Ammonia emissions from a naturally and a mechanically ventilated broiler house in Brazil

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Key words:
emission factor
inventory
ventilation rate
tropical conditions

ABSTRACT
This study was conducted with the aim of monitoring NH₃ emissions from a mechanically and a naturally ventilated broiler house (MVB and NVB, respectively) and calculate their ammonia emission factors (fNH₃). Bird stocking density was 13.5 and 11.1 birds m⁻² for the MVB and NVB, respectively. The marketing age was 43 days and bedding consisted of dried coffee husks in its first time of use. Ventilation rates were calculated with the metabolic carbon dioxide mass balance method. Values of fNH₃ were 0.32 ± 0.10 and 0.27 ± 0.07 g bird⁻¹ d⁻¹ for the MVB and NVB, respectively, and are in agreement to what was presented in other studies performed under similar conditions. The fNH₃ estimated on yearly basis was 58 g bird-place⁻¹ year⁻¹. It was concluded that the different types of ventilation system between the studied broiler barns did not significantly affect emissions in the modeling process. The results obtained help providing reliable methodology for the determination of a solid database on NH₃ emission factors for tropical conditions that can be used for future inventories, when performed in a sufficient number of barns that is representative for the Brazilian scenario.

Emissão de amônia de galpões de frangos de corte com ventilação natural e mecânica no Brasil

RESUMO
Este estudo foi conduzido com o propósito de monitorar a emissão de amônia (NH₃) de um galpão de frango de corte com ventilação mecânica e outro com ventilação natural (GVM e GVN, respectivamente) e, por fim, calcular seus fatores de emissão de NH₃ (fNH₃). A densidade de alojamento das aves foi 13.5 e 11.1 aves m⁻² para o GVM e GVN, respectivamente. As aves foram removidas para o abate aos 43 dias e a cama consistiu de casca de café, em primeiro uso. As taxas de ventilação nos galpões foram calculadas com base no método do balanço de dióxido de carbono. Os valores de fNH₃ obtidos foram 0.32 ± 0.10 e 0.27 ± 0.07 g ave⁻¹ d⁻¹ para o GVM e GVN, respectivamente, e estão de acordo com o que foi apresentado em outros estudos independentes, realizados em condições similares. O valor estimado de fNH₃ em base anual foi 58 g ave-alocada⁻¹ ano⁻¹. Concluiu-se que o tipo de sistema de ventilação adotado em cada galpão não afetou, de modo significativo, a parametrização da equação de emissão no processo de modelagem. Os resultados validam a acurácia da metodologia de determinação da emissão de amônia para galpões nas condições brasileiras e contribuem para a formação de base de dados confiável de fatores de emissão em climas tropicais, quando aplicada em um número suficiente de galpões que seja representativo do cenário brasileiro.

INTRODUCTION

At global scale, Brazil is the third biggest producer and first ranked exporter of broiler chicken (MAPA, 2013). However, even with the considerable magnitude of animal production systems, very little effort has been given to estimate ammonia (NH₃) emission factors (fNH₃) from poultry houses under the unique Brazilian conditions: tropical climate and non-insulated broiler houses, that can either be mechanically or naturally ventilated (Tinôco, 2001).

Studies on NH₃ emissions from confined animal operations such as broiler housing systems have been carried out around the world since at least 30 years. One of the outcomes of scientific research on NH₃ emissions from animal activity that have become a paradigm in the field is that excess NH₃ in the atmosphere is detrimental to natural ecosystems (Galloway et al., 2008). The countries that first started their emission studies are now at either of the following stages: (1) conducting emissions inventories, (2) developing mitigation techniques and
In recent years, a few studies on \( \text{NH}_3 \) emissions conducted in Brazil have evidenced an increasing interest of the scientific sector on that issue. For instance, Miraglia et al. (2004) reported one of the first studies on the development of a statistical model for \( \text{NH}_3 \) emissions from Brazilian broiler houses, based on correlation of emissions with variables such as pH, environmental temperature and relative humidity; Lima et al. (2011) presented \( \text{NH}_3 \) emission factors for mechanically ventilated broiler barns under different litter conditions (new vs. used) combined with different stocking densities; Osorio (2010) developed a practical method for determining \( \text{NH}_3 \) emission rates in naturally ventilated Brazilian broiler barns; Souza & Mello (2011) presented an attempt of inventory of \( \text{NH}_3 \) emissions from all domestic animal categories over the state of Rio de Janeiro, however, using emission factors from studies performed in Europe and the U.S.A, and thus under temperate climate conditions. Some effort has also been given on the evaluation of mitigation strategies to reduce Brazilian \( \text{NH}_3 \) emissions, such as the study reported by Medeiros et al. (2008), who evaluated the effect of chemical additives to the litter as a means to reduce \( \text{NH}_3 \) volatilization.

