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AMMONIA EMISSIONS FROM DAIRY CATTLE MANURE UNDER VARIABLE VENTILATION RATES*

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Abstract

The effect of variable ventilation rates on ammonia emission rates from manure was determined through mass flow measurements in a laboratory test unit and the possibility of reducing ammonia emissions by regulating the intensity of the ventilation in cowsheds. The air exchange rate represents an important determinant of ammonia emissions. A 4.5 times increase in ventilation rate causes ammonia emission to increase by 1.7–2.5 times. The effect of ventilation rate on ammonia emission from manure was found to increase under the condition of extremely high airflow rates, i.e. over 250 m^3 h^{-1} m^{-2}. Under the recommended ventilation rate of 105–420 m^3 h^{-1} per cow, ammonia emission will vary from 2016 to 3195 mg h^{-1}, respectively. The ammonia emissions can be significantly reduced in dairy cattle barns by reducing ventilation rates provided the air quality indicators remain in conformity with the requirements. The ammonia emissions can also be reduced in barns by controlling and diverting air flows inside the barns by preventing the clean air from reaching fresh manure as much as possible while reducing the vertical concentration gradient of ammonia.

Key words: cattle barn, manure, ventilation rate, ammonia emission

Intensive agriculture operations increase emissions of harmful gases into the environment. According to scientists, as much as 83–91% of total ammonia emission to the environment is accounted for by livestock operations (Bluteau and Daniel, 2009; Sanz et al., 2010). The reduction of ammonia emissions is one of the most widely considered matters within modern farming. Ammonia emissions not only lead to poor quality of air in livestock barns, but also contribute to the acidification of soils and surface waters, eutrophication, deforestation, etc. (Erisman et al., 2008; Menzi et al., 2006; Pereira et al., 2010), which in turn have a major effect on the atmosphere, the environment and the sensitive natural ecosystem. Over the last 140 years ammo-

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nia emission has increased by almost 4 times in land and water ecosystems (Lynch and Kerchner, 2005).

Consequently, the reduction of ammonia emissions into the atmosphere and reduction of air pollution with these gases in cattle barns continues to gain importance. The concentration of ammonia in a barn is associated with other factors related to its microclimate. Many scientists consider the microclimate in a barn to be influenced by several weather factors such as wind velocity, air temperature and relative humidity (Ngwabie et al., 2011; Pajumägi et al., 2008; Zhang et al., 2008; Wu et al., 2012). One of the prerequisites for maintaining a non-harmful environment in different types of animal houses is an appropriate ventilation system. As natural ventilation systems are the most common, many scientists (Philippe et al., 2011; Samer et al., 2012) have studied the influence of air exhaust location and ventilation rate on the emission of NH_3 in dairy cattle barns. The concentration of ammonia is by 37% higher in a cattle barn under low ventilation rate (5–16 m^3 h^{-1}) when compared to intensive ventilation (15–40 m^3 h^{-1}). However, an increase in ventilation rate by 2.7 times causes the emission to increase by 37%. A disproportion of the concentration of ammonia to variation in ventilation rate is also proved by research papers published by other scientists (Blanes-Vidal et al., 2008). A 4.5 times increase in ventilation rate in a cattle barn causes the air concentration of NH_3 to decline by 1.7 times, whereas its spread into the atmosphere rises by 2.5 times; thus, in order to reduce the atmosphere pollution it is recommended to reduce the ventilation rate in cattle barns. However, excessive reduction of ventilation rates leads to reduced air quality in cattle barns (Kang and Lee, 2008).

