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Model Estimation and Measurement of Ammonia Emission from Naturally Ventilated Dairy Cattle Buildings with Slatted Floor Designs

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ABSTRACT

Laboratory experiments were carried out in a wind tunnel with a model of a slurry pit to investigate the characteristics of ammonia emission from dairy cattle buildings with slatted floor designs. Ammonia emission at different temperatures and air velocities over the floor surface above the slurry pit was measured with uniform feces spreading and urine sprinkling on the surface daily. The data were used to improve a model for estimation of ammonia emission from dairy cattle buildings. Estimates from the updated emission model were compared with measured data from five naturally ventilated dairy cattle buildings. The overall measured ammonia emission rates were in the range of 11–88 g per cow per day at air temperatures of 2.3–22.4 °C. Ammonia emission rates estimated by the model were in the range of 19–107 g per cow per day for the surveyed buildings. The average ammonia emission estimated by the model was 11% higher than the mean measured value. The results show that predicted emission patterns generally agree with the measured one, but the prediction has less variation. The model performance may be improved if the influence of animal activity and management strategy on ammonia emission could be estimated and more reliable data of air velocities of the buildings could be obtained.

INTRODUCTION

Ammonia (NH₃) emission is one of the main causes of environmental acidification. Agricultural activities, animal husbandry, in particular, contribute the main NH₃

emission worldwide. Dairy cattle production systems account for ~12% of the total yearly global NH₃ emissions. In addition, dairies are one of the major emission sources in the livestock sector.¹ NH₃ emitted by dairy buildings has potential risks to the health and well being of workers and animals, to people in areas surrounding the facilities, and to the global environment. Some measurements have been taken to evaluate the emission, and efforts have been performed to find possible technical solutions that may be applied to reduce the NH₃ emission. However, basic information on NH₃ emission, such as emission rate, diurnal pattern, and so forth, as well as reliable models for predicting NH₃ emission rate and pattern from the naturally ventilated dairy cattle buildings, are still needed.

Compared with the mechanical ventilation of the swine facilities, dairy buildings in Northern Europe are normally naturally ventilated with side walls and ridge openings. Most of the newer dairy buildings in this region have cubicles, a slatted floor, and manure storage pits under the slats. For these dairy buildings, it is more complicated to study the NH₃ emission process because of the difficulties in determining some of the important factors relating to the emission, for example, the ventilation rate of the building and air velocity above the floor. In dairy buildings, the influence of cow activities on NH₃ emission and the fact that NH₃ originates both from the slatted floor and the manure storage facilities inside the building also complicate the study of the NH₃ emission.² Field measurement of the NH₃ emission rate from naturally ventilated animal buildings is expensive, labor intensive, and technically difficult. Thus, a model with the function to predict the NH₃ emission by using easily measured or obtained parameters from the available literature would be very helpful.

Models for NH₃ volatilization from swine manure in under-floor pits and from finishing houses have been reported.^{3,4} However, little information is published on a reliable model for predicting NH₃ emission from the naturally ventilated dairy cattle buildings. In this study, a model for predicting NH₃ emission from an NH₃ solution to free airstream was extended and applied to estimate NH₃ emissions from naturally ventilated dairy cattle

IMPLICATIONS

Because of the activities of the animals and complexities of the emission process, it is difficult to study ammonia emissions from naturally ventilated dairy cattle buildings. This work describes the ammonia formation and volatilization from dairy manure and provides some fundamental information on ammonia emission rate from the naturally ventilated dairy buildings with slatted floor designs. The model developed could be used to estimate ammonia emission levels and patterns.

buildings with slatted floor designs. For this purpose, laboratory experiments were conducted, and the results were used to update the basic model. The model estimations were compared with field measurement results of NH_3 emissions from five naturally ventilated dairy cattle buildings.

