Post-Effect of Ammonia on Energetics of Laying Hens at High Temperatures

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INTRODUCTION

Poultry producers continue to search for ways of maximizing operation profits. Decreasing winter ventilation rate of a laying house is one of the practices that has drawn attention. Decreased ventilation rates increase the air temperature of the laying house, resulting in a reduced maintenance energy requirement for the hen and which improves feed efficiency (grams of feed/grams of egg). Feed efficiency is generally improved as environmental temperature increases until additional work is required by the bird to increase its heat loss. Elevated environmental temperature between 20 and 30 °C, compared to 7 to 21 °C (Scott et al., 1983) (ASAE recommendation for maximum egg production rate) reduces both egg size and maintenance energy requirement. In the United States jumbo-size eggs are usually of less value compared to regular-size eggs on a per unit weight basis. Therefore, a reduction in egg size would lead to a higher cash return to the producer based on price per unit of egg weight.

One problem which accompanies reduced ventilation rate is deterioration of air quality inside the poultry facility, adversely affecting the hens’ health, production, and egg quality (Charler and Payne, 1966a; Quarles and Kling, 1974; Carr and Nicholson, 1980; Reece and Lott, 1980). Ammonia is usually found to be the most abundant air contaminant in poultry facilities, varying between 15 and 90 ppm (Valentine, 1964). Ammonia concentration is dependent on factors such as temperature, humidity, animal density, and ventilation rate of the facility.

Histopathological signs of damage to the respiratory tract in chickens have been observed following NH₃ exposure. Ciliary loss and increases in mucus-secreting goblet cells have been detected in both nasal and tracheal epithelia of birds exposed to 30 to 100 ppm NH₃ for only a week or less (Anderson et al., 1964; Al-Mashhadani and Beck, 1985). Al-Mashhadani and Beck (1985) also found an increase in the thickness of atrial walls and a shrinking of air capillaries with increasing NH₃ concentration.

These histopathological changes caused by NH₃ may alter the latent heat loss response of the hen under heat stress conditions. However, this was not noted at 27 °C (Al-Mashhadani and Beck, 1985). Under high Tᵥ, the hen could perceive a higher Tᵥ than that being measured because of the potentially reduced capacity for evaporative heat loss. This reduced evaporative heat loss could result in less feed energy consumption to maintain homeothermy and thus lower productivity.

The objective of this study was to determine whether the hen’s exposure to a typical poultry house NH₃ environment during a simulated winter condition would impair subsequent evaporative heat loss response of the hen in simulated summer conditions.

MATERIALS AND METHODS

Thirty White Leghorn laying hens were initially housed in the laying house at the University of Nebraska Poultry Farm for fourteen months, and then moved to the Bioenergetics Laboratory of the Agricultural Engineering Department. There they were acclimated to a Tᵥ of 22 °C and a relative humidity (RH) of 40% for 7 days or longer. Hens were then placed individually, one each day, into environmental chambers (0.8 × 0.8 × 0.8 m) containing an average NH₃ concentration of 60 or 10 ppm, and were kept there for 30 days. After 30-day exposure, hens were removed from the chambers to individual cages in an environment of 5 ppm NH₃ at 22 °C.

Acknowledgments: The authors wish to thank Kit Lee and Auday Maki for their cooperation with the SEM procedures; and Joe Zulovich and Gary Sherman for their assistance in the operation of experimental instrumentation.
and 40% RH) for a 7-day recovery period. NH₃ levels inside the 10 ppm chambers were controlled by cleaning the chambers once every four or five days. NH₃ levels inside the 60 ppm chambers were obtained by passing the flow-controlled air stream and 10% NH₃ gas (standard purity with argon balance) into a mixing box inside the 60 ppm chambers were obtained by passing the flow-controlled air stream and 10% NH₃ gas (standard purity with argon balance) into a mixing box before entering the chambers. NH₃ levels were checked once a day with Kitagawa NH₃ detector tubes* (5 to 260 ppm) by the length-of-stain.

