Integrated solutions to reduce gaseous emissions from pig production

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Abstract

This paper describes the development and validation of a housing system for growing-finishing pigs with an integrated solution for source oriented measures to reduce emissions of ammonia, greenhouse gases (methane), and odor. In the development phase a simple calculation tool was used to make an estimate of the ammonia emission that could be expected. In the validation phase the system was tested on two farms in a case-control setup. Preliminary studies were done to determine the effect of cooling and flushing on the ammonia emission. From this study the following can be concluded: - a rather simple model can be very useful in design studies to reduce (ammonia) emissions; - cooling of manure is effective in reducing ammonia emissions, but is less suitable in combination with a biogas digester; - ammonia emission only showed a minor rise during flushing of manure; - the designed low emission housing system, with daily removal of manure, small emitting area and diluted manure, lowered ammonia emissions by 54%, methane emissions by 90%, and odor emissions by 28%; - reductions of ammonia and odor can be increased by good management of the whole system.

Keywords: ammonia, methane, odor, emissions, pig housing, indoor climate

Introduction

The Netherlands has the highest nitrogen emission level per square kilometer from all countries in Europe. A large part of it is coming from livestock production, mainly in the form of ammonia. While nature areas are threatened, these emissions should be reduced. Therefore a program has been started to test innovative systems at commercial farms that not only mitigate the emission of ammonia, but also of methane, and odor. To create a win-win situation it is not only stimulated to reduce emissions to the environment, but also to improve indoor climate by reducing emissions at the source. In the Netherlands, more than 50% of the pigs are housed behind air scrubbers. Although air scrubbers are very effective in reducing emissions of ammonia and odor to the environment, they fail to improve the indoor climate and they cannot remove the methane from the air. The source oriented innovative systems are generally based on one or more of the following principles: - frequent and complete removal of manure (flushing, scraping, belt); - separation of urine and feces; - cooling of manure; - dilution of manure; - optimizing indoor climate (e.g. cooling in summer); - reducing the emitting area. Within this paper a description is given of the development and validation of a housing system for growing-finishing pigs with an integrated solution for source oriented measures to reduce emissions of ammonia, greenhouse gases (methane), and odor. In the development phase a simple calculation tool was used to make an estimate of the ammonia emission that could be expected (Aarnink et al., 2023). In the validation phase the system was tested on two farms in a case-control setup. Preliminary studies were done to determine the effect of cooling and flushing on the ammonia emission. In the next paragraphs the design study, the preliminary studies and the validation study are presented.

Design study

The design study was especially focused on emission reduction of ammonia but an important boundary condition was that methane emission should be (highly) reduced, as well. A typical pen design for growing-finishing pigs in the Netherlands is given in Figure 1. The estimated ammonia emissions from the different sources are based on the following starting points (Aarnink et al., 2023):

- Emission from the manure pit: 4.2 kg per m^2 emitting area per year.
- Emission from concrete slatted floors: 0.75 kg/y per animal place.
- Emission from fouled solid floors: 4.3 kg per m^2 emitting area per year.
- Fouled solid floor: 10% of solid floor area.

These starting points are valid for an average situation at Dutch fattening pig farms. Ammonia emissions per m^2 are depending on a lot of factors, especially related to the diet, determining the TAN concentration and the pH of the manure, and related to indoor climate and airflow patterns. In this study we are especially interested in relative differences and to a lesser extend in absolute emission values. Therefore, to simplify the design study, these standardized emissions per m^2 have been used.

