming and exhaust air, kg dry air m$^{-3}$ moist air
Results and Discussion

Diurnal Variations in PM Concentration, ER, Environmental Factors and BA

As shown by the data in Figure 3, PM_{10} concentrations, ER, VR, RH and BA exhibited distinctive diurnal variations. The PM_{10} ER followed the same trend of BA, especially when VR remained constant at 40 d of age. For example, a BA spike (0.6) at 3 AM led to the corresponding PM_{10} ER increasing from 5 mg/hr-bird at 2 AM to 9 mg/hr-bird at 3 AM. The BA and PM_{10} ER were much higher during the day than at night, even with the presence of artificial lighting at night. The lower BA at night could have been attributed to the less natural light that would be available through the nylon curtains during the day. The PM_{10} concentration had a stronger relationship with VR. Figure 3 shows that the PM_{10} concentration declined under higher VR at 100 d of age but the corresponding PM_{10} ER was elevated, as compared to those at 40 d of age. Both elevated BA and VR could enhance the PM_{10} generation and emission of the turkey houses when the stirred-up PM from dry litter and bird feather by air turbulence was exhausted by the ventilation fans. There was no strong evidence to show that higher RH would lower the PM concentrations or emissions. Since PM_{10} and PM_{2.5} concentrations and ER are highly correlated (fig. 4), the impacts of BA, VR, and RH on PM_{10} concentration and ER would be applicable to PM_{2.5}.

Effect of BA and Environmental Variables on PM Emissions

Hourly PM ER

The 30-s average ER data and variables were processed and summarized as 60-min (hourly) averages. Higher BA led to elevated PM_{10} concentration and ER. Figure 5 shows the relationship between the hourly PM_{10} ER and BA over the three flocks with 6306 valid data points. There was a fairly strong linear relationship between the two variables. In addition, RH and VR had impact on the PM_{10} ER. Figure 3 reveals that both VR and BA positively affected the PM_{10} ER. For instance, the PM ER and concentration were highly related to the BA while the VR was kept constant on the day 40 (figs. 3a and 3b). PM_{10} ER also markedly followed the VR trend when the VR had a remarkable diurnal pattern and changed from 10 to 28 m\(^3\)/hr while the PM_{10} concentration had the reversed trend (figs 3d and 3e). The indoor RH tended to be lower during the period of high PM_{10} ER. In general, the PM_{10} ER from the turkey house will rise with elevation of BA and VR and lower RH. As mentioned above, PM_{10} ER and concentration could also be influenced by other variables, such as temperature, litter condition, and bird size. To evaluate the relationship between the various input variables and PM ER, a multiple linear regression analysis was performed, of the form,

\[
\sqrt{\text{ER}_{PM}} = \beta_0 + \beta_1 X_1 + \ldots + \beta_i X_i \quad [2]
\]

where \( \sqrt{\text{ER}_{PM}} = \text{mg hr}^{-1}\text{bird}^{-1} \)

\( X_i = \) influencing variables

\( \beta_i = \) regression coefficient

Variability in PM_{10} and PM_{2.5} ER was mainly affected by bird age, BA, VR, and RH (R\(^2\)=0.54 for PM_{10} and 0.57 for PM_{2.5}, Table 2). BA positively impacts both PM_{10} and PM_{2.5} ERs as higher BA stimulates more PM generation from the litter. VR affected PM ER in that higher VR reduced PM concentration (due to greater dilution) but increased PM emission. Elevated RH led to less PM generation and thus lower emission to the environment. The quantity \( \sqrt{\text{ER}_{PM}} \) also increased...
with bird age that had been seen from a previous study with southeastern broiler air emissions monitoring (Burns et al., 2008).

**Daily PM ER**

Daily ERs of PM$_{10}$ and PM$_{2.5}$ and daily averages of major environmental factors were also used to assess the effects of the variables. Figure 6 shows that the daily PM$_{10}$ and PM$_{2.5}$ ER dramatically increased with the bird growth during the first 8 weeks and remained constant or started to decrease. The bird growth (bird age) is the predominant variable that affects PM emissions from broiler houses (Burns et al., 2008). The litter moisture contents from weekly visits were linear-interpolated to generate the daily litter moisture content. To evaluate the relationship between the various input variables and daily PM ER, a multiple linear regression analysis was performed by using Equation 2. Similar regression patterns were found for daily PM ER with the environmental variables and bird age. The effect of bird age on daily PM$_{10}$ ER was not significant which might be caused by the large variation of daily PM$_{10}$ ER after 12-13 wk of bird age. The outcome may also indicate that BA and VR were the predominant variables after certain growth stage. Increased litter-floor coverage by the birds might have been another cause for the leveling or declining ER with bird age. No strong evidence showed that the litter moisture content could significantly affect the PM ER (P-value=0.5).