However, given the magnitude and variability of Brazilian territorial area and poultry production, the number of studies dedicated to determine \( \text{NH}_3 \) emissions from this sector is very limited. Furthermore, because the majority of the livestock barns in Brazil are naturally or semi-naturally ventilated, including most poultry barns (Tinôco, 2001; Nazareno et al., 2009; Menegali et al., 2013), specific methodologies for determination of \( \text{NH}_3 \) emission rates (ER) in these conditions must be developed, to strengthen the existent database on emission factors of this pollutant.

Hence, this study was conducted with the purpose of simultaneously monitoring \( \text{NH}_3 \) emissions from a typical mechanically and also a typical naturally ventilated Brazilian broiler houses and calculate their ammonia emission factors \( f_{\text{NH}_3} \).

**Material and Methods**

The study was conducted in two commercial broiler barns, one naturally ventilated (NVB) and the other mechanically ventilated (MVB), both located on the same farm in the state of Minas Gerais, Brazil. The MVB had a dimension of 120.0 × 14.0 × 2.5 m (L × W × H), fiber-cement tile roof, and a polyurethane drop ceiling (the same material as used for the sidewall curtains). The sidewall curtains were closed most of the time, and the ventilation was provided with 8 newly installed exhaust fans (specified capacity of 39,329 m\(^3\) h\(^{-1}\) each at 1.5 HP and static pressure of 12.0 Pa) placed on the west end of the building. Fresh air was brought into the barn through air inlets located at the east end, and the inlet openings were adjusted manually, as needed.

The ventilation program was based on indoor air temperature and consisted of 7 stages including minimum ventilation at the early age of the birds (< 3 week). The barn had an initial placement of 23,100 male Cobb\(^\circ\) chicks (stocking density of 13.5 birds m\(^{-2}\)), and freshly dried coffee husks, serving as floor bedding, which was never used to raise broilers before. Chicks were reared up to marketing age of 43 days.

The NVB had the dimension of 75 L × 12 W × 2.75 H m. It was roofed with ceramic tiles and polyurethane drop ceiling (same as used for sidewall curtains). Ventilation was provided through manual opening of the sidewall curtains (fully open, half open, or nearly closed). The initial bird placement was 10,000 female Cobb\(^\circ\) (stocking density of 11.1 birds m\(^{-2}\)), and had the same kind of non-used litter described for the MVB. This flock was also reared up to a marketing age of 43 days.

The lighting program was similar for both sex/barns and consisted of 1 hour dark between the ages 2-10 days; then the number of dark hours was increased to 9, and then decreased again to 8, 7 and 6 hours of dark at the ages of 22, 23 and 24 d, respectively. The light schedule then remained the same until bird age was 39 days, from whereon the number of dark hours was set to 5, decreasing one hour a night till pick up day.

Measurements of gaseous concentrations of \( \text{CO}_2 \) were performed in order to calculate air flow rate throughout the barns through the method proposed by Pedersen et al. (2008) with a hand-held sensor (model AZ 77535 \( \text{CO}_2 \) concentration, AZ Instrument Corp., Taichung City, Taiwan) that had a measuring range of 0-100 ppm\( _o \), resolution of 1 ppm\( _o \) and accuracy of ± 30 ppm\( _o \) ± 5% of the reading (according to specifications and calibrated at the factory). Concentrations of \( \text{NH}_3 \) were measured with an electrochemical detector “Gas Alert Extreme \( \text{NH}_3 \) Detector” (BW Technologies®, Oxfordshire, UK), with a measuring range of 0-100 ppm\( _o \), operating temperature of -4 and 40 °C, and accuracy of 2% (at 25 °C and relative humidity between 15 to 90%). Both the \( \text{CO}_2 \) and \( \text{NH}_3 \) sensors were calibrated at the factory prior to the start of the study.

