Comparison of Ammonia Emissions from Poultry Houses Based on Diurnal Integration vs. Daily Means of Gas Concentration and Building Ventilation Rate

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Abstract
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Keywords
Poultry, air emission, measurement method

Disciplines
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Abstract. Quantification of aerial emissions from animal feeding operations (AFOs) requires the knowledge of both concentration of the constituent of interest and the ventilation rate (VR) through the emitting source. Daily emissions can be and are normally determined from diurnal integration of frequent measurements, referred to as the diurnal integration method (DIM), but is resource intensive. Alternatively, daily emission may be more economically estimated from daily means of concentration and VR, referred to as diurnal means method (DMM). In this study, DMM was compared with DIM in determining daily ammonia (NH₃) emissions from mechanically ventilated laying-hen, turkey and broiler houses under U.S. production conditions. Results show that deviations in daily NH₃ emissions between DMM and DIM methods ranged from as small as < 3% (e.g., for medium age turkey under both cold and warm weather conditions) to as high as 98% (e.g., broiler houses in summer). Deviations were related with coefficient of variation (CV) of VR or NH₃ concentration, although prediction of the deviation using CV of VR and/or NH₃ concentration alone will likely not produce reliable results. The study suggests that caution must be taken when using DMM to estimate daily NH₃ emissions from poultry houses under typical US production conditions.

Keywords. Poultry, air emission, measurement method

Introduction

Baseline data on ammonia emissions from AFOs under the U.S. animal production conditions are needed to enhance the completeness and accuracy of the national emissions inventory (Xin et al., 2003). The two primary parameters needed for determination of ammonia emission rate (ER) are ammonia gas concentration and the air exchange rate or ventilation rate (VR) through the emitting source. Basically, daily emissions can be calculated as the sum of products of concentration and VR at all diurnal integration points during the day. The integration interval can be as short as ten minutes, which may be considered as continuous measurement method, or as long as one day, i.e., using daily mean values of concentration and VR for determination of daily emission.

Continuous measurement of ammonia emissions from AFOs requires ammonia concentration and ventilation rate to be monitored simultaneously and frequently. Chemiluminescence analyzers, photoacoustic monitors, Fourier Transform Infrared (FTIR) analyzers, or electrochemical sensors may be used for the concentration measurement (Xin et al., 2003; Estelles et al., 2010). Continuous measurement is a challenging task as it is both complex and resource-intensive (Liang et al., 2006). An alternative approach to determining daily ammonia emissions from AFOs could be rough strategic, intermittent measurement and use of daily mean values of the gaseous concentration and VR. The latter makes the use of cost-effective wet chemistry-based methods (e.g. impingers) for determining ammonia concentration (Estelles et al., 2010). Mathematically it can be proven that if either concentration or VR remains constant through the day (or any specified measurement period), then the corresponding daily means can be used to yield the same daily emissions as determined using the dynamic readings.
However, because both gaseous (ammonia) concentration and VR likely undergo substantial diurnal variations, ammonia ER derived from daily mean method could deviate from the more accurate values obtained from continuous measurement. It is therefore prudent to delineate the magnitude of such deviation under different production conditions.

The objective of this study was to investigate the magnitude of discrepancy in daily ammonia emissions for poultry houses between two estimation methods: diurnal integration method (DIM), considered as the reference method, and diurnal means method (DMM) or alternative method.

Materials and Methods

Datasets

Continuously monitored NH₃ emissions data at 1-min sampling intervals from three types of mechanically-ventilated poultry production systems were used as the reference dataset from which sub-datasets were selected and used to carry out the comparison between DMM and DIM. The three types of poultry housing involved included a) one high-rise layer house (~250,000 hens capacity) in central Iowa whose dynamic NH₃ emissions were monitored for one year (Li et al., 2012); b) two broiler houses in western Kentucky whose dynamic NH₃ emissions were monitored for seven consecutive flocks (52-day growth period per flock) (Burns et al., 2007); and c) one turkey house in Central Iowa whose dynamic NH₃ emissions were monitored for four consecutive flocks of tom turkeys (140-day growth period per flock, including 35-day brooding period) (Li et al., 2011).