Emissions of ammonia are often different among regions because the amount of emitted pollutants is dependent on different microclimatic factors (Samer et al., 2012; Snell et al., 2003). Although there is an abundance of scientific studies that have been carried out in naturally ventilated cattle barns to determine the effect of ventilation rate on the gas emission from manure, the research results obtained by many scientists are very different and highly variable. In these cattle barns, air exchange takes place through the entire wall and rooftop of the barn making accurate measurement of gas emission very difficult and time consuming. There is a lack of standardized methodology and accurate measurement equipment which makes comparison of measurement results for ammonia emissions very difficult. Scientific literature often describes emissions of ammonia expressed in non-standard units, e.g. per heat release of one animal, per animal body weight, per animal space, per accumulated amount of manure. Comparison of results is also difficult due to the use of research methods with different reliability levels (Flesch et al., 2005; Ni and Heber, 2010).

To ensure a good microclimate within a cattle barn and reduce ambient air pollution, it is highly important to determine the optimum ventilation rate for a cattle barn. Optimization of the ventilation rates in cattle barns requires for the ventilation rates to be associated with ammonia emission rates from cattle manure.

The objectives of this study were to establish air flow influence of ammonia emissions from manure and to evaluate the possibilities to reduce ammonia emissions by regulating the intensity of the ventilation in cowsheds.

Material and methods

The present study of ammonia emissions from manure was accomplished in accordance with the mass flow measuring method (Amon et al., 1997). Knowing the chamber ventilation rate, G, m^3 h^{-1} and gas concentration in the chamber intake air, C_o, mg m^{-3} and its outlet air, C_i, mg m^{-3} the emission rate was calculated using the Equation as follows:

$$E = (C_i - C_o)\ G$$

While modelling the ventilation rates in a cattle barn in the laboratory test unit (Figure 1), the patterns of gas emissions from manure were analysed. This research enabled us to find out the variation of harmful gas emissions from different cattle manure depending on the ventilation rates. The rates of ammonia emissions from manure were related to the humidity evaporation rates from manure. The water evaporation rate was determined through mass flow measuring and calculated from Equation 1 after replacing the ammonia concentration with the absolute humidity values of chamber intake air and outlet air. For the purpose of the obtained emission data to be suitable for forecasting ammonia emissions in cattle barns, the analysis of the research results used comparative values: ammonia emission rate was recalculated for a square metre of the manure surface area, and ventilation rate in m^3 h^{-1} per square metre of the manure surface area, i.e. in m^3 h^{-1} m^{-2}.

The source of gas emissions – manure (1) was spread of 0.12–0.13 m thickness layer into the air-tight chamber with controlled air flow (3) with the capacity of 100 litres. The temperature of the manure was measured using thermo sensors (2). The controlled air-flow chamber was sealed by closing the cover (4) and connected to the duct for air supply into the chamber (5) as well as to the rigid air duct with a diameter of 50 mm (7) that was used for exhausting the air out of the chamber. The length of this duct was more than 0.5 m, i.e. its length was more than 10 times its diameter. This was to ensure the laminar air flow at the location of air sampling. This duct was fitted with a valve (10) and a ventilation fan with frequency inverter (11) for the control of the air flow rate. The clean air of the pre-set temperature travels from the climatic test chamber (19) Memmert Model 100-800 (MEMMERT GmbH, Germany) through the air supply duct (5), and enters into the controlled air-flow chamber (3), whereas contaminated air is evacuated through another duct (7) out of the chamber. This duct, which serves for the supply of the contaminated air to the laser gas analyser (15) GME700 (SICK MAIHAK GmbH, Germany), is fitted with an air sampling probe (8). The measurement range of the NH_3 analyser is 0 ppm to 2000 ppm, measuring principle – laser spectroscopy. The heating option of intake gas is built into the analyser to protect the measuring cell from contamination and condensation from water vapour. Air is supplied to the analyser through heated hoses (18) and power-heated 3-channel valves (16).