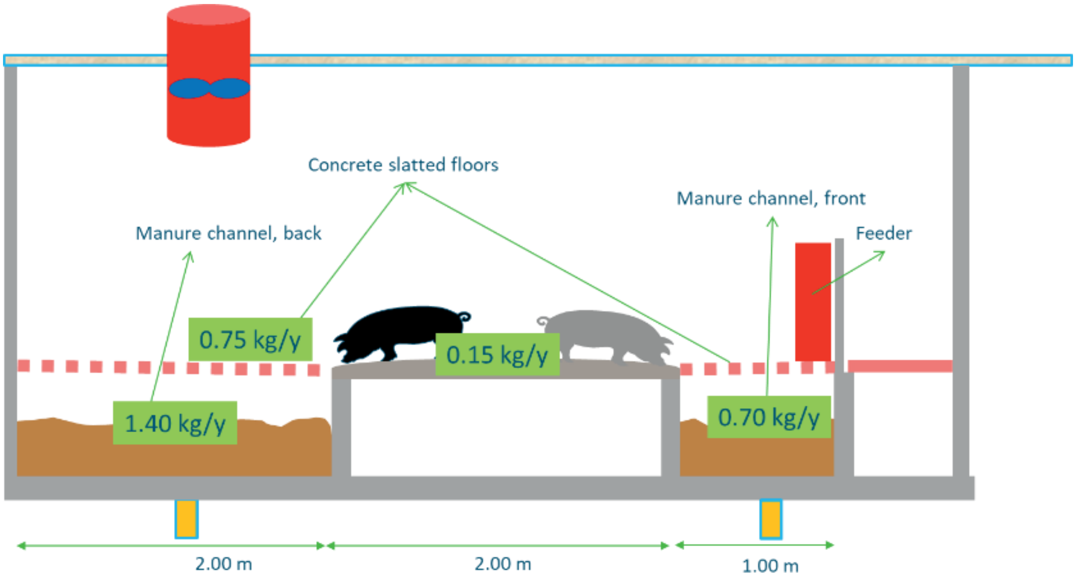

Figure 1: Typical pen design for growing-finishing pigs in the Netherlands. The green blocks give the estimated ammonia emission from the different sources in kg/y per animal place.

From the reference pen as given in Figure 1, a new pen design was made with an expected high reduction of ammonia emission. The following reduction principles were used:

- Reducing the emitting area
- Lowering the manure temperature
- Lowering the TAN concentration by dilution with water

The emitting area was reduced by decreasing the slatted floor area, and at the same time increasing the solid floor area, by using slanted walls in the manure channel, by daily removal of the slurry (by flushing with manure from another room), by using metal slatted floors, and by reducing pen fouling. The manure temperature was lowered by cooling the slanted walls with ground water. The TAN concentration in the front manure channel was lowered by starting the fattening period with a layer of water in this channel. The following additional starting points to calculate the ammonia emissions from the different sources were used:

- Emission from metal slatted floors: 0.24 kg/y (Groenestein et al., 2014).
- Fouling of solid floor is reduced from 10 to 5% of the solid floor area by cooling the floor in the summer season (assumption).
- The slanted walls form an additional source of ammonia. In a study of Aarnink et al. (2018) it was found that approx. 17% of the slanted wall at the solid floor side was fouled with urine and approx. 33% of the slanted wall at the wall side. It was assumed that the ammonia emission per m^2 fouled slanted wall is similar as the emission from the manure pit.
- Cooling the manure channel with the slanted walls to a temperature of 14°C the ammonia emission from this manure and from the fouled slanted walls can be reduced with approx. 50% (Aarnink et al., 2023).
- Because pigs generally don't excrete where they are eating and lying, it was expected that only a small part of the manure is produced in the front manure pit (Aarnink et al., 2018) and that by starting with a layer of 20 cm of water in combination with spoiled drinking water from the drinking nipples, the manure would be diluted with a factor 5. Because of the linear relationship between TAN concentration and ammonia emission (Aarnink and Elzing, 1998), ammonia emission from this manure pit is expected to be reduced with the same factor as the dilution factor.

The finally designed pen is given in Figure 2. It was expected that this pen design would achieve an ammonia emission reduction of 75% when compared with the reference pen in Figure 1.