For the MVB, background or outdoor \( \text{CO}_2 \) and \( \text{NH}_3 \) concentrations were measured at the inlet, nearby the east end of the building while indoor concentrations were measured at the outlet (upstream to the exhaust fans).

For the NVB, indoors gaseous concentrations of \( \text{CO}_2 \) and \( \text{NH}_3 \) were measured at three different distances along the central axis of the building (at 18, 36 and 54 m from the eastern extremity of the barn), and at two different heights (0.50 and 1.25 m above the litter). Outdoor concentrations were measured at three different points along the south side of the building, which was considered the air inlet, as during the experimental period the wind was consistently coming from the south.

Data collection of concentrations of \( \text{CO}_2 \) and \( \text{NH}_3 \) was done once every three hours, for a 48 hours period, performed weekly throughout the 7 week grow-out period.

Building ventilation rate was estimated through Eq. 1 (Pedersen et al., 2008).
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\[
Q = \frac{A \cdot (CO_2)_{\text{metabolic}} + (CO_2)_{\text{litter}}}{\Delta[CO_2]} \tag{1}
\]

where:
- \( Q \) - building ventilation flow, m\(^3\) d\(^{-1}\) hpu\(^{-1}\)
- \( A \) - relative animal activity, dimensionless (Pedersen et al., 2008)
- \((CO_2)_{\text{metabolic}}\) - metabolic \(CO_2\) production by the animals, m\(^3\) d\(^{-1}\) hpu\(^{-1}\)
- \((CO_2)_{\text{litter}}\) - \(CO_2\) released by the litter, m\(^3\) d\(^{-1}\) hpu\(^{-1}\)
- \(\Delta[CO_2] = ([CO_2]_{\text{indoors}} - [CO_2]_{\text{outdoors}})\), the indoor and outdoor \(CO_2\) concentrations, respectively

Ventilation rates in m\(^3\) d\(^{-1}\) hpu\(^{-1}\) were then converted in m\(^3\) d\(^{-1}\) bird\(^{-1}\) by using the conversion factor proposed by Pedersen et al. (2008) of 1 hpu (heat production unit) at 1000 W of total heat at 20°C. Additionally, a correction factor for metabolic \(CO_2\) production was performed with temperature measurements made in the barns. A more detailed algorithm for the calculation of \(Q\) for both buildings was developed and described in the work presented by Mendes et al. (2014).

Daily \(NH_3\) ER was calculated with Eq. 2.

\[
NH_3\text{ER} = \frac{Q \cdot \Delta[NH_3] \cdot W_{NH_3}}{V_{NH_3}} \tag{2}
\]

where:
- \( Q \) - building ventilation flow, m\(^3\) d\(^{-1}\) hpu\(^{-1}\)
- \( NH_3\text{ER} \) - ammonia emission rate, g bird\(^{-1}\) d\(^{-1}\)
- \( \Delta[NH_3] = ([NH_3]_{\text{indoors}} - [NH_3]_{\text{outdoors}})\), the averaged indoor and outdoor \(NH_3\) concentrations, respectively ppm,
- \( W_{NH_3} \) - molecular weight of \(NH_3\) (17.031 g mol\(^{-1}\))
- \( V_{NH_3} \) - molar volume of \(NH_3\) at standard temperature (25°C) and pressure (1 ATM, 0.0245 m\(^3\) mol\(^{-1}\))

The ANOVA was performed for each model using the procedure PROC GLM in SAS®. In order to test whether the extra degrees of freedom included in the full model has a significant impact on the estimate of \(NH_3\) ER, an extra sum of squares test (Ramsey & Schafer, 2002) was performed from the ANOVA output obtained from each model. Additionally, an analysis of regression was performed with PROC REG in SAS® for the determination of model coefficients.