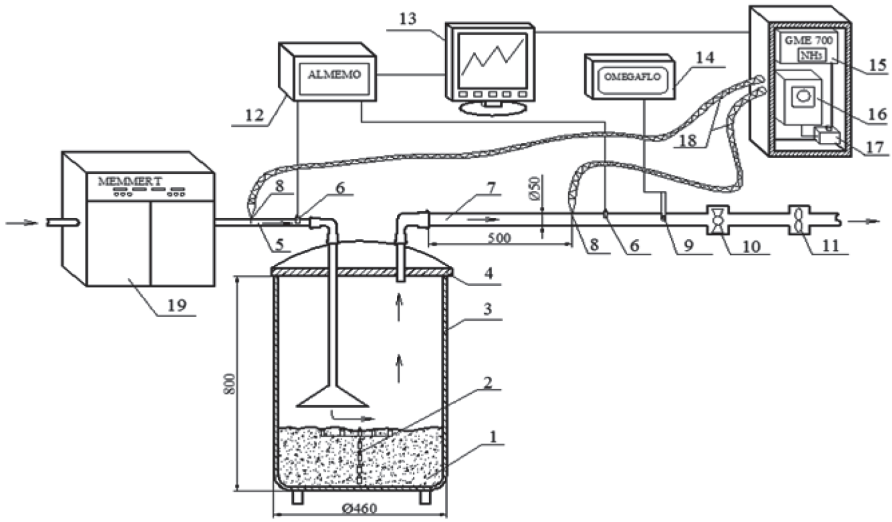

Figure 1. The schematic representation of the experimental test unit for analysis of gas emissions from manure: 1 – source of gas emission (manure); 2 – thermo sensors; 3 – controlled air-flow chamber; 4 – chamber cover; 5 – air supply duct into the chamber; 6 – sensors of temperature and humidity; 7 – rigid air duct (with a diameter of 50 mm); 8 – air sampling probes; 9 – sensor of a thermal anemometer; 10 – valve; 11 – ventilation fan with frequency inverter; 12 – measuring data logger; 13 – computer (with AMR software); 14 – anemometer; 15 – laser gas analyser; 16 – power-heated 3-channel valves; 17 – a diaphragm-type air pump; 18 – heated air-supply hoses; 19 – climatic test chamber

Before starting the experiment, the gas analyser and data logger Almemo 3290 (12) with sensors FH A646–21 (Ahlborn GmbH, Germany) were synchronized and pre-programmed to log data continuously in time intervals of 1 min. During the experiment, the temperature of the air fed into the chamber was held constant (about 19°C, corresponding to an average air temperature in cowsheds during the warm periods of the year in Lithuania), whereas the air flow supplied into the chamber was varied. The test experiment was started with low air velocity within the duct (around 0.4 m s^{-1}) which was then gradually increased to 6 m s^{-1}. This way the ventilation rate of the chamber was varied within a range of 2.61 to 40.0 m^3 h^{-1}, and when subdivided by the area of manure surface above which the air movement appeared, the air flow ranged from 15.7 to 236.7 m^3 h^{-1} m^{-2}.

Air velocity within the duct was measured using an anemometer (14) Omegaflo HH-600 Series, Model 615M (Omega, USA), measuring range 0–30 m s^{-1}, accuracy ±0.1 m s^{-1}. The temperature and relative humidity of the air entering the controlled air-flow chamber and that emitted out of it were measured using the respective sensors (6), connected to the data logger (12). Measuring range of temperature was from –30 to 60°C, relative humidity from 5 to 98%, and accuracy of the device was ±0.1%.

For the purpose of experiment, fresh cattle manure was collected at the stable period in the half-deep dairy cattle barn. The liquid manure (DM<12%) was collected in the parlour near the milking room, semi-liquid manure (12%< DM<20%) – from the pathway along the feed table, and the thick manure (DM>20%) – in the cubicle.

Before starting the experiment, the manure dry matter content based on the standard LST 1530:2004 requirements was established. Twelve samples prepared for drying were placed in the climatic test chamber (19) and dried at 105ºC for 24 hours. Emission studies from manure were repeated on 6–8 occasions. Analysis of the research data enabled the calculating of arithmetic means and their standard errors. The average values and confidence intervals for the 95% reliability were calculated. The correlation regression analysis of the final results was conducted.