The sub-datasets were selected to cover the effects of season and animal production stage. Table 1 lists the bird and climatic information on the datasets extracted for the analysis. As can be seen, each species involved a total of 12 weeks or more of emissions data.

Table 1. Bird and climatic information for the datasets used in this comparative analysis

<table>
<thead>
<tr>
<th>Poultry Species</th>
<th>Bird Age (day)</th>
<th>Months of Different Seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broiler</td>
<td>1 – 51</td>
<td>Dec – Feb (5.7)</td>
</tr>
<tr>
<td></td>
<td>92 – 97</td>
<td>January (-4.1)</td>
</tr>
<tr>
<td></td>
<td>105 – 110</td>
<td>April (8.0)</td>
</tr>
<tr>
<td></td>
<td>22 – 27</td>
<td>August (24.5)</td>
</tr>
<tr>
<td>Laying Hen*</td>
<td>35 – 48</td>
<td>January (8.1)</td>
</tr>
<tr>
<td></td>
<td>38 – 51</td>
<td>Sept (19.3)</td>
</tr>
<tr>
<td></td>
<td>73 – 86</td>
<td>February (11.1)</td>
</tr>
<tr>
<td></td>
<td>84 – 97</td>
<td>June – July (22.0)</td>
</tr>
<tr>
<td></td>
<td>126 – 139</td>
<td>December (-6.8)</td>
</tr>
</tbody>
</table>

Ta = ambient or outdoor air temperature. *week

Calculations of ammonia ER and deviations

For DIM and DMM, daily ER was quantified using the following equations, respectively:
\[ ER_d = \sum_{j=1}^{n} Q_{ej} \left( \frac{[G]_{ij}}{T_{ij}} - \frac{v_{ij}}{v_m} \times \frac{[G]_{ij}}{T_{ij}} \right) \times 10^{-6} \times T_{std} \times \frac{P_{aj}}{P_{std}} \times \frac{w_m}{V_m} \]  

(1)

\[ ER_d = \bar{Q}_{ed} \times \left( \frac{[G]_{ed}}{T_{ed}} - \frac{\bar{v}_{ed}}{\bar{v}_{ed}} \times \frac{[G]_{ed}}{T_{ed}} \right) \times 10^{-6} \times T_{std} \times \frac{P_{ad}}{P_{std}} \times \frac{w_m}{V_m} \]  

(2)

Where \( ER_d \) is the daily emission rate of ammonia (g d\(^{-1}\) house\(^{-1}\)); \( Q_{ej} \) and \( \bar{Q}_{ed} \) are, respectively, instantaneous and daily VR of the house at field temperature and barometric pressure (m\(^3\) hr\(^{-1}\) house\(^{-1}\)); \([G]_{ij} \), \([G]_{ij} \), \([G]_{ed} \) and \( \bar{G}_{ed} \) are, respectively, instantaneous and daily average readings of gas concentration of incoming and exhaust ventilation air (ppmv). \( T_{ij}, T_{aj}, T_{ed} \) and \( T_{std} \) are, respectively, instantaneous and daily average readings of absolute temperature of incoming and exhaust air (K); \( v_{ij}, v_{aj}, v_{ed} \) and \( \bar{v}_{ed} \) are, respectively, instantaneous and daily average readings of specific volume of incoming and exhaust air (m\(^3\) moist air per kg dry air), calculated from air temperature and RH; \( T_{std} \) is standard temperature (273.15 K). \( P_{aj} \) and \( P_{ad} \) are, respectively, instantaneous and daily average readings of atmospheric barometric pressure at the monitoring site (kPa); \( P_{std} \) is standard barometric pressure (101.325 kPa); \( w_m \) is molar weight of the gas (g mole\(^{-1}\)); \( V_m \) is molar volume of gas at standard temperature (0\(^\circ\)C) and pressure (101.325 kPa) or STP (0.022414 m\(^3\) mole\(^{-1}\)); and \( N \) is the number of dynamic ER measurements per day.