Following the recovery period, hens were tested one at a time for 16 h in an NH₃-free environment at Tₑ of 25, 29, 33 or 37 °C, associated with a dew-point temperature of 13 to 18 °C. The two initial NH₃ levels and the four subsequent Tₑ levels produced a total of 8 NH₃-temperature treatment combinations. Each treatment combination had four replications except for the 25 °C treatment which had three replications. Fig. 1 shows a schematic diagram of the experimental procedures.

The Nebraska Partitional Calorimeter equipped with an infrared moisture analyzer, as described by Olson and DeShazer (1974), was used to measure sensible and latent heat losses of the bird continuously. Birds were provided with water and feed at all times while in the calorimeter for the period of 24 h starting at 12 noon. A metal water tank with a drinking cup was attached on the side of the bird cage to provide water; a feeder was suspended in front of the cage. A plastic dropping pan containing used engine oil was placed under the cage to collect feces and prevent fecal moisture from evaporating and contributing to the moisture content of the air. Respiratory rate (RR) was recorded with a Beckman Type RB Dynograph using a Statham low pressure transducer and a 14 mm diameter bellow around the hen’s thorax.

The testing hours used in data analysis were from 8 pm until 12 noon of the next day, i.e., 16 h. This provided at least 3 h for stabilization of temperatures in the calorimeter, the drinking water, and the oil in the dropping pan. Lighting was provided during the test between 7 am and 10 pm which was the photo period used in the environmental chambers. Thus there were 7 h of light and 9 h of dark provided for the birds during data collection. Air entered the calorimeter at a dry-bulb temperature of 23 °C and a dew-point temperature of 12 °C. Air exchange rate in the calorimeter was 0.9 L/s. Heat loss data (both sensible and latent) were collected once every 4 min. Respiratory rate was sampled for 1 min out of every 10. Feed intake was measured by weighing the feeder before and after the test. Egg production was recorded. Hens were weighed to a resolution of 5 g with a Toledo balance scale before and after test.

Lung samples of representative experimental birds were taken and scanning electron microscopy (SEM) was conducted just before birds were brought to the laboratory and immediately after testing in order to monitor changes in surface ultrastructure of the lung due to NH₃ exposure and following recovery. The procedure for the SEM is described by Al-Mashhadani and Beck (1985).

RESULTS AND DISCUSSION

Surface Ultrastructure of Lungs

The SEM images showing the surface ultrastructure of lungs before NH₃ treatment and after calorimetry measurements are presented in Fig. 2. From these images, the lungs of hens before acclimation (in the laying house) appear to have clearer atrial infundibula (gas exchange areas) than those of hens 7 days after treatment. Further, the 10 ppm NH₃-treated lungs had slightly clearer atrial infundibula than the 60 ppm NH₃-exposed lungs. Thus, lungs exposed to ammonia did appear to show some evidence of damage, apparently accumulation of cell debris, even after 7 days of recovery. Effect of recovery was consistent with expected levels (Doster, 1985).

Respiratory Rate

RR increased with increased environmental temperature (Table 1). Although not significantly different (P>0.05), RR of hens exposed to 60 ppm NH₃ tended to have reduced values when compared to the 10 ppm NH₃-treated hens, averging 17, 24, and 8% less at 25, 29, and 33 °C respectively. Charles and Payne (1966b) reported a 7 to 24% reduction in RR when hens were exposed to 100 ppm NH₃, a response caused directly by NH₃. Effects of histological damage on RR might have been expected to cause an increase in RR to provide adequate gaseous exchange across impaired surfaces. This appeared to be the case at 37 °C, where 60 ppm exposed hens had slightly higher RR than 10 ppm exposed hens.

Heat Losses

The latent heat loss of hens exposed to 60 ppm NH₃ at 25 °C was slightly higher than that of hens exposed to 10 ppm NH₃ (Table 1). The greater latent heat loss in the high NH₃ group possibly resulted from the occurrence of

Fig. 1—Schematic diagram of experimental procedure.