EXPERIMENTAL WORK

Model Description

The model is based on the two-film theory developed by Whitman.⁵ NH_3 emission is a process of mass transfer from the NH_3 solution to the free atmosphere. In animal houses with slurry pits under the slatted floors, NH_3 emissions from urine puddles on the floor and slurry in the pit are the main sources, where NH_3 can be volatilized from the solution as free NH_3 . The following equation is generally used to describe the NH_3 volatilization under this condition⁶:

$$E_{\text{NH}_3} = k \times A \times (C_g - C_a) \quad (1)$$

where E_{NH_3} is the NH_3 volatilization from the surface of NH_3 solution (mol/sec); k is the mass transfer coefficient (m/sec); A is the area of emitting surface (m^2); and C_g and C_a are the NH_3 concentrations in the gas boundary layer and in the atmosphere, respectively (mol/m^3). NH_3 concentration in the atmosphere (C_a) is low compared with the concentration in the gas boundary layer (C_g) and is neglected in the model developed through this work.

At present, C_g can not be measured directly, but the value can be calculated from Henry's law equation:

$$C_g = \frac{C_l}{H} \quad (2)$$

where C_l is urea concentration in the liquid boundary layer (mol/m^3) and may be calculated by multiplying unionized fraction (f) and total NH_3 nitrogen concentration ([TAN]) in a solution; H is the Henry constant.

The Henry's constant was expressed by Hashimoto and Ludington, expressed in $\text{g}/\text{cm}^3/\text{atm}$ ⁷:

$$H = 1.013 \times (1.053)^{293 - T} \quad (3)$$

where T is the temperature of the emitting surface (K).

Rearranging eq 1 gives:

$$E_{\text{NH}_3} = \frac{k \times A \times f \times [\text{TAN}]}{H} \quad (4)$$

The mass transfer coefficient k is a function of air velocity and temperature, expressed in grams per squared centimeter per hour per atmosphere. It may be determined by the following empirical equation⁸:

$$k = 4930 \times (3.2808 \times v)^{0.8} \times T_a^{-1.4} \quad (5)$$

where v is the air velocity in meters per second and T_a is the air temperature above the emitting surface in K. Assuming no temperature gradient exists between the NH_3 emission surface and its above air, in the model of this work T_a equals T . By applying the ideal gas law, k can also be converted and expressed in meters per second.

The un-ionized fraction (f) can be derived from the dissociation constant of the ammonium and NH_3 equilibrium in a solution, according to the following equation:

$$f = \frac{10^{\text{pH}} \cdot K_d}{1 + 10^{\text{pH}} \cdot K_d} \quad (6)$$

where pH is the negative logarithm of hydrogen ion concentration; and K_d is dissociation constant. In the model, the dissociation constant of 0.81×10^{-10} is used.

From the manure, the volatilized NH_3 is formed by degradation of urea, and the Michaelis-Menten equation is applied to describe the rate of the conversion⁹:

$$\frac{dU}{dt} = \frac{-S_m \times U}{K_m + U} \quad (7)$$

where U is urea concentration at time t (mol/m^3); S_m is the maximum conversion rate at high urea concentration ($\text{mol}/\text{m}^3/\text{sec}$), and K_m is the Michaelis constant (mol/m^3).

The change of the [TAN] concentration with time can be calculated by using the following equation:

$$\frac{d[\text{TAN}]}{dt} = 2 \times \frac{dU}{dt} - \frac{E_{\text{NH}_3}}{V} \quad (8)$$

where V is the volume of the manure layer on the surface of the slatted floor model (for laboratory experimental trials) or of the urine puddle on the slatted floor (for the dairy building) in cubic meters.

From eq 4, the NH_3 emission can be calculated at any time.

Input Parameters. For K_m , the value of 2 (mol/m^3) was used in this paper. Based on the reports,^{10,11} the S_m values of 0.25–0.40 ($\text{mol}/\text{m}^3/\text{min}$) and a U value of 148 (mol/m^3) were used in the model. The pH values of the urine and slurry in the storage pit were 8.6 and 7.8, respectively.