Results

Depending on the layout and size of each cattle barn, the areas contaminated by cattle manure usually differ in size. In half-deep cattle barns, on average, the area contaminated by manure amounts to 6.7±0.6 m^2 per cow, whereas in cubicle barns it is 4.5±0.5 m^2. In Lithuania (Kavolelis, 2006), the recommended ventilation rate for dairy cattle barns in winter is 105 m^3 h^{-1} per cow (body weight of 600 kg), in spring and autumn – it is 210 m^3 h^{-1} per cow, and in summer – 420 m^3 h^{-1} per cow. Considering the sizes of the areas contaminated by manure, the ventilation rate indicated above per square metre of the barn area contaminated by manure is recalculated resulting in the ventilation rate for cubicle barn ranging from 23.3 to 93.4 m^3 h^{-1} m^{-2}.

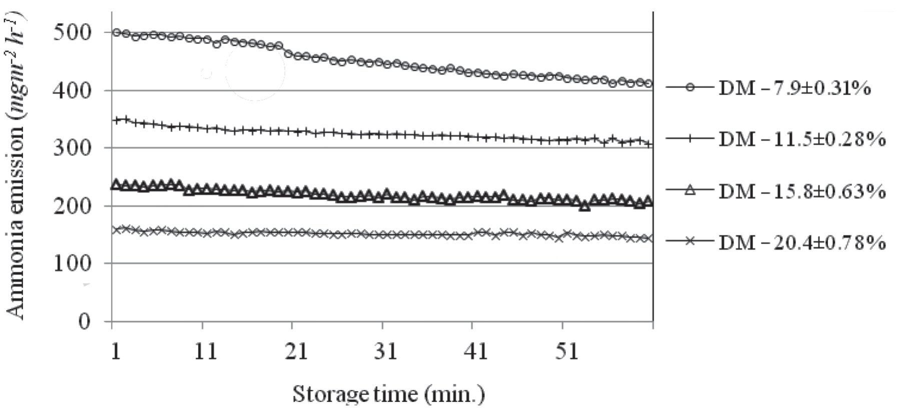

Figure 2. Ammonia emission rates during the storage of manure containing variable amounts of dry matter (DM – dry matter content in manure)

When testing ammonia emissions from manure, the variance in gas emission rate during the storage of manure was determined in the first place. In our experiment, the temperature of the clean air fed into the chamber was held constant at 19.4±0.7°C, relative air humidity amounted to 35.7±3.9%, and the chamber was ventilated at the constant rate (4.05 or 24.5 m^3 h^{-1} per square metre of the manure surface area).

The ammonia emission rate was found (Figure 2) to be declining much more when manure was stored in a liquid form. However, the reduction in this gas emission over the period of 10 min. was modest, below 3.6%; whereas over 15 min. it was 4.3% ($P<0.05$). For this reason, the investigation of the effect of ventilation rate on the gas emission process must be accomplished in a period of up to 15 min., due to the fact that when manure is stored, water intensively evaporates from the manure resulting in reduced water content (humidity) on the surface of the manure, and formation of a crust on the top of it which leads to reduced emission of ammonia. Although variation in the rates of evaporation of ammonia and water from manure was slightly different, a strong correlation was found to exist between these values ($R^2>0.92$), based on which, with the water evaporation rate known, ammonia emission from manure can be predicted (Figure 3).