\[ \frac{v_i}{v_e} = \frac{T_i (1 + 1.6078 W_i)(1 + W_e)}{T_e (1 + 1.6078 W_i)(1 + W_e)} \]  

(3)

\[ \frac{\bar{v}_{ed}}{\bar{v}_{ed}} = \frac{T_{ed} (1 + 1.6078 W_{id})(1 + W_{ed})}{T_{ed} (1 + 1.6078 W_{id})(1 + W_{ed})} \]  

(4)

Where \( W_i, W_e, W_{id} \) and \( W_{ed} \) are, respectively, instantaneous and daily average readings of humidity ratio of incoming and exhaust air (kg water vapor kg\(^{-1}\) dry air).

The deviation in NH\(_3\) ER between the DMM method and the DIM (reference) method was calculated with following equation:

\[ s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left( \frac{ER_{dim(i)} - ER_{dmm(i)}}{ER_{dim(i)}} \right) \times 100} \]  

(5)

Where \( ER_{dim} \) and \( ER_{dmm} \) are NH\(_3\) ER obtained with DIM and DMM, respectively (g d\(^{-1}\) house\(^{-1}\)). \( n \) is the number of days. F test was employed to test the significance of the linear relationship between the deviation and the coefficients of variation of indoor NH\(_3\) concentration and VR for the monitored days.

**Results and Discussion**

**Laying hens**

The deviations of the DMM-derived daily NH\(_3\) emissions from the DIM-derived values for the laying-hen house under different seasons are shown in figure 1. Coefficients of variation (CVs)
of the indoor NH$_3$ concentration and VR for the monitored days are listed in table 2. High CV indicates higher degree of diurnal fluctuation in NH$_3$ concentration or VR. From figure 1 and table 2, it can be seen that the smaller diurnal fluctuations in NH$_3$ concentration and VR lead to steeper change in the cumulative deviation distribution, or narrower range of deviation. However, the relatively constant NH$_3$ concentration and VR do not necessarily result in low deviations in daily NH$_3$ emissions by the DMM approach. As shown in figure 1, essentially all of the NH$_3$ emission values obtained with DMM under the warm conditions deviated 12% or more from those obtained with the DIM or reference method. In comparison, for the mild and cold weather, 80 – 85% of the deviations were less than 10%. Although statistical analysis (F-test) revealed the existence of significant relationship (P<0.01) between deviation and CV of VR, the coefficient of determination ($R^2$) was relatively low at 0.6494. Similar results were found between the deviation and CV of NH$_3$ concentration, in which case the $R^2$ value was 0.5104.

Table 2. Coefficient of variation (CV, %) of ammonia concentration and VR during measurement days in the laying-hen house for each selected season (mean± S.D.)

<table>
<thead>
<tr>
<th></th>
<th>warm</th>
<th>mild</th>
<th>cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV[NH$_3$]</td>
<td>19±8</td>
<td>25±11</td>
<td>21±5</td>
</tr>
<tr>
<td>CV[VR]</td>
<td>7±5</td>
<td>37±10</td>
<td>37±24</td>
</tr>
</tbody>
</table>

**Broiler**

The deviations of the DMM-derived daily NH$_3$ emissions from the DIM-derived values for the broiler houses under cold and warm seasons are shown in figure 2. Majority (92%) of the deviations were within ±9% for the winter (cold) season; whereas the deviations for the warm weather conditions were much greater, ranging from ±49% to ±134%. The CV values of the indoor NH$_3$ concentration and VR for the monitored days are listed in table 3. The CV values indicate that NH$_3$ concentrations fluctuated much less in winter (cold weather) than in summer (warm weather). However the degree of fluctuation (relative to the mean) in VR was quite similar for the two seasons. Hence, the much lower deviations for the cold weather were attributable to the smaller diurnal fluctuation in NH$_3$ concentrations. Statistical analysis (F-test) showed highly significant (P<0.01) linear correlation between CV of VR and the deviation, however the regression coefficient of the slope was not significant. Hence, the regression equation could not be used to predict the deviations. For NH$_3$.
concentration, highly significant (P<0.01) linear correlation existed between CV of NH3 and the deviations and the regression coefficient was also significant. However, low coefficient of determination (R^2=0.1386) gave little confidence in predicting the deviation employing the regression equation.