It was difficult to measure the air velocities near the slatted floor and in the slurry pit directly because of the presences and activities of the animals. Muck and Steenhuis¹² determined the air velocities near the floors ranging from 0.05 to 0.3 m/sec in the air temperature ranges of ~5–25 °C in the naturally ventilated dairy barns. Monteny¹¹ stated a method for calculating air velocities near the floor and in the slurry pit. A similar method was used, and eqs 9 and 10 were used for the estimations of air velocities near the floor (v_f) and the air velocities in the slurry pit (v_p) in the model:

$$v_f = 0.1 + 0.01 \times V_R \quad (9)$$

$$v_p = 0.05 + 0.015 \times \Delta T \quad (10)$$

where V_R is the ventilation rate ($\text{m}^3/\text{sec}/\text{animal place}$) and ΔT is the temperature difference between the indoor and outdoor air. For $\Delta T < 0$, a constant value of 0.05 m/sec was taken for v_p . Monteny et al.¹³ reported that urination frequency of the dairy cattle varied from 9 to 11 urinations per cow per day depending on the diet. In this paper, a urination frequency of 10 times per day was used. The area covered by a urine puddle on a slatted floor was assumed to be 0.8 m^2 by Monteny.¹⁴ In a scale model system, Ezling and Monteny¹⁰ calculated the depth of the urine puddle on the floor of 0.00048 m in their experiments. Both values were also taken as constant inputs in the model for simulating NH_3 emission.

Laboratory Experiments

Three experimental trials were carried out in the Manure Laboratory at Research Centre Bygholm, Danish Institute of Agricultural Sciences, Denmark. Each trial lasted 9 days.

Experimental Setup. A wind tunnel made of galvanized iron was used for the NH_3 emission simulation experiments (Figure 1). The overall dimensions of the wind tunnel were $3.00 \times 0.40 \times 0.30$ m (L $\times$ W $\times$ H). A $0.65 \times 0.45 \times 0.30$ m (L $\times$ W $\times$ H) model (manure container) of a slurry pit, topped by a model of a slatted floor with the size of 0.65×0.32 m (L $\times$ W), built in Plexiglas, was placed under the wind tunnel. An exhaust fan was placed at the outlet end, and a metal screen with 3-mm-diameter holes was installed at the inlet end of the wind tunnel to provide uniform air velocity over the slatted floor surface. The opening ratio between the model and slatted floor over the manure container corresponded with the practical ratio used in the dairy cattle buildings.

Measurement. A hot wire anemometer was placed inside the wind tunnel at ~ 5 cm above the bottom to monitor the air velocity. The humidity and temperature inside the tunnel were recorded using Tinytag Ultra TGU data logger (1500, Gemini Data Loggers Ltd.), with temperature and relative humidity (RH) measurement ranges of -30 to 50 $^{\circ}\text{C}$ and 0–95%, respectively.

Two sections near the inlet and outlet end of the wind tunnel were chosen to measure the NH_3 concentrations of the incoming and outgoing air by using an ECO PHYSICS analyzer (CLD 844 CM hr, ECO PHYSICS AG) for trials 1 and 2, whereas a Brüel & Kjær Photoacoustic

Multigas monitor (type 1312, Brüel & Kjær) was used for the same purpose for trial 3. Both measurement points were in the center of the cross-section of the tunnel. The reading of gas concentration was recorded every minute for trials 1 and 2, but every 5 minutes during trial 3. According to the technical specifications of these instruments, the accuracy of the Brüel & Kjær Multigas monitor for NH_3 measurement was ± 0.1 ppm, depending on the filter setting, and for the CLD 844 CM hr analyzer, the minimum detectable concentration of NH_3 was 0.025 ppm.

Fouling Method and Manure Collection and Storage. The fouling method described by Elzing and Monteny² of spreading feces and urine separately on the slatted floor surface was applied. The manure container was filled with the dairy cattle manure ≤ 25 cm below the slatted floor before starting the measurement. For the fouling on the slatted floor, 1.5 kg of feces were spread over the floor surface uniformly with the help of a brush. Then the feces were removed manually into the manure container immediately with a scraper, leaving a thin layer of feces on the slatted floor surface. Afterwards, 1 kg of urine was sprinkled over the feces-fouled floor. The urine and feces ratio (2:3) used for fouling was roughly similar to the ratio between the amount of urine and feces produced by dairy cows.¹⁵ The fouling procedure was repeated daily. After fouling, NH_3 concentrations in the airflow were measured for a 24-hr period. Before a new layer was applied on the floor surface, the old one was scraped manually and put into the manure container.