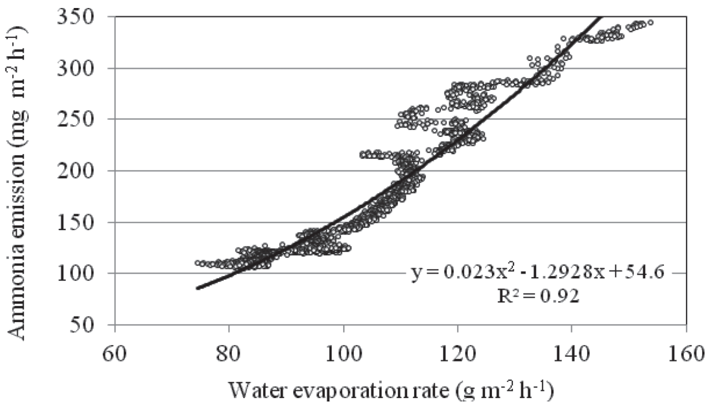

Figure 3. Dependency of ammonia emission on the rate of water evaporation from manure (dry matter content in manure 11.5±0.36%)

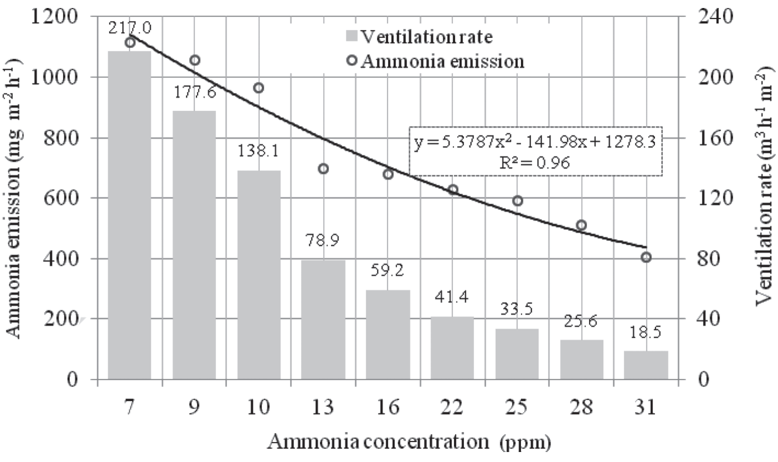

Figure 4. The dependency of ammonia emission from the liquid cattle manure on the ammonia concentration under different ventilation rates (dry matter content in manure 8.1±0.6%)

With the aim to find the effect of ventilation rate on the concentration of ammonia gas within the chamber, and the rate of emission from manure, we undertook the experimentation on fresh manure with different humidity, and on manure stored for a period of several days under natural conditions leading to a dried surface. The experiment with each type of manure took 8–12 min. during which the air of a constant temperature of 19.5±0.8°C was supplied into the chamber, and the ventilation rate within the chamber was varied.

With an increased ventilation rate, the concentration of ammonia within the chamber decreased, and emission rapidly increased (Figure 4). As the ventilation rate increased from 18.5 to 217.0 $m^3 h^{-1} m^{-2}$, the concentration of ammonia decreased from 31 to 7 ppm, and emission from liquid manure increased from 406.4 to 1124.2 mg $m^{-2} h^{-1}$.

With increasing air flow above the layer of manure under investigation, the vertical gradient of gas concentration increased above the manure. For this reason, the molecules of the manure on the surface are rapidly released through chemical and microbiological processes, and molecules diffuse to the surface through peripheral layers of the manure. A reliable correlation between the rate of ammonia emission from manure and the concentration of ammonia above the manure was discovered, which is expressed as a polynomial function of the second degree ($R^2 = 0.96$).

Experimentation with fresh manure and manure stored for different periods of time showed different ammonia emissions from manure and different effects of ventilation rate on ammonia emission. Figure 5 depicts the influence of the ventilation rate on ammonia emission from fresh manure and manure stored for different periods of time rates (dry matter content in manure 18.1±0.72%).