With the adjusted equation, cumulative \(NH_3\) emission data was calculated throughout a one year period using a methodology similar to that of Gates et al. (2008), by incorporating downtime between flocks and variation in days to achieve market weight, mimicking the effect of multiple flocks in the same barn.

**Results and Discussion**

Mean \(f_{NH_3}\) obtained from the MVB and NVB were 0.32 \(\pm\) 0.10 and 0.27 \(\pm\) 0.07 g bird\(^{-1}\) d\(^{-1}\), respectively, and are presented in Table 1. The results of the paired t-test indicated that the mean difference in daily \(NH_3\) ER measured in the MVB and NVB was 0.05 \(\pm\) 0.07 g bird \(d\) \(^{-1}\) and was not significantly different from zero (\(p = 0.394\)). This outcome suggests that for the studied MVB and NVB, the use of different ventilation systems (mechanical vs. natural) when combined with different stocking density allocations (13 and 11 birds m\(^{-2}\)) did not allow for different ERs.

The daily \(f_{NH_3}\) obtained from similar studies performed in Brazil and abroad are also presented in Table 1. Unfortunately, not all the emission factors presented in the considered studies were accompanied by an uncertainty estimate, such as a standard error (SE), which makes it difficult to draw comparisons. The emission factor presented by Lima et al. (2011) of 0.78 g bird \(d\) \(^{-1}\) was relatively higher than the ones presented in this study, even though the monitoring study performed by those authors also took place in Brazil. The difference might be due to the fact that in the study of Lima et al. (2011) the broiler barns were ventilated with lower mean ventilation rates. Lower levels of air exchange rate enhance conditions for \(NH_3\) volatilization from litter in MVBs, causing, thus, an increase in emission rates. As
for a comparison with the $f_{\text{NH}_3}$ obtained by Osorio (2010), in a study performed inside a NVB, the value of $0.28 \pm 0.16$ g bird$^{-1}$ d$^{-1}$ was comparable with the values obtained for both barns of this study, this similarity might be due to the fact that the broiler barns from both studies were located in the same state, and presumably having the similar types of management, and feed protein content.

Considering the comparison of $f_{\text{NH}_3}$ obtained in this study with those obtained in the U.S.A and northern Europe, data in Table 1 indicate that the values obtained from two American studies (Wheeler et al., 2006; Burns et al., 2007) are considerably higher ($0.47$ and $0.63$ g bird$^{-1}$ d$^{-1}$, respectively). However, data from this study seems to fit well with those presented by Groot Koerkamp et al. (1998) for four northern European countries (Denmark, England, Germany and the Netherlands), varying from $0.21$ to $0.47$ g bird$^{-1}$ d$^{-1}$. It is speculated that the emission factors for the U.S.A. are considerably higher than those of Northern Europe and the ones obtained in this study potentially due to reuse of litter over a couple of cycles, while in European farms new litter is used every cycle.

The calculated F-statistics of the regression analysis performed for reduced and full models were higher than the critical F-values for both models at a significance level of 1%, suggesting that both models presented good fit to the experimental data (Table 2).

The test of significance for the coefficients $\beta_1$, $\beta_3$, and $\beta_5$ in Eq. 3 indicated that all of them are significantly different than zero ($p$-value < 0.001), and results are presented in Table 3. A comparison of the estimates of the coefficients obtained for

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\beta_1$ (g bird$^{-1}$ d$^{-1}$)</th>
<th>$\beta_2$ (g bird$^{-1}$ d$^{-1}$)</th>
<th>$\beta_3$ (g bird$^{-1}$ d$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced model</td>
<td>-3.5 ± 0.4</td>
<td>0.24 ± 0.03</td>
<td>-0.0034 ± 0.0004</td>
</tr>
<tr>
<td>Full model: MVB</td>
<td>-4.0 ± 0.6</td>
<td>0.27 ± 0.04</td>
<td>-0.0040 ± 0.0006</td>
</tr>
<tr>
<td>Full model: NVB</td>
<td>-3.2 ± 0.6</td>
<td>0.21 ± 0.04</td>
<td>-0.0028 ± 0.0006</td>
</tr>
</tbody>
</table>