**Conclusions**

The following conclusions were drawn from this study.

- Diurnal patterns exist in bird activity, PM emission rate, and PM concentration in the turkey barn.
- Bird activity positively impacts both PM emission rate (ER) and concentration. Increased ventilation rate (VR) reduces PM concentration but increases PM emission. Indoor relative humidity is negatively related to PM concentration and ER.
- During the one-year monitoring period (bird age of 35 - 140 d) in Iowa, PM$_{10}$ and PM$_{2.5}$ ER varied from 0 to 0.58 g d$^{-1}$bird$^{-1}$ and 0 to 0.05 g d$^{-1}$ bird$^{-1}$, respectively.

**Acknowledgements**

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**References**


Table 1. Data of the three flocks of tom turkeys monitored for air emissions in Iowa

<table>
<thead>
<tr>
<th>Flock #</th>
<th>Flock dates</th>
<th>Bird age, d</th>
<th>Bird weight, kg</th>
<th>No. of birds</th>
<th>Density, birds/m²</th>
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<tr>
<td>1</td>
<td>08/31/07–12/17/07</td>
<td>35 – 143</td>
<td>0.9-17.0</td>
<td>6059</td>
<td>3.3</td>
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<tr>
<td>2</td>
<td>01/07/08–04/28/08</td>
<td>38 – 150</td>
<td>1.4-19.5</td>
<td>5550</td>
<td>3.0</td>
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<tr>
<td>3</td>
<td>05/09/08–08/26/08</td>
<td>35 – 144</td>
<td>1.4-17.9</td>
<td>5124</td>
<td>2.8</td>
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</tbody>
</table>

Table 2. Multi-variate linear regression of hourly PM₁₀ and PM₂.₅ emission rate (ER) vs. influencing variables (BA = bird activity, VR = ventilation rate, RH = indoor relative humidity)

<table>
<thead>
<tr>
<th>Variables</th>
<th>ER₂PM₁₀, mg/hr-bird (R²=0.54)</th>
<th>ER₂PM₂.₅, mg/hr-bird (R²=0.57)</th>
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<tbody>
<tr>
<td></td>
<td>β</td>
<td>SE</td>
</tr>
<tr>
<td>Intercept</td>
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<td>Bird age</td>
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<td>0.0004</td>
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<tr>
<td>BA</td>
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<td>VR, m³/hr-bird</td>
<td>0.028</td>
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<td>RH in, %</td>
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<td>0.001</td>
</tr>
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</table>

Table 3. Multi-variate linear regression of daily PM₁₀ and PM₂.₅ emission rate (ER) vs. influencing variables (BA = bird activity, VR = ventilation rate, RH = indoor relative humidity)

<table>
<thead>
<tr>
<th>Variables</th>
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<th>ER₂PM₂.₅, g/bird-d (R²=0.58)</th>
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<td>-</td>
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<td>0.0008</td>
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<tr>
<td>VR, m³/hr-bird</td>
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<td>0.0005</td>
</tr>
<tr>
<td>BA</td>
<td>1.00</td>
<td>0.11</td>
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Figure 1. Schematic layout of the mechanically ventilated tom turkey barn monitored at Iowa

Figure 2. Coverage pattern of the passive IR detection (PID) motion sensor site
Figure 3. Hourly PM$_{10}$ and PM$_{2.5}$ concentrations, emission rate (ER), ventilation rate (VR) and bird activity (BA) for 40-d and 100-d old tom turkeys.

Figure 4. Diurnal PM$_{10}$ and PM$_{2.5}$ ER from 40 d old tom turkeys and hourly ER comparison over the three flocks measurement.
ER = 28.9 BA + 0.36
R² = 0.24

ER = 0.13 VR + 8.1
R² = 0.09

ER = -0.18 RH + 21.3
R² = 0.07

Figure 5. Relationship of PM₁₀ emission rate (ER) to bird activity (BA), ventilation rate (VR), and indoor relative humidity (RH) of a turkey barn.

Figure 6. PM₁₀ and PM₂.₅ emission rate (ER), building ventilation rate (VR) and bird activity during the three-flock monitoring of air emissions from a tom turkey barn in Iowa.