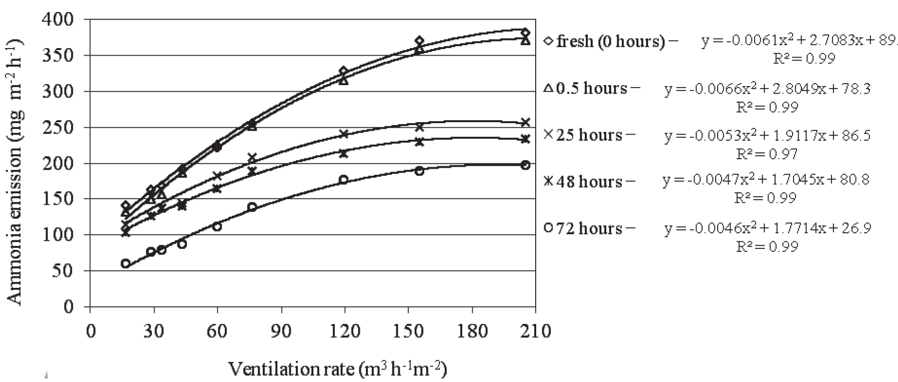

Figure 5. The effect of ventilation rate on ammonia emission from cattle manure following manure storage for different periods of time (dry matter content in manure 18.1±0.72%)

When manure is stored, its surface dries and a crust forms on the top of it, which leads to a reduced emission rate of ammonia from manure. After manure has been stored for 3 days, ammonia emission from it decreases by 1.8 to 2.4 times when compared to fresh manure; moreover, under a lower ventilation rate the emission is decreased further. The effect of ventilation rate on ammonia emission is higher under a more intensive ammonia emission from manure, i.e., in the case of fresh manure. An increase in ventilation rate from 16.7 to 205.4 $m^3\ h^{-1}\ m^{-2}$ caused the ammonia emission from each square metre of fresh manure to increase by 240 mg per hour, whereas that from manure stored for 3 days, increased by only 130 mg per hour. Similar results were obtained through research with fresh manure of different humidity (Figure 6).

Ammonia emission from manure containing 7.5% of dry matter was significantly higher when compared to manure with a dry matter content of 20.4% (Figure 6). In the case of more humid manure, a more pronounced effect of the ventilation rate on the ammonia emission was also observed.

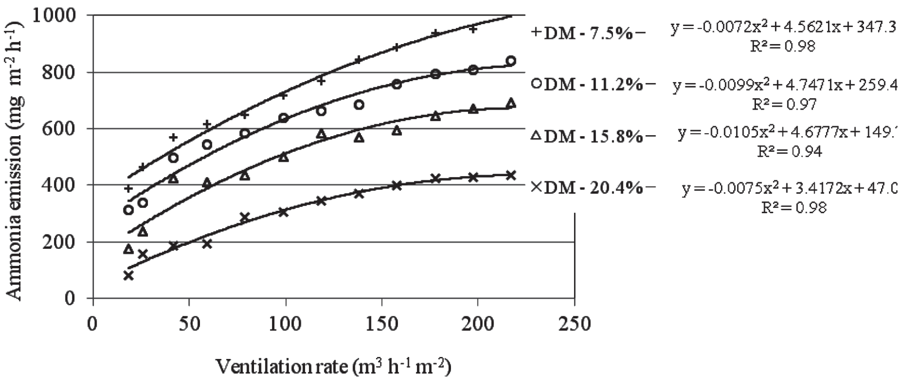

Figure 6. The effect of ventilation rate on ammonia emission from cattle manure with different dry matter contents (DM – dry matter content in manure)

An increase in ventilation rate from 18.5 to 217.1 $m^3\ h^{-1}\ m^{-2}$ caused the ammonia emission from manure with a DM content of 20.4% to increase by 351 mg per hour, whereas that from manure with a DM content of 7.5% increased by as much as 618 mg h^{-1}.