The manure was collected directly from the storage pit of dairy cattle house. The urine and feces were collected separately and stored at temperatures of 2–4 $^{\circ}\text{C}$ in the manure laboratory. To avoid unnecessary chemical and biological changes in manure, the collected sample was maintained in a refrigerator during the experiments. A new sample was collected for each trial. Therefore, the maximum storage period for each trial was ~ 10 days. According to Sommer and Husted,¹⁶ when environmental temperature is < 8 $^{\circ}\text{C}$, very limited changing in manure may occur.

Climate Condition of the Experiments. RH during the experiments was between 65% and 70%. Air temperatures were 3.5, 13.5, and 18 $^{\circ}\text{C}$, respectively for the three trials. For trials 1 and 2, air velocity was 0.2 m/sec, whereas four different velocities of 0.15, 0.20, 0.25, and 0.3 m/sec were applied to the third trial. The sensors were used during the

Figure 1. Schematic representation of the wind tunnel for NH_3 simulation experiments showing the relative position of the manure container.

experiments to monitor the variation of air temperature, velocity, and humidity inside the wind tunnel.

Estimations of Ventilation Rate and NH₃ Emission Rate. Assuming the air velocity of the tunnel was generally uniform, the ventilation rate was calculated on the basis of the measured air velocity by the following equation:

$$VR_m = A_m \times V_m \quad (11)$$

where VR_m is the ventilation rate (m³/sec); A_m is the area of the cross-section (m²); and v_m is the air velocity of the tunnel (m/sec).

NH₃ emission rate was determined by the calculated ventilation rate and the difference of NH₃ concentrations:

$$E_m = 6 \times 10^4 \times VR_m \times (G_{m,out} - G_{m,in}) \times \rho_g \quad (12)$$

where E_m is NH₃ emission rate (mg/min); $G_{m,out}$ and $G_{m,in}$ are the NH₃ concentrations (ppm) measured from the outgoing and incoming airstream through the tunnel, respectively; and ρ_g is NH₃ density (g/m³).

Measurements of NH₃ Emission from the Naturally Ventilated Dairy Cattle Buildings

Filed measurements of NH₃ emission were conducted in five newer type freestall dairy buildings with slatted floors and manure storage pits. The measurements were performed in the period from August 2002 to December 2003 covering both the warm and the cold periods of the year in middle-north Jutland, Denmark. A detailed description of the measurements was given by Zhang et al.¹⁷

Building. All of the surveyed dairy cattle buildings were naturally ventilated with side walls and ridge openings. The buildings were placed with cubicles, slatted floor, and manure storage pits under the slats. Configurations and manure handling systems of the investigated buildings are listed in Table 1. The information of the herd housed inside for each measurement is listed in Table 2.

Measurement. Air temperature, carbon dioxide (CO₂), and NH₃ concentrations were measured in five representative points in a 20-m-long measurement section inside the building and one point outside as reference ~5 m from a side wall. The temperature sensors used were Testo 174

Table 1. Configurations and manure handling systems of the surveyed five dairy cattle buildings.

Building No.	Length (m)	Width (m)	Eave Height (m)	Roof Slope (°)	Manure Handling Systems
1	81.9	36.2	4.3	20	Channel scraper
2	96	16	2.6	20	Back flushing
3	45.9	26.6	3.4	20	Circulation
4	54	29.3	3.0	25	Scraper on slatted floor
5	60	33.4	3.6	25	Circulation

Table 2. Manure handling system and production information of the five dairy cattle buildings with slatted floor for NH₃ emission measurements.