*Product names are presented in this paper only for the clarity of the report and does not imply endorsement of the product by the author or by the University of Nebraska.
slightly slower but deeper breathing at the lower $T_s$, resulting in more air expired and thus higher respiratory heat loss. The slower RR at the lower $T_s$ for the 60 ppm NH$_3$-exposed birds was consistent with the report that respiration of birds exposed to NH$_3$ tends to be slow and deep to minimize discomfort to their respiratory system (Eaton, 1971). As $T_s$ increased to 33 °C, hens started panting and the difference in depth of breathing tended to be smaller. Increased $T_s$ caused higher latent heat loss and more moisture generation. Because of the hen’s panting and increase in moisture content of the air, the latent heat loss of the hen through respiration would be less effective on a per breath basis.

Sensible heat loss values for both NH$_3$ levels were similar and decreased linearly with increasing $T_s$ (Table 1). This was as expected since NH$_3$ exposure would not change the thermal gradient between the bird and its surroundings which is the driving force for sensible heat dissipation.

The total heat loss pattern was similar to that of latent heat loss. As $T_s$ approached warm and hot conditions of 33 and 37 °C, total heat loss of hens for both NH$_3$ levels gradually increased. This increase in heat loss was due to the active thermal regulatory mechanism of the hen, e.g., panting, and the possible rise in body temperature.

### Table 1. Energetic Responses and Respiratory Rate of Hens at Air Temperatures of 25 °C, 29 °C, 33 °C, Or 37 °C After Subjected to 30-Day Ammonia Exposure of 10 ppm or 60 ppm with 7-Day Recovery

<table>
<thead>
<tr>
<th>Air temp. °C</th>
<th>Rate of heat losses* W/kg0.75 (W/hen)</th>
<th>Resp. rate* Br./min</th>
<th>Eff. of EHL** W/kg0.75·Br.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 ppm</td>
<td>60 ppm</td>
<td>10 ppm</td>
</tr>
<tr>
<td>25</td>
<td>4.3</td>
<td>3.2</td>
<td>7.5</td>
</tr>
<tr>
<td>29</td>
<td>2.9</td>
<td>3.1</td>
<td>6.0</td>
</tr>
<tr>
<td>33</td>
<td>2.1</td>
<td>4.8</td>
<td>6.9</td>
</tr>
<tr>
<td>37</td>
<td>0.9</td>
<td>7.2</td>
<td>8.1</td>
</tr>
</tbody>
</table>

*Values between ammonia levels are not significantly different at 5%.
†kg0.75 is metabolic body weight of the hen.
‡Sensible Heat Loss rate
§Latent Heat Loss rate
‖Total Heat Loss rate
**Evaporative Heat Loss rate
the calorimeter remained fairly constant in body weight. Body weight at the end of test, reduced by 3 to 8% of the
energy content of egg.

Elevated temperature increased the metabolic rate of the hen, as there was less difference in heat loss at the higher
temperature. Hens that laid eggs while in the calorimeter were found to have lower
production. Birds were found to lay soft-shelled eggs and to excrete liquid feces at T^ of 33 °C and above.

Feed Energy Intake and Energy Retained
Feed energy intake values of the hens during acclimation, exposure, and recovery are presented in Table 2 and during calorimetry measurement in Table 3. The feed energy intake values presented in Table 2 were
within the range found in the literature (Riskowski et al., 1977; Nasser, 1986). Feed intake for the hens in the calorimeter at 25 °C was 8.5% less than for the birds during the acclimation period. There was no significant
difference (P>0.05) between the two NH3 levels feed energy intake at any T^, but energy intake decreased with increasing T^, with a slight plateau occurring between 29 and 33 °C. Also, it can be seen from Table 1 and 3 that the total heat loss of the hen was greater than its energy intake except for the treatment of 10 ppm of NH3 at 25 °C. The 2.5 W deficit in energy retention rate for hens exposed to 60 ppm NH3 at 25 °C compared to hens exposed to 10 ppm NH3 at 25 °C can be translated into 33 g less of egg per day (using 6.5 kJ/g as the energy content of egg). This energy deficit was mainly due to the additional latent heat loss of the 60 ppm NH3 exposed hens. There was less difference in heat loss at the higher T^, and therefore less difference in retained energy or predicted productivity. The absolute retained energy values were probably depressed because of the apparent decreased feed intake in the calorimeter. Hens that laid eggs while in the calorimeter were found to have lower body weight at the end of test, reduced by 3 to 8% of the initial body weight. Hens that did not lay eggs while in the calorimeter remained fairly constant in body weight. However, if the latent heat loss of the hen is actually
elevated because of NH3 level, especially at lower T^, then the decrease in egg production can not be caused by a reduction in the ability of the hen to lose heat. Instead, from these data, it appears that an energy deficit caused by excess loss of heat may have occurred. At the higher end of the T^ spectrum, a shift between cutaneous and respiratory evaporative heat loss might occur and hence mask the damaging affect of NH3 on respiratory heat loss.

