Influence Ventilation Rate on Ammonia Concentration and Emission in Animal House

B. Kavolelis*

Institute of Agricultural Engineering, Lithuanian University of Agriculture, Raudondvaris, LT - 4320 Kaunas, Lithuania

Received: 10 February, 2003
Accepted: 15 April, 2003

Abstract

The mathematical model to analyze ammonia concentrations inside lifestock facilities has been made. The regression relationship of the intensity of the ammonia evaporation in the pigsty for the farrowing sows and their piglets has been determined. When the surface of the concrete floor of the stall is uneven and there is a manure layer of 0.5-1.0 cm thickness, the ammonia concentration in the pigsties of sows with piglets exceeds the upper permissible limit (20 ppm). When the relative humidity of the air is normal and the ammonia concentration exceeds the permissible limit, it should be reduced by technical and zoohygienic means (by carefully cleaning the floor surface). This lowers the ammonia concentration from 25 ppm to 10-15 ppm, and its emission.

Keywords: mathematical model, ammonia concentration and emission, ventilation rate, floor state.

Introduction

Approximately 40% of the airborne pollution of nitrogen (N) appears in the form of ammonia (NH_3) [1]. About 90% of the ammonia comes from agriculture. And losses from venting lifestock facilities make up 18-37% [1, 2]. Ammonia evaporating is harmful for animals, people and the environment. Thus, not only in the greatest permissible ammonia concentration in the air of the building, but its emissions from the building to the atmosphere as well are limited. According to the standards of some countries the limit of NH_3 emission from one fattening pig is up to 3 kg per year, but on ecological farms - up to 1.5 kg [3]. Housed pigs are exposed chronically to atmospheric ammonia at concentrations that may exceed 30 ppm (upper permissible limit 20 ppm) in buildings with poor environmental control [4]. The effects of ammonia on animal performance and health are reasonably well understood.

Many researchers mention the following factors affecting the release of ammonia: N content of the manure, adsorption of ammonia N, urease activity, pH of the manure, manure temperature, C/N ratio of the manure, manure surface area, air movements in the building, air velocity above the manure surface, air flow rate through the building, air temperature and availability of oxygen. When manure occupies 25% of stall area NH_3 emission from a fattening pig place is 1.8 kg, but when 100% - 3.7 kg per year [3]. When ventilation rate increases 3.2 times, NH_3 emission increases 2.1 times [5]. In summer emission is higher. When the temperature rises from 9^{o}C to 25^{o}C emission increases 2.9 times [6].

Analysis of the tests shows that the increase of the ventilation rate decreases the ammonia concentration in the premises, but maximizes the emission of ammonia. The required heating intensity also increases in the heated premises. The object of this work is to find the mathematical relationship of NH_3 concentration inside the premise on the ventilation rate and to determine the rational limits to increase the ventilation rate. Then to investigate ammonia emission in pigsties with piglets.

*e-mail: bkavolelis@mei.lt

Theory (Model)

Many authors have determined the mathematical relationships of the change of the harmful concentrations of admixtures in the air of the premises from the time point of view [7]. Our aim is to get the mathematical relationship of the ammonia concentration inside the premise on the change of ventilation rate. Here is the differential equation of the ammonia balance:

$$\frac{V}{\tau}\frac{dC}{dG} = C_i + z\tau - C \tag{1}$$

where:
C - the ammonia concentration in the outlet air, mg/m^3;
C_i - the ammonia concentration in the inlet air, mg/m^3.

In order to solve the differential equation (1), both variables should be transferred to the opposite sides of the equation. Besides, we will make the assumption that the ventilation rate increases from G_1 (the self-ventilation of the premise, when all the ventilation equipment is switched off) to G, while the ammonia concentration in the premise changes from C_1 to C. Then:

$$\int_{G_1}^{G} \frac{\tau}{V} dG = \int_{C_1}^{C} \frac{dC}{C_i + z\tau - C} \tag{2}$$

After the integration and the change of the signs, we receive:

$$-G\frac{\tau}{V} = ln(C - C_i - z\tau) + ln\, c \tag{3}$$

The reference data from literature shows that the air in the premise self-changes once an hour, i.e. G_1 = V. If equation (3) is substituted with these main conditions G = G_1 = V and C = C_1, then we get the integration constant:

$$ln\, c = -ln(C_1 - C_i - z\tau) - \tau \tag{4}$$

If we substitute equation (3) with equation (4), we get:

$$\left(\tau - G\frac{\tau}{V}\right) = ln\frac{C - C_i - z\tau}{C_1 - C_i - z\tau} \tag{5}$$