Discussion

The effect of air ventilation rate on the ammonia emission from manure was found. The results of this study confirm findings previously reported by other scientists (Blanes-Vidal et al., 2008; Kang and Lee, 2008; Philippe et al., 2011; Samer et al., 2012) that, with increasing ventilation rate, ammonia concentration decreases indoors, whereas emission non-proportionally increases. The effect of air ventilation rate on the ammonia emission found in our research has been expressed as a polynomial function of the second degree (R^2>0.97), and was slightly higher than that reported by other scientists. Following a 4.5 times increase in ventilation rate, ammonia concentration inside the chamber decreased by 1.9–2.4 times, whereas emission increased by 1.7–2.5 times ($P<0.05$). However, a more accurate comparison of actual values of emissions with research results reported by other authors necessitates the taking into consideration of all the factors that contribute to the effect of ventilation rate on gas emission from manure. The present experimental research showed that the more intensive evaporation of ammonia from manure, the higher the effect of the air flow on the ammonia emission rate. Consequently, the effect of ventilation rate on ammonia emission will also be influenced by the dry matter content in manure, its chemical composition, protein content in manure, temperature, storage time of manure, and crust formation on the top of the manure (surface drying), etc.

It is absolutely necessary to ventilate cattle barns not only in summer and spring, but also in winter time even though the weather is cold, in order to eliminate excessive humidity from the barn (Kavolelis et al., 2010). The main reason behind the poor microclimate inside dairy cattle barns is the incorrect adjustment of ventilation rate under variable outdoor air temperature. Therefore, the air inside barns often happens to be contaminated with harmful gases. The best way to reduce harmful gas concentration is by increasing ventilation rates. However, an increase in ventilation rate causes the vertical gradient of gas concentration above the manure layer to increase, resulting in a significant increase in ammonia emission. The ventilation rate will have no significant effect on the variation of ammonia emissions only under extremely intensive air exchange, i.e., above 250 $m^3 h^{-1} m^{-2}$; however, taking into consideration the area of cattle barn contaminated by manure, it results in 1125 $m^3 h^{-1}$ per cow. We have found that increasing the ventilation rate leads to a variation in the speed of ammonia emission increase, which is linearly decreasing. The speed of increase in ammonia emission from thick manure (DM content 20.4%) becomes very low after the ventilation rate is increased up to 185–206 $m^3 h^{-1} m^{-2}$, whereas an increase in ammonia emission from liquid manure (DM content 7.5%) is significantly slowed down only after the ventilation rate exceeds 250 $m^3 h^{-1} m^{-2}$. Similar data was obtained through experimentation with manure stored for 3 days under natural conditions, when the surface of manure was dried off, and the emission from it was significantly reduced resulting in a significantly reduced effect of ventilation rate on ammonia emission. This effect was as insignificant after the ventilation rate increased above 150–160 $m^3 h^{-1} m^{-2}$. Based on data reported herein, it follows that the effect of ventilation rate on ammonia emission is highly significant within the entire range of ventilation rates recommended for cattle barns, which following recalculation per square metre of the barn area contaminated by manure is from 23.3 to 93.4 $m^3 h^{-1} m^{-2}$.

In pursuit of reducing ammonia emissions from barns, the control of ventilation rates is highly purposeful. For example, under an air temperature of 19ºC, a reduction of ventilation rate by 10% (from 400 to 360 $m^3 h^{-1}$ per cow) will result in reduced ammonia emission per cow by some 5.4% (from 3.15 to 2.98 $g h^{-1}$), which is equal to reduction of ammonia emissions per cow during the stable period of 210 days by 857 g.

However, this optimization of the above indicated processes lacks data regarding the formation of the crust on the surface of manure. In our attempts to analyse these processes we have faced methodological problems, e.g. how to accurately determine the humidity of manure surface layer-crust. For this reason, the issue regarding the effect of crust formation rate at the surface of manure on the ammonia emission from it remains an open question.

The following conclusions were drawn:

– The potential for reducing atmosphere pollution with ammonia gas from cattle barns by reducing air exchange inside them is rather good.

– The ammonia emissions can also be reduced in barns by controlling and diverting air flows inside the barns by preventing the clean air from reaching fresh manure as much as possible while reducing the vertical concentration gradient of ammonia.

– It is also recommended to promote drying of the surface of manure and formation of the crust under natural conditions and using artificial means such as litter bedding, etc.

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