The Development of Seasonal Emission Factors Produced by a Commercial Layer Facility

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Abstract From a human health perspective, pollutants emitted from agricultural facilities are a growing concern. Quantification of these aerial pollutants is difficult due to variable climatic conditions, the number of animal species used in commercial operations and the wide range of management conditions used for each species. A project was initiated to quantify the emissions of ammonia and particulate matter over a period of one year from a commercial poultry layer facility in Wellington County, Ontario, Canada. An on-site mobile trailer was used to monitor in-house concentrations of ammonia and size fractioned particulate matter via a heated sample line. Along with a developed ventilation profile, emissions rates were produced for the facility. Average emissions of 19.53 ± 19.97, 2.57 ± 2.17, and 1.10 ± 1.52 g/day/AU for ammonia, PM$_{10}$, and PM$_{2.5}$, respectively, were observed from the layer facility. Emissions peaked during the winter months except for PM$_{2.5}$ which had increased emissions in the summer.

Keywords. Ammonia, Particulate Matter, Emission Factors, Poultry, Layer

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Introduction

There has been a growing concern with aerial pollutant emissions generated from commercial animal housing facilities. Quantification of these pollutants is difficult due to variable climatic conditions, the number of animals housed in these commercial operations and the wide range of management conditions used. Varying management conditions include: feeding and watering regimens, manure removal and storage systems, and ventilation systems. The emissions from these housing facilities are important to study as an increase in atmospheric pollutants impact public health and environmental quality.

From a human health perspective, the pollutants of interest that are typically found exhausting from poultry facilities are ammonia and size-fractioned particulate matter. Ammonia is the primary pollutant of concern emitted as it is a precursor pollutant for secondary fine particulate matter formation (Lin et al, 2011). Ammonia is listed on the Toxic Substance List by Environment Canada (2012b) and is listed as a hazardous substance by the U.S. Environmental Protection Agency (US EPA, 2011). Fine particulate matter has been linked to aggravated cardiac and respiratory diseases and is included in the Canada-U.S. Air Quality Agreement (Environment Canada, 2012a) as well as the Toxic Substance List (as PM$_{10}$).

Due to the wide range of environmental conditions, housing conditions, ventilation, and manure management, aerial pollutants from housing facilities are very difficult to quantify and compare with other facilities. For this reason, it is important for studies to be performed on multiple facilities in many geographical areas with different management conditions which will characterize baseline emissions for many types of barns. This will give governments, as well as facility operators and commodity groups, a more representative interpretation of the quantity and range of pollutants being emitted from these facilities.

The objective of this paper was to quantify the emissions of ammonia, and particulate matter less than or equal to 10 and 2.5 microns in aerodynamic diameter (PM$_{10}$ and PM$_{2.5}$, respectively), from a commercial poultry layer facility using continuous measurement techniques. The characterization of diurnal and seasonal emission trends are also addressed in this paper in order to determine which house management and/or environmental factors are most influential on the emissions of the pollutants of interest.

Methodologies

Facility Description

The commercial poultry layer facility used in the study was a two storey mechanically ventilated house located in Wellington County, Ontario, Canada. The facility has a caging area that is 123 m by 12 m and houses approximately 65,000-70,000 birds during a production cycle (53 weeks). Conveyor belts are located underneath each row of cages which are run twice a week on Tuesday and Friday at approximately 10:30 a.m. for an hour. The excreta removed by the belts is transported to a manure storage area in another housing facility.

The lighting periods in the facility were initially set to 13.5 h per day starting at 6:00 a.m. when a new flock arrives. After the first 20 weeks, more light was added at the discretion of the facility manager at 15 minute increments at a time. The maximum light that the birds were allowed at this specific facility was 16 h per day, usually occurring at the 30th week of the production cycle.
The facility was equipped with fourteen 0.61 m variable speed fans, four 0.91 m single speed fans, twelve 1.22 m single speed fans, and six 1.37 m single speed tunnel ventilation fans located on the north end of the barn, for a total of 36 fans. Ventilation rates at the facility were dependent upon the average temperature within the barn. The average temperature was obtained from eight temperature probes evenly spaced throughout the barn. House ventilation was based upon keeping the average temperature as close as possible to the set point temperature which ranged from 18.9-22.2°C depending on flock age and seasonality.

The measurement campaign spanned over the 2010-2011 production cycle, as well as the 2011 summer data from the 2011-2012 production cycle. These flocks were raised during representative seasons of winter, spring, summer, and fall for the geographic region.