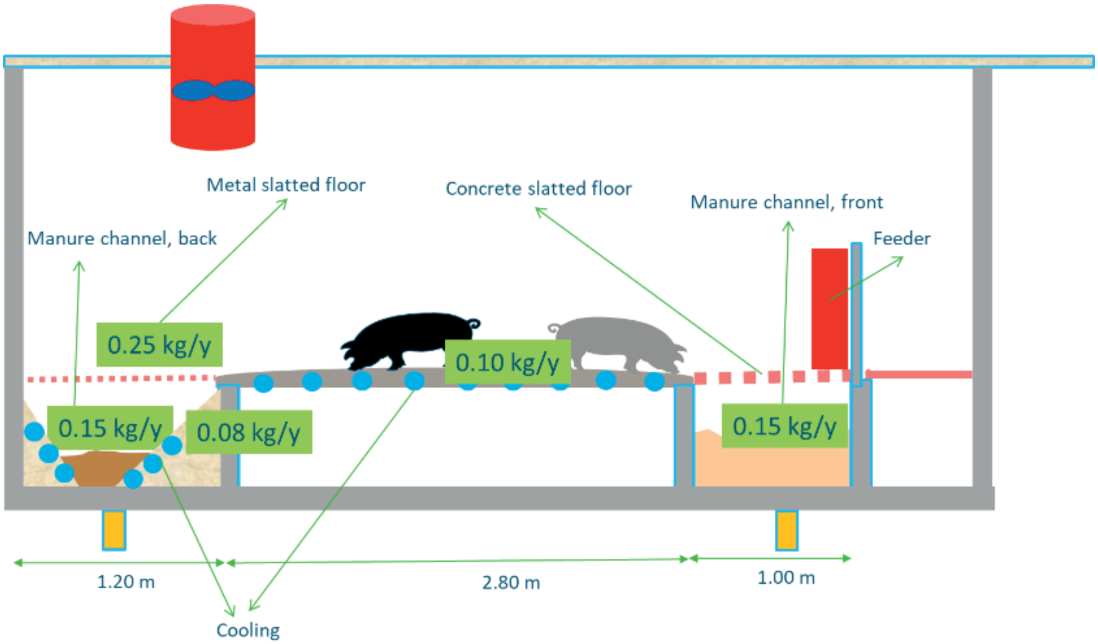

Figure 2: Newly designed pen for growing-finishing pigs with an expected low emission of ammonia. The green blocks give the estimated ammonia emission from the different sources in kg/y per animal place. Expected ammonia emission reduction compared with reference pen: 75%.

Preliminary studies

Two preliminary studies were performed. A manure cooling study and a manure flushing study.

Manure cooling

The effect of manure cooling in a room for fattening pigs, as shown in Figure 2, has been studied during a winter and a summer period. The winter trial was performed during day 1 to 36 and the summer trial from day 48 to 75 after the start of the fattening period (at approx. 25 kg). During the winter trial, the cooling of the sloping walls and the manure was switched on and off for 3 periods each with a minimum period of on and off of at least 6 days. During the summer period, the cooling was on for 4 periods and off for 3 periods. These periods also alternated with the minimum period of on and off being at least 3 days. It should be noted that for the summer trial the capacity of the cooling system was largely increased. The effect of cooling on the ammonia emission was determined by comparing the ammonia emission of periods with cooling with periods without cooling. During the summer trial, in addition to the ammonia emission, the surface temperature of the sloping walls and of the manure was measured. The effect of manure cooling on ammonia emissions has been analyzed with the following statistical model:

$$E_{7r+} = b0_{!} + b1 \cdot x1_{!} + b2 \cdot x2_{!} + power(day\ no_{!}) + \varepsilon_{!}$$

Where: E_{NH_3} is the ammonia emission (kg/y per animal place); b0, b1, b2 are regression coefficients; x1 is the day number of the trial (trial day number = 0 at start trial; i is trial number (winter trial: i=1; summer trial: i=2); x2 is a dummy variable (no cooling: x2=0; with cooling: x2=1); power(day no) is the increase of ammonia emission during the growing period (day no = 0 at start growing period); ε is the residual variance

The analysis showed that during the winter trial ammonia emissions decreased by 5.9% (n.s.) and in the summer trial by 25.4% ($P<0.05$) when the cooling was turned on. There was a significant interaction effect of trial period and cooling. This can be explained by the fact that the capacity of the cooling system during the winter trial was insufficient to cool the manure. Before the summer trial this capacity was increased. During the summer trial, the average temperature of the sloping walls in periods without cooling was 21.5 ± 1.8°C and the surface temperature of the manure was 21.5 ± 1.7°C; with cooling these were 17.8 ± 1.3°C and 19.9 ± 2.0°C respectively. This means an average difference between manure cooling off and on of 3.6°C for the sloping walls and 1.6°C for the surface of the manure. Theoretically, the expected effect would be 7% per °C decrease in the surface temperature of the manure (Aarnink and Elzing, 1998). The measured effect of 25.1% is higher than expected. This could be caused by the formation of a stable (cold) layer of air in the manure channel that hardly mixes with the air above the slatted floor, slowing down the transport of ammonia from the manure channel.