Building No.	Production Information				HPU	
	Cows (n)	Weight (kg)	Milk Production (kg/cow/day)	Calves (n)	Total	Per Cow
1	152	600	26.0	60	240	1.6
	148	600	24.3	86	254	1.7
2	159	600	34.2	0	237	1.5
	170	600	30.7	0	238	1.4
3	192	450	23.4	0	233	1.2
	192	450	23.4	0	238	1.2
4	115	600	28.7	25	180	1.6
	121	600	26.9	28	183	1.5
5	166	600	31.9	25	276	1.7
	159	600	29.0	17	252	1.6
	163	600	29.0	17	253	1.6

with a built-in data logger. The gas concentrations were measured with a Brüel & Kjær Multigas monitor 1312. At least two measuring periods for each building were taken in different climate seasons, and each measuring period lasted ≥3 days.

Estimations of Ventilation Rate and NH₃ Emission Rate. A model-aided CO₂ balance method was used to estimate the ventilation rate of the naturally ventilated buildings. In this approach, the dairy cows in the building were considered as the only source for CO₂ production. Therefore, the CO₂ produced by dairy cows in the buildings was used as a tracer gas. Based on the mass balance, the ventilation rate is calculated by:

$$VR_c = 10^6 G_p / (G_{CO_2,in} - G_{CO_2,out}) \quad (13)$$

where VR_c is the ventilation rate of the buildings (m³/sec); G_p is CO₂ production from dairy cattle (m³/sec); and $G_{CO_2,in}$ and $G_{CO_2,out}$ are CO₂ concentrations inside and outside of the buildings respectively (ppm). In this study, $G_{CO_2,out}$ was a measured value at a reference point outside the building, whereas $G_{CO_2,in}$ was the average of measured values at five represented points of the building space.¹⁷ The CO₂ production of the animals is estimated according to a method that is correlated with the total heat production, which is recommended in a Commission Internationale du Génie Rural report.¹⁸ For livestock housing where CO₂ is only generated by the animals, the average CO₂ production on a 24-hr basis is given as 0.185 m³/hr/HPU.¹⁸ HPU is an abbreviation of a heat-producing unit, which is defined as 1000-W total heat production by animals at the environmental temperature of 20 °C. The total heat production of the dairy cattle and heifer were estimated by the following eqs 14 and 15, respectively¹⁹:

$$y = 5.2x^{0.75} + 30 \text{ m} + 1.6 \times 10^{-5} D \quad (14)$$

$$y = 65(150 + x)^{0.5} - 800 \quad (15)$$

where y is total heat production of the animal (W); m is milk production (L/day); x is the live weight of the animal (kg); and D is pregnancy days of the cows. Because of a lack of data, the correction part by the pregnancy ($1.6 \times 10^{-5} D$) of the total heat production was considered to be negligible.¹⁷

NH₃ emission rates from the dairy cattle buildings were calculated based on:

$$E_{\text{NH}_3} = 8.64 \times 10^4 VR_{c(G_{\text{in}} - G_{\text{out}})p_g/N_c} \quad (16)$$

where E_{NH_3} is NH₃ emission rate (g/cow/day); G_{in} and G_{out} are the NH₃ concentrations inside and outside the dairy buildings (ppm); and N_c is the total number of animals.

RESULTS AND DISCUSSION

NH₃ Emission from Field Measurement of the Naturally Ventilated Dairy Cattle Building

Eleven measuring periods were taken for these five naturally ventilated dairy buildings. Zhang et al.¹⁷ reported the NH₃ emission rates of these buildings and the performance of CO₂ balance method in estimating ventilation rate of the buildings.

The overall NH₃ emission and indoor air temperature data are presented in Table 3 as averages for the whole measurement periods with the standard deviations. The NH₃ emission rate from the buildings with slatted floors increased from 11 to 88 g per cow per day as the air temperature increased from 2.3 to 22.4 °C with a standard deviation from 1 to 14 g per cow per day. In all of the cases, the NH₃ emission rate increased with temperatures, and the increase was also affected by a manure handling system.