**Instrumentation**

The ammonia and size-fractioned particulate matter were continuously monitored throughout the measuring campaign. Ammonia concentrations were measured using a chemiluminescence ammonia analyzer (Model 17i, Thermo Electron Corporation) that was housed in a research trailer outside of the facility. Sample air was drawn from the facility using a heated sample line (Model 0723-100, Clean Air Engineering Inc.) to ensure condensation would not occur within the sample stream prior to entering the analyzer. The inlet for the heated sample line was located inside the facility at a horizontal distance of 1.0 m from one of the 0.61 m ventilation fans, at a height of 2.5 m above the ground. The sample port set-up was designed to minimize the impact of the daily operation of the facility.

The PM$_{10}$ and PM$_{2.5}$ concentrations were measured using two DustTrak® aerosol monitors (Model 8520, TSI Incorporated) that were equipped with inlets limiting particles larger than 10 and 2.5 microns, respectively. The monitors were factory calibrated using IO 12103-1, A1 test dust. To account for this calibration, a bulk density test was performed taking dust samples at the layer facility and used to adjust the calibration density of the DustTrak® monitors to an average density of the particulates in the facility. The DustTraks were housed inside the facility due to constraints on the sample line length. The inlets were placed in the same location as the heated sample line inlet in order to obtain comparable results.

A Flow Assessment Numeration System (FANS) device was used to measure in-situ volumetric exhaust flow from the ventilation fans. The FANS unit operates by vertically traversing an array of six propeller anemometers (Model 27106T Gill Propeller Anemometers) over a cross-sectional area. The anemometers are used to convert propeller rotation to a DC voltage that is linearly proportional to air velocity. Averaging the measured velocity of the six anemometers and multiplying by the cross-sectional area yields an average air flow of the ventilation fan.

**Emission Calculations**

The facility emission rate is simply the multiplication of the volume of air exiting the house per time by the observed ammonia or particulate matter concentration within the facility. Since the measured concentrations of ammonia were volumetric (ppm), they were converted into a mass concentration using the ideal gas law. The emission rates were normalized using an animal unit (AU) equivalent to 500 kg of live mass. Equations (1) and (2) outline the calculation for ammonia and particulate matter emissions, respectively.

\[
EF_{NH3} = \left[\frac{V_{NH3}}{V_{air}}\cdot (P\cdot MW_{NH3}/R\cdot T) - C_0\right]\cdot 1000 g/kg\cdot Q\cdot (500 kg/BM_{total}) \quad (1)
\]

Where; 
- \( EF_{NH3} \) = Emission factor (g/day/AU)
- \( V_{air} \) = Volume of air (m$^3$)
- \( V_{NH3} \) = Volume of ammonia (m$^3$)
\[ EF_{PM} = C_{PM} \cdot (\rho/\rho_{FC}) \cdot Q \cdot (500 \text{kg}/BM_{\text{total}}) \]  

Where:  
\( EF_{PM} \) = Emission factor (g/day/AU)  
\( C_{PM} \) = Concentration of particulate matter (g/m\(^3\))  
\( \rho \) = bulk density of dust in facility (kg/m\(^3\))  
\( \rho_{FC} \) = bulk density of dust in factory calibration (kg/m\(^3\))  
\( Q \) = Facility ventilation rate (m\(^3\)/day)  
\( BM_{\text{total}} \) = Total live bird mass in the barn (kg)

**Data Quality Assurance and Control**

The instruments used in the concentration data collection were kept under strict technical maintenance during operation. The ammonia gas analyzer was regularly calibrated and the particulate matter instruments underwent zero-checking to ensure appropriate readings were recorded. The total sampling periods for ammonia, PM\(_{10}\) and PM\(_{2.5}\) are displayed in Figure 1. Breaks in data collection occurred throughout the monitoring campaign due to various situations including: equipment servicing, power surges, depopulation/repopulation of flock, and scheduled shutdowns. PM\(_{10}\) data was not able to be collected during the late summer due to continuous malfunctioning of the DustTrak\(^{\circledR}\) power adapter. Due to this, summer 2011 data for PM\(_{10}\) cannot be accurately compared to the PM\(_{2.5}\) data as the averages would not represent the same collection periods.

![Figure 1. Total sampling periods for data collection](image-url)
Results and Discussion

Ammonia Concentration and Emission Rates

The ammonia concentrations within the barn were constantly changing. Fluctuations in concentration were based on a variety of factors, with the main influences being manure evacuation and ventilation. As stated previously, the conveyor belts were operated every Tuesday and Friday at 10:30 a.m. The ventilation rate fluctuated daily, generally decreasing at night when the ambient temperature cooled down and increasing during the day. In addition to diurnal variations in ventilation, there were large seasonal changes due to increases in ventilation during the summer compared to the winter.