Egg Production
Egg production data for acclimation, exposure, and recovery periods are shown in Table 2, from a pre-
exposure production rate of 83% to 66 and 59% during exposure to 10 and 60 ppm NH3 respectively. During
recovery, production returned to pre-exposure levels, with low NH3 treated hens having slightly higher
productivity. Egg production rates during the calorimetry period are presented in Table 3. Because of the large variance in egg production for each treatment, no significant difference (P>0.05) was detected. Production levels during the 24-h calorimetry period were not considered reliable because only one day was involved. Other stress factors such as isolation and unfamiliar environment could also have contributions to the variation in egg production. Birds were found to lay soft-shelled eggs and to excrete liquid feces at T^ of 33 °C and above.

Efficiency of Evaporative Heat Loss
Efficiency of evaporative heat loss was defined as the amount of latent heat dissipated per breath on a unit
metabolic weight basis (Table 1). Efficiency of evaporative heat loss decreased at least three-fold when temperature increased from 25 to 29 °C, decreased slightly from 29 to 33 °C, then increased at 37 °C. It is hypothesized that as RR increased at 29 and 33 °C, the exhaled air was less saturated and therefore each breath was less efficient.

The relationship between latent heat loss and RR on an average basis for both NH3 levels is presented in Table 1. In general, latent heat loss increased with increasing RR. There was no evidence of NH3 effect on reduced efficiency of evaporative heat loss, although the efficiency of hens exposed to 60 ppm NH3 appeared to be slightly higher.

**Table 2. Feed Consumption and Egg Production of the Hens during Acclimation, Ammonia Exposure, and Recovery Periods**

<table>
<thead>
<tr>
<th></th>
<th>Acclimation 10 ppm</th>
<th>Ammonia exposure 10 ppm</th>
<th>Recovery 10 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg prod.</td>
<td>0.83</td>
<td>0.66</td>
<td>0.85</td>
</tr>
<tr>
<td>(egg/hen-day)</td>
<td>0.59</td>
<td>0.85</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Feed energy content of 12 kJ/g was used.

**Table 3. Performance Responses of Hens at Air Temperatures of 25 °C, 29 °C, 33 °C, or 37 °C After Subjected to 30-Day Ammonia Exposure of 10 ppm or 60 ppm with 7-Day Recovery**

<table>
<thead>
<tr>
<th>Air temp., °C</th>
<th>Feed intake g/kg0.75.d (g/hen-day)</th>
<th>Energy intake W/kg0.75 (W/hen)</th>
<th>Energy retained W/kg0.75 (W/hen)</th>
<th>Egg prod. egg/hen-d</th>
<th>Body weight* kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>59.5 (86.6)</td>
<td>8.3 (12.1)</td>
<td>0.8 (1.2)</td>
<td>1.00</td>
<td>1.65</td>
</tr>
<tr>
<td></td>
<td>54.5 (80.1)</td>
<td>7.6 (11.3)</td>
<td>-1.7 (-2.5)</td>
<td>0.33</td>
<td>1.69</td>
</tr>
<tr>
<td>29</td>
<td>39.4 (54.2)</td>
<td>5.5 (7.6)</td>
<td>-0.5 (-0.7)</td>
<td>0.67</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>41.4 (59.7)</td>
<td>5.8 (8.4)</td>
<td>-0.8 (-1.1)</td>
<td>1.00</td>
<td>1.53</td>
</tr>
<tr>
<td>33</td>
<td>35.1 (50.6)</td>
<td>4.9 (7.1)</td>
<td>-2.0 (-2.9)</td>
<td>0.67</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>35.0 (51.6)</td>
<td>4.9 (7.2)</td>
<td>-1.8 (-2.7)</td>
<td>1.00</td>
<td>1.63</td>
</tr>
<tr>
<td>37</td>
<td>16.6 (23.2)</td>
<td>2.3 (3.2)</td>
<td>-5.8 (-8.2)</td>
<td>0.50</td>
<td>1.57</td>
</tr>
<tr>
<td></td>
<td>21.4 (32.0)</td>
<td>3.0 (4.5)</td>
<td>-5.1 (-7.6)</td>
<td>0.50</td>
<td>1.71</td>
</tr>
</tbody>
</table>