A diurnal pattern was found in all of the measurements.¹⁷ Examples of the variation of the NH₃ emission rates during a measurement period are shown in Figure 2 for buildings 1 and 5. The figure shows that the NH₃ emission levels varied considerably through the measurement. The lowest emission rates tended to occur after midnight during a 24-hr period. The possible reason is that animal activity was lower, and both air and floor

Figure 2. Examples of the variations of NH₃ emission rates during the measurements: (a) building 1; (b) building 5.

temperatures, as well as air velocity above the floor, were lower. During a 24-hr period, a few emission peaks that normally occurred in the afternoon were observed. The occurrence of the peaks is probably because of different management schedules, such as milking, floor scraping, and feeding.

Laboratory Experiments

Figures 3 and 4 show the measured and predicted NH₃ emissions on the fourth day after starting the fouling on the slatted floor in the experimental trials 2 and 3, respectively. For each daily measurement, NH₃ emission increased after the application of the feces and urine and then reached a peak. Afterward, the emission declined gradually and had a tendency of stabilization at a low level. On the first day, the peak was low and broad. The value of the peak increased, and the time interval between floor fouling and the occurrence of the peak became shorter with each subsequent day, which agreed with the

Figure 3. Measured (dashed line) and predicted (solid line) NH₃ emission from the laboratory simulation experiment trial 2.

Table 3. NH₃ emission rates and indoor air temperatures.

Building No.	NH ₃ Emission (g/cow/day)		Indoor Air Temperature (°C)	
	Mean	SD	Mean	SD
1	23	3	9.6	2.0
	46	7	19.0	3.6
2	55	8	22.4	0.8
	16	1	8.3	1.3
3	49	5	13.2	3.0
	11	1	2.3	1.4
4	33	14	19.5	2.9
	27	5	5.8	3.8
5	49	8	16.6	1.2
	56	9	17.3	0.7
	31	3	6.3	2.0

SD = standard deviation.

Figure 4. Measured (dashed line) and predicted (solid line) NH_3 emission from the laboratory simulation experiment trial 3.

results of a model developed by Elzing and Monteny.² Although it tended toward stabilization, the emission had not fully stabilized even after 9 days of measurement in all three of the trials. This is different from the findings of Elzing and Monteny.² For their scale model, after 7–8 days, the NH_3 emission curve was becoming similar to that of the previous day; the situation stabilized, and the emission peak normally occurred at ~ 2 hr after applying the feces and urine. The results of our experiments show that the occurrence of the peak was later than that of their findings.

The relation between the daily average NH_3 emission rate and different air velocity for experimental trial 3 was given in Figure 5. The high emission rate was observed at high air velocity. The tendency line shows that the emission rate is a power function of air velocity ($r^2 = 0.78$).

The predicted NH_3 emissions by the model for experimental trials 2 and 3 are also plotted in Figures 3 and 4, respectively. A reasonably good fit (with a standard error < 0.20) was found with an S_m of $0.35 \text{ (mol/m}^3\text{/min)}$ in predicting NH_3 emission from the trials. The same value of S_m was also used to predict the emission from the five dairy buildings. Because the feces, urine, and slurry were collected from different dairy farms with different diets, the variations of NH_3 emission rates of the two trials are different.

Model Performance

To estimate the performance of the model, the measured results from the commercial dairy buildings were used to compare with the model prediction. The means of the

Figure 5. The relation between daily average NH_3 emission rate and the air velocity 5 cm above the bottom of the wind tunnel for experimental trial 3.

Figure 6. Measured and model-predicted NH_3 emission rates from the five naturally ventilated dairy buildings with slatted floors.

model-predicted NH_3 emission rates versus the measured values of all of the measurement periods of the five buildings is presented in Figure 6. The overall predicted NH_3 emission rates were in the range of 19–107 g per cow per day. The average simulated NH_3 emissions for all of the buildings were 11% higher than the mean measured values from the dairy buildings. The predicted emission levels show relatively good accordance with the measured levels ($r^2 = 0.86$).

One measurement period from each of the five buildings was selected to compare with the predicted emission pattern by the model. For these periods, the results of measured and simulated NH_3 emissions for a time period of ~ 72 hr are shown in Table 4. The mean difference between the model estimation and field measurement for the five buildings was 1.3 g per cow per day. Maximal underestimation was 13.1% for building 3, and maximal overestimation was 17.1% for building 4. The predicted emissions from the slatted floors contribute the majorities and account for 76–79% of the total predictions of the buildings.