Concentrations of ammonia in the facility were observed to be the highest in the winter months with peaks of ~35 ppm. Ammonia concentrations greatly decreased in the warmer months when the ventilation increased the air exchange rate. Another effect of the increase in ventilation is the potential drying of the excreta on the conveyor belts which would decrease the amount of ammonia generation by microbes and the subsequent volatilizing into the air.

Figure 2 displays the trends in ammonia concentration, ventilation, and ammonia emission rate for a segment of winter of 2011. A segment from the winter sampling period was chosen since the decreased ventilation that occurs during this time allows for a more direct relationship to be observed between the excreta cleaning cycle of the facility and the in-house ammonia concentrations. Throughout the week as excreta accumulates; the ammonia concentration rises until it peaks at the actual cleaning period. After the cleanout, a rapid decline in the concentration occurs when all the excreta is removed from the facility. It can be seen that the larger spikes occur on March 1st and 8th coinciding with the Tuesday cleaning periods where the excreta has been allowed to accumulate for four days, instead of only three days for the Friday cleaning periods.

Fewer spikes with smaller magnitude fluctuations in concentration were observed in the colder months due to the low temperatures yielding less variable ventilation. These smaller variations in ventilation dictate that the ammonia emission rates follow a nearly identical trend line as the ammonia concentrations for these time periods. The ventilation varies greatly in the warmer months due to the single speed large fans that get introduced in the higher fan stages. The single speed fans cause the total ventilation to dramatically increase or decrease from one stage to another. These constant large fluctuations in ventilation will affect the ammonia emissions and also decrease the overall magnitude of the ammonia concentration within the facility.

The average concentrations of ammonia in the facility during the fall, winter, spring, and summer were observed to be 4.39 ± 4.13, 8.78 ± 7.10, 4.28 ± 3.07, and 0.40 ppm ± 0.22 ppm, respectively. The average emission factors for the facility during the fall, winter, spring, and summer were observed to be 12.97 ± 15.37, 28.89 ± 23.13, 26.25 ± 18.83, and 8.13 g/day/AU ± 7.32 g/day/AU, respectively.

Particulate Matter Concentration and Emission Rates

Particulate matter concentrations constantly fluctuate in layer facilities. Generation of particulate matter within the facility is based on a variety of factors, including bird activity and ventilation. The activity level of the birds is based on the amount of light that the birds are exposed to during the day. When the lights are shut off, the concentration of particulates are drastically reduced as the birds settle and enter a sleep cycle. Sweeping occurrences were anticipated to have a slight
affect on the concentration of particulates in the air, however they were conducted on an \textit{ad hoc} basis by the facility’s management staff and therefore could not be correlated with the data.

Figure 3 displays the trends in particulate concentration, ventilation, and particulate emission rate for a segment of winter 2011. A segment from the winter sampling period was chosen because the decreased ventilation that occurs during this time allows for a more direct relationship to be observed between the lighting periods and the in-house concentrations. A distinct diurnal pattern was observed with a drastic increase in particulate matter (PM$_{10}$ and PM$_{2.5}$) when the lights were turned on and a subsequent decline when the lights were shut off for the night.

Concentrations of PM$_{10}$ were observed to be highest in the colder months due to the decrease in ventilation increasing the retention time of the air within the facility. The PM$_{10}$ emissions were found to remain at a fairly consistent magnitude with seasonal changes. This was anticipated, due to the increase in ventilation and the decrease in concentration in the warmer months, and vice versa in the colder months. Therefore even though the emissions for PM$_{10}$ remain fairly steady throughout a production cycle, the main driving force behind the emissions varies greatly with each season.

The concentrations of PM$_{2.5}$ were observed to be high in the coldest and warmest months, with the lower concentrations occurring in the fall and spring when the ambient temperatures are moderate. The increase in concentration during the colder months can be described by the increase in air retention time, similar to the increase in PM$_{10}$. Concentration increases in PM$_{2.5}$ in the warmest months is hypothesized to be attributed to the warm ambient and house temperatures which could promote the formation of secondary aerosol particles within the facility environment. A study by Roumeliotis (2010) that performed emissions testing on a broiler facility found that there was a greater ratio of inorganic aerosols to PM$_{2.5}$ in the warmer months, supporting this hypothesis.

Due to the increase in PM$_{2.5}$ concentration in the warmer months combined with the increase in ventilation at this time period, the emissions for PM$_{2.5}$ are at their peak during the summer. Table 1 contains a summary of PM$_{10}$ and PM$_{2.5}$ emissions quantified from the facility over the course of the sampling campaign.