From equation (5) we can get the relationship of the ammonia concentration in the premise air on the ventilation intensity:

$$C = C_i + z\tau + (C_1 - C_i - z\tau)exp\left[\tau\left(1 - \frac{G}{V}\right)\right] \tag{6}$$

For the convenience of analyses the general values of the units z, G and V of equation (6), we change by the comparative ones and get:

$$C = C_i + \frac{z_a}{G_a} + \left(C_1 - C_i - \frac{z_a}{G_a}\right)exp\left[\tau\left(1 - \frac{G_a}{V_a}\right)\right] \tag{7}$$

In order to better analyse the dynamics of ammonia concentration in the premise, the members of equation (7) will be equal to the dimensions used in practice. Then ammonia concentration C, ppm:

$$C = \frac{z_a}{\rho G_a} + \left(C_1 - \frac{z_a}{\rho G_a}\right)exp\left[\tau\left(1 - \frac{G_a}{V_a}\right)\right] \tag{8}$$

In order to analyse the dynamics of ammonia concentration in the premise according to equation (8), one should know the intensity of ammonia emission z_a, the value of ammonia concentration C_1, that corresponds at least one ventilation rate and the dimensions of the premise. We have determined these values experimentally for one type of the premises, i.e., for the pigsty for sows with piglets.

Experimental Procedures

The tests were fulfilled in the pigsties of the sows with piglets in the natural exploitation conditions. The sows were kept in separate stalls of 9 m^2.

The medium space capacity of the premise per sow was 50 m^3. Sows were fed by liquid feeds. The floor of the den was solid and compact, but of various structures and states: they can be even concrete floor and covered with manure of 0.0-0.5 cm thickness; they can also be uneven concrete floor and covered with manure of 0.5-1.0 cm thickness or they can consist of wood chips. In all cases the floor was littered with straw, which was changed daily. Manure from a 320 mm wide channel was transferred by the scraper-conveyer.

Air from all the pigsties was withdrawn through the chimneys. In winter clean heated air was introduced by the ventilators through the air inlets. This air was heated by electricity. The piglets were heated by the infrared lamps.

Tests were fulfilled in all the seasons and the ventilators were operating sometimes and were not operating on other occasions. The amount of the output air in the chimneys was changed with the help of a valve.

The debits of the inlet and outlet air were determined, as well as the ammonia concentration in the premise, in the inlet and outlet air, inside and outside air temperature and relative humidity of the air. The ammonia concentration in the premise was also measured when the ventilation openings were shut. The debits of the inlet and outlet air were defined by estimating the air speeds in the air duct and chimneys. The ammonia concentration was measured by Drager Pac IIIS, the speed of the air movement, the temperature and humidity were measured by the universal device Almemo-2299-3.

The intensity of ammonia emission Z, mg/h, in the premise is estimated from the measurement data and expressed by:

$$Z = GC - G_i C_i \qquad (9)$$

where: C_i, C - ammonia concentration of the inlet and outlet air, mg/m^3 (mg/m^3 = 0.71 ppm).

The data was analyzed statistically and the values of ammonia emissions for one sow were determined and the relationships of ammonia concentration on the ventilation intensity were defined.

Results

Experimental tests (Fig.1 shows the dots and full lines) show, that ammonia concentrations in the premise air and the intensity of its emission is determined by the state of the stall floor and ventilation rate.

This direct regression equation expresses the relationship of the intensity of ammonia emission for a sow with piglets (or stall area of 9 m^2), z_a, mg/h, on the ventilation rate for one sow with piglets, G_a, m^3/h:

$$z_a = a + bG_a \qquad (10)$$

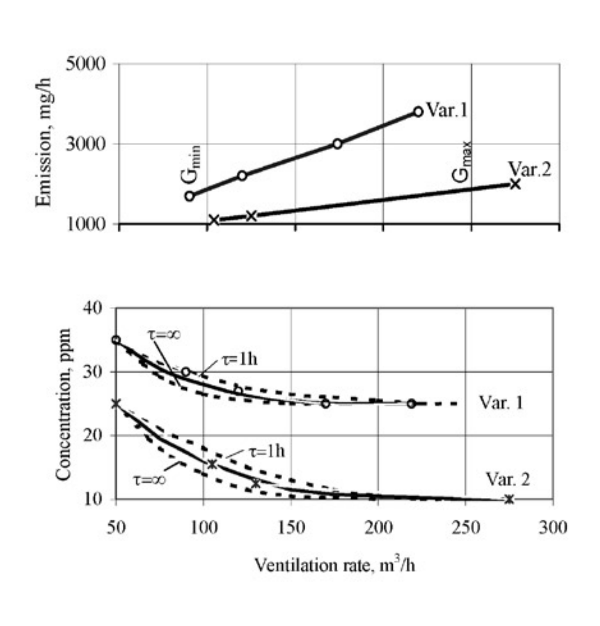

Fig. 1. The relationship of ammonia concentration and the emission intensity for one sow on the ventilation rate for one sow: — experimental data; ----- calculation data (equation 8); Var. 1 - when the floor surface is uneven; Var. 2 - when the concrete floor surface is even; G_{min} - the least ventilation intensity, required for the transfer of the excess water vapour in winter; G_{max} - the greatest ventilation intensity, required for the transfer of the excess water vapour in summer.

The correlation coefficient is R = 0.99, its error is m_r = 0.12, reliability is t_r = 8.1. When the surface of the concrete floor is uneven and covered by manure layer of 0.5-1.0 cm thickness, or when the floor is made of wood (var. 1), the regression coefficients are a=170, b=17. When the surface of the concrete floor is even and it is cleaned every day, and the layer of manure is 0-0.5 cm thickness (var. 2), then the regression coefficients of the equation are a=460, b=5.4.

When the surface of the concrete floor is uneven and for this reason covered by the layer of manure of 0.5-1.0 cm thickness or when the floor is made up of wood chips (var.1), the concentration of NH_3 in the pigsty for sows with piglets exceeds the upper permissible limit (20 ppm), even when ventilation intensity to remove the excess water vapour and heat in summer is sufficient (G_{max}=250 m^3/h). When the ventilation intensity is increased from 100 to 220 m^3/h i.e., 120%, the ammonia emission for one sow increases from 1870 to 3910 mg/h, i.e. 109%, and its concentration in the premise decreases from 29 ppm to 25 ppm, i.e. 14%.

When the surface of the concrete floor is even and cleaned every day, ammonia concentration does not exceed the permissible limit, provided the ventilation intensity is such that the relative humidity and the temperature of the air in the premise are normative.

Experimental tests (full lines in Figure) and statistical analysis confirms that the mathematical model is rather precise and can be used to analyze the change of ammonia concentration.

When the annual ventilation intensity is medium (175/ m^3/h), we can calculate according to equation (10), that 12-28 kg of NH_3 evaporate from the stall of the sow with piglets per year.

Investigations show that when the relative humidity of the air is normal, and the ammonia concentration exceeds the permissible limit (20 ppm), it should be reduced not by maximizing the ventilation intensity, but by technical and zoo-hygienic means (even out the floor surface and clean it carefully).

Discussion

The need to decrease the emissions of ammonia and other gases produced by livestock and their waste products has grown in recent years. As a result of data indicating that these gases have the potential to contribute to the greenhouse effect, acid rain, and/or stratosphere ozone deplation, many European countries currently have regulations limiting ammonia emissions from concentrated animal feeding operations. Scientists have estimated that as much as 50% of feed N is lost as ammonia [8]. Ammonia is formed by the break-down of excreted urea in the urine of the animals. This reaction is catalyzed by the enzyme urease, present in the feces and surfaces regularly fouled with feces and urine [9]. Several chemical amendments and additives have been studied to reduce ammonia emissions as well. Chemical amendments such as alum

($Al_2(SO_4)_3$) and calcium chloride ($CaCl_2$) reduce ammonia emissions firsts by decreasing pH and second through cation exchange. A laboratory study demonstrated that ammonia emissions from open-lot beef cattle feedlots can be reduced from 26.4% to 98.3% using amendment, but the costs may be prohibitive [8].

Ammonia and dust concentrations in swine confinement buildings were reduced by spraying a mixture at water and sulfiric acid. Shot-term observations in these buildings showed a reduction of ammonia concentrations from 8 to 10 ppm to down to 1 to 2 ppm. Pig performance was improved. The average weight gain in the treatment barn increased [10].

The reduction of emissions is on the agenda. Various possibilities offer themselves for the sustainable integration of animal production into this process. This includes the areas of husbandry techniques, feeding, storage, stall construction, stall climate control, spreading and waste gas treatment [11].

Worldwide research on ammonia emissions and concentrations in animal buildings, which don't evaluate all farming and natural environment conditions and other factors has been carried out. In that case it is advisable to continue research [12].