Patterns of simulated and measured NH_3 emission for a 72-hr period from three buildings are shown in Figure 7. The emission pattern from model predictions generally matches that of the measurements. The measurement results showed considerable variations between the lower and higher emission rates. The lowest measured emission rate usually occurred after midnight, and the emission level increased with the animal activity level, air temperature, as well as the floor temperature. Meanwhile, a few peaks of NH_3 emission could be found. Although the emission trends derived from both methods are generally

Table 4. Measured and simulated NH_3 emission (g/cow/day) for a period of ~ 72 hr for the surveyed buildings.

Building No.	Measured	Simulated			Difference	(%)
		Total	From Floor	From Pit		
1	23.0	23.5	18.0	5.5	0.5	2.1
2	16.5	18.0	14.1	3.9	1.5	9.1
3	13.7	11.9	9.2	2.7	-1.8	-13.1
4	27.1	31.7	25.1	6.6	4.6	17.1
5	22.8	24.5	18.7	5.8	1.7	7.6
Average	20.6	21.9	17.0	4.9	1.3	4.6

Figure 7. Examples of comparison of field measured and model-predicted NH_3 emission for a 72-hr period: thin solid line, measured; thick solid line, total simulated; dashed line, simulated from slatted floor, and dotted line, simulated from the slurry pit. (a) building 1; (b) building 4; (c) building 5.

agreed, the simulated NH_3 emission rates do not have such big variations as those of measured values, and the simulated emissions do not have peaks that high either. It might be because of the emission levels affected by the cow activity patterns and management strategies, such as urinating, feeding, and manure handling, as well as milking. However, these factors were not considered in the current model because of the uncertainties and lack of information. For example, the uncertainty of the excretion pattern, such as the time and location of urination, cannot be precisely modeled. The laboratory experiment showed that NH_3 emission reached the peak several hours later after the fouling of the slatted floor. Similarly, if most animals in a building urinate and defecate at almost the same time, a high emission rate is expected to happen several hours later because of NH_3 production from the

fresh urine. This type of effect on NH_3 emission was not taken into account in the model, because behavior patterns for dairy cows are needed. Air velocity has a sensitive effect on NH_3 emission. In naturally ventilated buildings, air velocity may fluctuate greatly with time. The differences between the evaluated and the field air velocities near the floor (v_f) and in the pit (v_p) may also have some negative effect on the simulated NH_3 emission. The differences between predictions and measurements at the highest and lowest NH_3 emission levels might be somewhat corrected by taking into account the influences of animal activity and management and by using more accurate air velocities in the model. Generally, the levels and patterns of NH_3 emissions from naturally ventilated dairy cattle buildings can be modeled.

CONCLUSIONS

Laboratory experiments were conducted to simulate the NH_3 emission process by using a wind tunnel with different temperatures and air velocities above a model of a slurry pit. NH_3 emissions from the experiments were simulated by a model. A good fit between the simulated and measured curves was found with a value of $0.35 \text{ (mol/m}^3/\text{min)}$ for the maximum conversion rate S_m at high urea concentrations.

Measurements of NH_3 emission from five naturally ventilated dairy buildings with slatted floors were carried out. The levels and patterns of NH_3 emission from the surveyed dairy cattle buildings were simulated reasonably well by using the model developed. The average simulated NH_3 emission rate was 11% higher than the mean measured value. The emission patterns predicted by the model generally match the variations of the measurements, although the predictions do not have peaks that high. Generally, the model could be applied in estimating NH_3 emission from the naturally ventilated dairy buildings. To improve the model, further research on the effects of animal activity and management strategy on NH_3 emission should be considered in the future.

ACKNOWLEDGMENT

This project is supported by the Program of the 13th Session (2002–2004) Sino-Danish Scientific and Technological Cooperation and the Cooperative Program of Beijing Municipal Commission of Education (Grant No. XK100190550).

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