*all coefficient estimates were significantly different than zero at a confidence level of 0.95

Table 1. Ammonia emission factors ($f_{\text{NH}_3}$) estimated from this study and other studies

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type of ventilation system</th>
<th>NH$_3$ER (mean ± SE, g bird$^{-1}$ d$^{-1}$)</th>
<th>Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>Mechanical</td>
<td>0.32 ± 0.10</td>
<td>MG/Brazil</td>
</tr>
<tr>
<td>This study</td>
<td>Natural</td>
<td>0.27 ± 0.07</td>
<td>MG/Brazil</td>
</tr>
<tr>
<td>Osorio (2010)</td>
<td>Natural</td>
<td>0.28 ± 0.16</td>
<td>MG/Brazil</td>
</tr>
<tr>
<td>Lima et al. (2011)</td>
<td>Mechanical</td>
<td>0.78</td>
<td>SP/Brazil</td>
</tr>
<tr>
<td>Burns et al. (2007)</td>
<td>Mechanical</td>
<td>0.47</td>
<td>KY/USA</td>
</tr>
<tr>
<td>Wheeler et al. (2006)</td>
<td>Mechanical</td>
<td>0.63</td>
<td>KY &amp; PN/USA</td>
</tr>
<tr>
<td>Groot Koerkamp et al. (1998)</td>
<td>Mechanical</td>
<td>0.21-0.47</td>
<td>Northern Europe</td>
</tr>
</tbody>
</table>

1For comparison purposes, only broiler barns with new litter were considered; 2Standard error of the mean; 3Minas Gerais and São Paulo states; 4Kentucky and Pennsylvania states; 5Denmark, England, Germany and the Netherlands

113 11.12
Residual 111 04.07 0.04

Total 113 11.12
Reduced model 003 06.87 2.29 59.83 **
Residual 111 04.25 0.04

Total 113 11.12
Full model 005 09.44 3.03 94.71 **
Residual 111 06.06 0.04

Total 113 11.12

Table 2. Summary of analysis of variance (ANOVA) for the regression of NH$_3$ emission rate (NH$_3$ER, g bird$^{-1}$ d$^{-1}$) as a function of bird age (x, day) only (reduced model); the regression of NH$_3$ emission rate against bird age and type of barn (NVB or MVB) (full model)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean sum of squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced model</td>
<td>3</td>
<td>6.87</td>
<td>2.29</td>
<td>59.83 **</td>
</tr>
<tr>
<td>Residual</td>
<td>111</td>
<td>4.25</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
<td>11.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full model</td>
<td>6</td>
<td>7.05</td>
<td>1.17</td>
<td>32.01 **</td>
</tr>
<tr>
<td>Residual</td>
<td>111</td>
<td>4.07</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
<td>11.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**The calculated F-statistic is higher than the critical F-statistic from a F distribution table (Ramsey & Schafer, 2002) at a confidence level of 0.95

Table 3. Results from regression analysis for the relationship between bird age and NH$_3$ emission rate, according to the type of model (reduced and full)

The negative sign of the coefficient $\beta_3$ indicates that the daily NH$_3$ER increases with bird age, reaching a maximum, and starts to decrease. The behavior of increasing NH$_3$ER with increase in age can be explained by the fact that the manure accumulated in the new litter gradually starts to release NH$_3$, only being detected by our NH$_3$ sensor at $x > 21$ d. However, the sudden increase in ventilation rate that happened when the birds reached the fifth week of age, as an attempt to keep thermo neutrality conditions in the barns (Figure 1), presumably causing litter moisture content to decrease with consequent reduced volatilization of NH$_3$, and thus reducing NH$_3$ER.