*Body weight uses average values of the replicates before and after test in the calorimeter.
Latent heat loss is relatively constant even with variations in the respiratory rate of the bird. Thus, the latent heat loss could remain relatively stable, given a constant latent heat loss level and a regulated temperature environment. Respiratory latent heat loss decreases to maintain a constant environmental temperature level. Lasiewski et al. (1971), as reported by van Kampen (1976), stated that seven avian species, varying in size from 12.5 to 300 g, lost 45% to more than 90% of their total latent heat by evaporation via skin at 30 and 35 °C. The latent heat loss tended to increase with increasing respiratory rate. There were two possible explanations. First, the partitioned calorimeter did not respond fast enough to the fluctuation of latent heat loss caused by the respiratory fluctuation, so that latent heat fluctuation could have been dampened. The decay time of the partitioned calorimeter under current experimental conditions was found to be less than 2 min after a sudden change in latent heat from the bird. Since RR was sampled every 10 min and the latent heat loss was sampled once every 4 min, the decay effect of the calorimeter would have been unlikely to damp the latent heat loss measurement. However, if the change in respiratory rate had occurred within 2 min, the data would have been biased to some extent.

The second possibility is that this occurrence was a reflection of some thermoregulatory mechanism of the bird. That is, panting may not be the only significant means of latent heat dissipation for birds under hot thermal conditions. Cutaneous evaporative heat loss and/or operation of gular flutter may play an important role as well. Lasiewski et al. (1971), as reported by van Kampen (1976), stated that seven avian species, varying in weight from 12.5 to 300 g, lost 45% or more of their total latent heat by evaporation via skin at 30 and 35 °C. Van Kampen (1976) found that cutaneous evaporation of the bird increased as the temperature increased from 10 to 35 °C, but fell again at 40 °C. Smith and Suthers (1969) reported a significant contribution of cutaneous water loss to temperature regulation in heat-stressed pigeons. The interplay between cutaneous heat loss and respiratory heat loss in the bird may be such that they complement each other to maintain homeothermy. Cutaneous evaporation may be increased at times when the respiratory latent heat loss decreases to maintain a given latent heat loss level and relieve the bird of the work of panting. Thus the latent heat loss could remain fairly constant even with variations in the respiratory rate of the bird.

REFERENCES

15. Smith, R. M. and R. A. Suthers. 1969. Evaluation of ammonia production, especially at conventional winter poultry house temperatures. Research should be developed to determine to what extent the lung of a bird could be damaged before causing energetic and acid-base problems and how it is related to cutaneous evaporative heat loss, especially under hot conditions.

CONCLUSIONS

The evaporative heat loss response of White Leghorn layers to temperatures of 25 °C up to 37 °C was not impaired by exposure to 60 ppm of NH₃ for 30 days followed by a 7-day recovery period.

FUTURE STUDIES

An interplay between the cutaneous and respiratory heat loss may play a more important role than previously thought in maintaining homothermy of the bird at high environmental temperatures. Therefore, the mechanism of this interplay between cutaneous and respiratory latent heat loss should be explained more fully.

The effect of NH₃ on the increase in latent heat loss should be more fully investigated as an explanation of reduced egg production, especially at conventional winter poultry house temperatures. Research should be developed to determine to what extent the performance of broiler chickens could be damaged before causing energetic and acid-base problems and how it is related to cutaneous evaporative heat loss, especially under hot conditions.