The results of our research greatly complement the data about the ammonia concentration and emission in pigsties. These results are defined by these findings.

The mathematical model (equation 8) to analyze the ammonia concentration inside the premise and its change depending on the ventilation rate is made. The regression relationship of the ammonia evaporation rate in the pigsties of sows with piglets on the floor state and ventilation rate (equation 10) is determined. When the annual ventilation intensity is medium (175 m^3/h for an animal), 1-3 g/h or 12-28 kg of ammonia per year evaporate from the stall (9 m^2) of the sow with piglets.

When the surface of the concrete floor is uneven and for this reason covered with the layer of manure of 0.5-1.0 cm thickness, the ammonia concentration in the pigsties of the sows with piglets exceeds the upper permissible limit (20 ppm), even when the ventilation rate is sufficient to remove excess water vapour and heat in summer. When the relative humidity is normal and the ammonia concentration exceeds the upper permissible limit, it should be minimized by technical and zoohygienic means. When the floor surface is made even and when it is cleaned carefully, the ammonia concentration decreases from 25 to 10-15 ppm, and its emission per year for one sow is reduced from 28 to 12 kg.

Units and Nomenclature

C - ammonia concentration in the inside (outlet) air, mg/m^3 (ppm)

C_i - ammonia concentration in the inlet air, mg/m^3 (ppm)

C_1 - initial ammonia concentration in the inside air, mg/m^3 (ppm)

c - integration constant

d - differential

G - ventilation rate (debit of the outlet air), m^3/h

G_1 - initial ventilation rate, m^3/h

G_i - debit of the inlet air, m^3/h

G_a - ventilation rate for one sow with piglets, m^3/h

V - premise volume, m^3

V_a - premise volume for one sow with piglets, m^3

z - intensity of ammonia emission in the volume unit of the premise, $mg/(h \cdot m^3)$

z_a - intensity of ammonia emission for one sow with piglets, mg/h

Z - intensity of ammonia emission in the premise, mg/h

τ - time, h

ρ - density of ammonia, mg/cm^3 (when the temperature is 20 ^oC, $\rho = 0.71$ mg/cm^3)

References

1. SWENSSON C., GUSTAFSON G. Characterization of influence of manure handling system and feeding on the level of ammonia release using a simple method in cow houses. Animal science. **52**(2), 49, **2002**.
2. DOHLER H. Organic fertilizing. Yearbook agricultural engineering. Editors Mathies H. J., Meier F. VDMA Landtechnik. **15**, pp 115, **2003**.
3. AARNINK A., Van den BERG A. Effects of slatted floor area and climate control. Pigs-misted. **11**(6), 36, **1995**.
4. WATHES C. M., JONES J. B., KRISTENSEN H. H., JONES E. K. M., WEBSTER A. J. F. Aversion of pigs and domestic fowl to atmospheric ammonia. Transactions of the ASAE. **45**(5), 1605, **2002**.
5. GUSTAFSSON G. Reduction of ammonia in swine houses. Swedish University of Agricultural Sciences, Lund. 14, **1993**.
6. EPINATJEFF P. Kühlere Stalluft-garingere Ammoniakemissionen. Landtechnik. **52**(6), 320, **1997**.
7. DASKALOV P. I. Prediction of temperature and humidity in a naturally ventilated pig building. J. Agric. Engng. Res.68, 329, **1997**.
8. SHI Y., PARKER D.B., COLE N.A., AUVERMANN B.W., MEHLHORN J. E. Surface amendments to minimize ammonia emissions from beef cattle feedlots. Transactions of the ASAE. **44**(3), 677, **2001**.
9. SWIERSTA D., BRAAM C. R., SMITS M. C. Grooved floor system for cattle housing: ammonia emission reduction and good slip resistance. Applied Engineering in Agriculture. **17**(1), 85, **2001**.
10. JENSEN A. O. Changing the environment in swine buildings using sulfuric acid. Transactions of the ASAE. **45**(1), 223-227, **2002**.
11. HAHNE J., KRAUSE K.-H., MUNACK A., VORLOP K.-D. Environmental Engineering - reduction of emissions. Yearbook Agricultural Engineering. Editors Matthies H. J., Meier F. VDMA Landtechnik. **15**, pp 35, **2003**.
12. Framework advisory code of good agricultural practice for reducing ammonia emissions. UN/ECE Ammonia Expert Group Proceedings. Berne, 18-20 September 2000. Environmental Documentation N 133. Swiss Agency for the Environment, Forests and Lanscape (SAEFL), pp 37, **2000**.