Manure flushing

Flushing manure could temporarily increase ammonia emissions, as the walls of the flushing channel become extra soiled with manure. To determine this, the development of the ammonia concentration in the air around the daily flushing of the fresh manure was analyzed. A total of 175 rinsing cycles were analyzed. A curve has been fitted that describes the course of the NH_3 concentration as a function of time after flushing. For this, three parameters have been estimated that describe this curve: - b1, which mainly controls the slow process of linear rise after flushing; - b2, this mainly regulates the rapid fall after the peak; - b3, this mainly controls the rapid rise in the very first phase before the peak. Parameters b2 and b3 were significantly different from 0 (b2: $p<0.001$; b3: $p<0.001$) and there was an indication of a significant difference for parameter b1 (b1: $p<0.10$). Figure 3 shows the fitted curve for ammonia concentrations in relation to time (hours) after flushing. It can be concluded from this figure that there is a small increase in the ammonia emission immediately after flushing and then it decreases gradually until the next moment of flushing. While during flushing ammonia emission is only minor increased, it is worth considering flushing the manure more often (e.g. twice a day), especially at the end of the fattening period when the animals produce more manure.

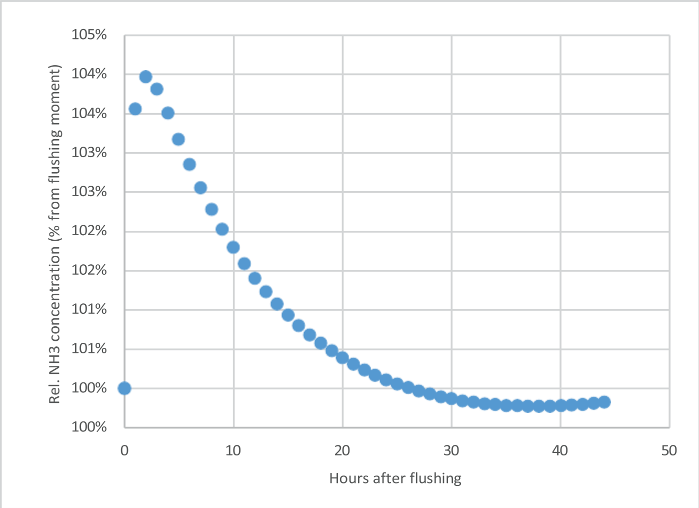

Figure 3: Effect of flushing on the course of the ammonia emission when the flushing moment itself is set to 100%. The X-axis shows the number of hours after flushing.

Validation study

Materials and methods

During one year, emissions have been measured on two farms in a case-control setup. The pens in the control rooms were similar to Figure 1 and the pens in the experimental rooms were similar to Figure 2 with the exception that within this final validation study no cooling of the manure and the slanted walls occurred. This was mainly done because of energy efficiency reasons, while the cooled manure was daily moved to a biogas digester in which the manure had to be heated again. The manure in the control room was stored for a long period. At regular intervals a part of the manure was removed from the pit. In the experimental room the manure was removed daily by flushing it with fresh manure from another room at a flow of 16 m^3 per hour. This manure was pumped into the pit (via a valve) at the beginning of the manure channel. The other side of the manure channel was connected to a sewer pipe, which ended in a pit outside the barn.

Emissions of ammonia (Ogink et al., 2017), methane (Groenestein et al., 2011) and odor (Ogink, 2011) were determined according standardized measuring protocols. Ventilation rate was measured with a calibrated anemometer with the same diameter as the fan duct. Temperature and relative humidity were measured in each room near the fan ducts (Vaisala HMP60). The following was additionally determined: number and age of the pigs and fouling of the solid floor (with urine).

The ammonia emission was calculated with the following equation:

$$E_{1\text{ö}} = \bullet C_{\mathbf{j}\,\text{åp}_{1\text{ö}}} - C_{1m_{1\text{ö}}} \text{¶} \cdot 0,71 \cdot V_{1\text{ö}} \cdot 24 \cdot 365/10\cdot$$

Where E_{ij} is the ammonia emission at farm i at measuring day j (kg/y per animal place); C_{out} is the ammonia concentration in the exhaust air (ppm), C_{in} is the ammonia concentration in the incoming air (ppm); 0.71 conversion factor from ppm to mg/m^3; V is the ventilation rate (m^3/h); $24 \cdot 365/10^{\cdot}$ is the conversion from mg/h to kg/y per animal place.