Additionally, the results of the extra sum of squares test, performed to compare full and reduced models are presented in Table 4, and indicate that the models are not significantly different in predicting NH$_3$ER, with a calculated F-statistics (1.55) that is less than the critical F-value (> 3.95). This outcome suggests that the extra complexity represented by the full model with the inclusion of the factor ‘type of barn’ did not make the model fit better than the reduced to NH$_3$ER data. For this reason, the full model was discarded and further data analysis and discussion in this paper were done with the data sets from MVB and NVB pooled together.
The adjusted model obtained for the relationship between daily NH$_3$ ER and bird age for the pooled data sets from MVB and NVB were used to calculate cumulative NH$_3$ emissions throughout an entire cycle of 43 days, and the results are graphically represented in Figure 2, a similar procedure was performed by Gates et al. (2008) for broilers housed in a mechanically ventilated barn with litter of first use and stocked at 15 birds m$^{-2}$, whose results are also included in Figure 2.

The observation of the curves in Figure 2 suggests that the increase in cumulative NH$_3$ emissions throughout a complete rearing cycle of 43 days for the barns used in the current study are relatively lower as compared to that of the study performed by Gates et al. (2008). It is speculated that the difference might be due to factors that play an important role on NH$_3$ emissions such as distinct feed protein content, mean barn ventilation rate and litter reusing practices.

In order to estimate f$_{NH3}$ in an yearly basis for the barns monitored in this study, cumulative emissions from multiple flocks throughout a year were calculated using the adjusted equation that resulted from the pooled data set, with coefficients shown in Table 3. In order to comply with the sanitary safety period between flocks, a gap of 14 days between flocks was used. It was assumed that at the start of every flock, only new litter was used, meaning that no NH$_3$ was emitted during the 14 d sanitary safety period. Similar calculations were performed with data presented by Gates et al. (2008). A graphical representation of the simulated cumulative NH$_3$ emissions is presented in Figure 3.

Simulated f$_{NH3}$ on yearly basis were 58 g bird-place$^{-1}$ year$^{-1}$, while the f$_{NH3}$ simulated from the study of Gates et al. (2008) was 141 g bird-place$^{-1}$ year$^{-1}$. The discrepancy with the yearly f$_{NH3}$ obtained in this study with that from Gates et al. (2008) might have arisen from factors such as differences in farm management, feed protein content offered to the birds and/or distinct mean ventilation rate. Winkel et al. (2011) arrived at 72 ± 25 g bird-place$^{-1}$ year$^{-1}$, averaged from several monitored mechanically ventilated broiler barns in the Netherlands, this value is much closer to the one obtained in this study than the one obtained from Gates et al. (2008), for the U.S.A. From these results, it is speculated that northern American commercial broilers are fed with very high protein content feed formulas, and the northern European countries, such as the Netherlands, have been implementing feed manipulation techniques to reduce NH$_3$ emissions as explained before in this paper.

Another important aspect brought up by the study of Winkel et al. (2011) in the calculation of f$_{NH3}$ was the inclusion of a standard deviation to estimate the emission uncertainty.
between barns. According to Ogink et al. (2008), including a spatial variability factor (uncertainty between farms) in the determination of \( f_{NH3} \) is just as important as considering variability due to seasonal or distinct management system (uncertainty within farm). Hence, it is recommended that the methodology described here be applied to barns located in different farms, so that a measure of uncertainty amongst farms can be included in the calculation of \( f_{NH3} \).

**Conclusions**

1. The method for determination of NH\(_3\) ER applicable to both barns, with the ventilation rates being calculated through the CO\(_2\) mass balance method, was successful.
2. Estimated values of \( f_{NH3} \), on a daily bases, were 0.40 ± 0.12 and 0.32 ± 0.08 g bird\(^{-1}\)d\(^{-1}\) for the MVB and NVB, respectively.
3. The types of ventilation system did not have a significant impact on the parameters of the NH\(_3\) emission equation, being thus discarded in the modeling.
4. Simulated value of \( f_{NH3} \), on yearly basis, was 58 g bird-place\(^{-1}\)year\(^{-1}\).

**Acknowledgements**

The authors would like to acknowledge the Brazilian government research fomenting agencies: CNPq (National Council for Research and Development), CAPES (National Council for Improvement of Highly Educated Personnel) and FAPEMIG (Foundation for Support of Scientific Research in the State of Minas Gerais).

**Literature Cited**