Table 3. Coefficient of variation (CV, %) of ammonia concentration and VR during measurement days in the broiler house for each selected season (mean± S.D.)

<table>
<thead>
<tr>
<th></th>
<th>warm</th>
<th>cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV[NH3]</td>
<td>14±11</td>
<td>39±22</td>
</tr>
<tr>
<td>CV[VR]</td>
<td>106±60</td>
<td>96±61</td>
</tr>
</tbody>
</table>

**Turkey**

The distribution of deviations in daily NH3 emissions from the turkey houses between the two methods is plotted in figure 3. It can be observed from figure 3 that more than 92% of the deviations were within ±8% for birds >10 weeks of age under both cold and warm weather conditions, and almost 80% of the deviations fell in the same range for birds of younger age under cold weather. However, deviations for the younger age (35 – 51 d) in the mild weather varied from 0.4% to 55.3% (accounting for 93% of the data). From the CV values shown in table 4, it can be noted that CV of VR for the younger age under mild weather varied most drastically (197%), meaning large diurnal fluctuations in VR. This drastic fluctuation, coupled with the considerably large CV of NH3, was believed to cause the large deviations for the DMM-derived daily NH3 emissions. The statistical (F-test) analysis did not show significant linear correlation between CV of NH3 concentration and deviation, although highly significant linear correlation was found between CV of VR and deviation (P<0.01). Despite being significant, the coefficient of determination was too low for the regression equation to be used for predicting deviations with the known CV of VR.

Table 4. Coefficient of variation (CV, %) of ammonia concentration and VR during measurement days in the turkey house for each selected season (mean± S.D.)

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Medium</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cold</td>
<td>warm</td>
<td>cold</td>
</tr>
<tr>
<td>CV[NH3]</td>
<td>23±13</td>
<td>27±14</td>
<td>15±5</td>
</tr>
<tr>
<td>CV[VR]</td>
<td>24±33</td>
<td>118±87</td>
<td>21±13</td>
</tr>
</tbody>
</table>

**Conclusions**

Uncertainty of daily ammonia (NH3) emissions from mechanically-ventilated poultry (broiler, layer and turkey) houses under U.S. production conditions associated with an alternative estimation method was investigated. The alternative method, referred to as diurnal means method (DMM), employs daily mean values of NH3 concentration and ventilation rate (VR) in
calculating the daily emissions. The DMM-derived values were then compared with those obtained through integration of dynamic emissions throughout the day, referred to as diurnal integration method (DIM) or the reference method. The following observations and conclusions were made from this study:

- For the laying-hen house, the DMM-derived daily NH\textsubscript{3} emissions deviated 12% or greater from the DIM-derived (reference) values for warm weather conditions (average ambient air temperature of 24.5 °C); whereas majority of the deviations (80-85% of the data points) were within ±10% for the cold or mild weather conditions (-4.1 to 8.0 °C ambient air temperature).

- For the broiler houses, the majority (92%) of the deviations were within ±9% for the winter season (average air temperature of 5.7°C), whereas the deviations for the warm weather conditions (average ambient temperature of 23.6 °C) ranged from ±49% to ±134%.

- For the turkey house, more than 92% of the deviations were within ±8% for birds >10 weeks of age under both cold and warm weather conditions, and almost 80% of the deviations fell in the same range for birds of younger age under cold weather. However, deviations for the younger age (35 – 51 d) under the mild weather condition varied from 0.4% to 55.3%.

- Caution needs to be exercised when using DMM to estimate daily NH\textsubscript{3} emissions from poultry houses under typical US production and management conditions to avoid considerable over- or under-estimation of the actual NH\textsubscript{3} emissions.

References