\textbf{PM$_{2.5}$/PM$_{10}$ Comparison}

Figure 4 displays the ratios of PM$_{2.5}$/PM$_{10}$ throughout an average day for each season. The ratios of PM$_{2.5}$ and PM$_{10}$ were developed solely from the data that was collected during the same sampling periods in order to obtain truly comparable results.

A distinct pattern was observed for all seasons with the ratio of indoor PM$_{2.5}$/PM$_{10}$ increasing at night, when the lights are shut off and bird activity decreases. This pattern can be explained by the slower settling velocity of smaller particles as well as possible generation of fine secondary aerosols (Roumeliotis et al, 2010). This indicates that PM$_{2.5}$ is less dependent upon bird activity then PM$_{10}$ emissions.

The average ratios of PM$_{2.5}$/PM$_{10}$ are 0.13 ± 0.07, 0.15 ± 0.08, 0.25 ± 0.08, and 0.55 ± 0.19 for fall, winter, spring, and summer, respectively. Each of the seasonal average ratios is statistically different from the others with the exception of the fall and winter data, based on a multiple comparison test.
Figure 2. Trends in ammonia during the winter of 2011
Figure 3. Trends in particulate matter during the winter of 2011
Emissions Summary

The average emissions from the commercial layer facility are summarized in Table 1. The concentrations and emission factors developed were produced using the data collected over the various seasons and the overall sample period.

<table>
<thead>
<tr>
<th>Season</th>
<th>Ammonia</th>
<th>PM2.5</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average barn Concentration (mg/m³ [ppm])</td>
<td>Average Emission Factor (g/d/AU)</td>
<td>Average barn Concentration (mg/s)</td>
</tr>
<tr>
<td>Fall</td>
<td>2.75 ± 2.60 [4.39 ± 4.13]</td>
<td>12.97 ± 15.37</td>
<td>0.04 ± 0.02</td>
</tr>
<tr>
<td>Winter</td>
<td>5.55 ± 4.51 [8.78 ± 7.10]</td>
<td>28.89 ± 23.13</td>
<td>0.06 ± 0.03</td>
</tr>
<tr>
<td>Spring</td>
<td>2.69 ± 1.95 [4.28 ± 3.07]</td>
<td>26.25 ± 18.83</td>
<td>0.04 ± 0.03</td>
</tr>
<tr>
<td>Summer</td>
<td>0.24 ± 0.14 [0.40 ± 0.22]</td>
<td>8.13 ± 7.32</td>
<td>0.08 ± 0.04</td>
</tr>
<tr>
<td>Overall</td>
<td>3.07 ± 3.77 [4.61 ± 5.88]</td>
<td>19.53 ± 19.97</td>
<td>0.03 ± 0.03</td>
</tr>
</tbody>
</table>

*Values averaged over early summer data for PM₁₀ therefore underestimating actual emissions
Conclusion

The average emission rate of ammonia on an animal unit basis was 19.53 g/day/AU ± 19.97 g/day/AU, and was greatly influenced by the manure cleanout periods. When the excreta were removed from the facility a drastic decline in in-house ammonia concentration was observed. Seasonal variation in ammonia emissions were observed during the course of the sampling period. The emissions were observed to be the highest during the winter due to indoor concentration build-up that resulted from decreased ventilation associated with cold ambient temperatures. Emissions of ammonia were found to be the lowest in the summer when the increase in ventilation decreased the retention time of in-house air. The increase in ventilation had potential to increase excreta drying creating a less biologically active manure.

The average emission rates of PM$_{10}$ and PM$_{2.5}$ on an animal unit basis were 2.57 g/day/AU ± 2.17 g/day/AU and 1.10 g/day/AU ± 1.52 g/day/AU, respectively, and were heavily influenced by bird activity. Seasonal variations in particulate matter emissions were observed over the course of the sampling campaign. PM$_{10}$ emissions were found to remain relatively consistent throughout the year, however being driven by concentration during the colder months, and driven by ventilation during the warmer months. PM$_{2.5}$ emissions varied with lower emissions in the colder months due to the low ventilation, and higher emissions in the warmer months when both the ventilation and concentrations within the facility were elevated. The ratio of PM$_{2.5}$/PM$_{10}$ was seasonally dependent such that, in the coldest season the average ratio was 0.13 ± 0.07 compared to the warmest season where the average ratio was 0.55 ± 0.19. There was also an increase in PM$_{2.5}$ concentration compared to total particulates during the lights off periods. This indicates that PM$_{2.5}$ is less dependent upon bird activity then PM$_{10}$ and that perhaps a possible secondary generation mechanism (i.e. formation of secondary inorganic aerosols) is present.

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References