Methane emission was calculated in a similar way, only with a conversion factor of 0.667. Odor emission was calculated in odor units per second (OU_E/s) without correction for the incoming concentrations. Odor data were analyzed at log-scale.

Results and discussion

The results of the indoor climate and emission measurements are shown in Table 1. On average the indoor temperature was higher inside the experimental room than in the control room. This probably was caused by a bit higher ventilation rate and by the cooling of the solid floor in summertime. A mean ammonia emission reduction of 53.7% was found. This is a lot lower than the predicted 75%. This was probably caused by omitting the manure cooling in the validation study. The predicted ammonia emission without cooling would be 65%. This reduction was almost achieved at farm 1. The lower reduction at farm 2 was probably caused by a lower dilution of the manure in the front pit as was shown by the manure analyses, and by more pen fouling.

Table 1: Average values (standard deviation in parentheses) for the case-control rooms for fattening pigs of the temperature (°C), relative humidity (%), ventilation rate (m3/h), ammonia, methane, and odor emissions. All variables are split per farm (farm1 and farm2) and then presented as a mean. Per farm and as a mean, the reduction percentages between case and control are given.

	Farm1			Farm2			Mean		
	Case	Control	Reduction	Case	Control	Reduction	Case	Control	Reduction
Temperature	21.3 (1.7)	23.4 (0.67)	-	23.1 (2.00)	23.8 (1.8)	-	22.2 (2.0)	23.6 (1.3)	-
Relative humidity	67.3 (5.9)	66.8 (5.4)	-	61.2 (5.4)	68.8 (3.9)	-	64.3 (6.3)	67.8 (4.6)	-
Ventilation rate	42.5 (7.3)	39.2 (18.4)	-	35.5 (11.7)	34.3 (11.4)	-	39.0 (10.0)	36.8 (14.8)	-
Ammonia (kg/y per animal place)	1.0 (0.51)	2.63 (0.83)	62.7% (7.4%)	2.0 (0.93)	4.1 (1.4)	44.7% (31.6%)	1.6 (0.90)	3.4 (1.4)	53.7% (24.7%)
Methane (kg/y per animal place)	3.1 (1.3)	22.0 (5.0)	86.1% (5.6%)	1.9 (0.87)	24.9 (7.2)	92.5% (4.2%)	2.5 (1.2)	23.4 (6.1)	89.5% (5.7%)
Odor (OU_E/s per animal place)	23.8 (20.2)	42.7 (31.7)	44.2% (39.1%)	39.6 (24.0)	43.0 (26.5)	7.9% (39.9%)	30.7 (22.6)	42.9 (27.9)	28.3% (40.5%)

For methane a high emission reduction was measured at both farms, on average 89.5%. Due to the daily removal of the manure, the anaerobic conversion of organic matter in the manure cannot take place (Amon et al., 2007), which means that methane does not have the opportunity to form. The methane production in the compartment can therefore be reduced relatively easily with this system and this production can be moved to a digester. Monteny et al. (2006) reported an enteric methane production from fattening pigs of 1.4 kg/y. The 2.5 kg methane emission measured within this study for the experimental rooms is higher, probably caused by some fermentation in the manure pit in front of the pens. The (diluted) manure from that pit was only removed at the end of the fattening period. The excreted manure in combination with some spoiled feed in this front manure pit could have caused this extra methane emission.

There was a high difference in odor reduction between farm 1 and 2, 44.2 and 7.9%, respectively. Generally, the management of the total system was a lot better at farm 1 than at farm 2, this in combination with extra pen fouling at farm 2 might be the reasons for the lower odor reduction at farm 2.

Conclusions

From this study the following can be concluded:

- A rather simple model can be very useful to be used in design studies to reduce (ammonia) emissions.
- Cooling of manure is effective in reducing ammonia emissions, but is less suitable in combination with a biogas digester.
- Ammonia emission only shows a minor rise during flushing of manure.
- The designed low emission housing system for fattening pigs proved to lower ammonia emissions by 54%, methane emissions by 90%, and odor emissions by 28%. Reductions of ammonia and odor can be increased by good management of the whole system.

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