Limited ammonia emission by inventive manure cellar ventilation and chemical air scrubber

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Abstract

EnviVice has performed ammonia measurements on a naturally ventilated dairy stable with an adaptable manure cellar ventilation system and chemical air scrubber (based on WUR report 1032a [1]). The big advantage of this cellar ventilation system is that the ammonia is directly extracted from the source (grid floor and manure cellar). After which the ammonia rich air can directly be forwarded through the chemical air scrubber. This allows for a small ventilation flow rate, which also means that the chemical air scrubber can have relatively small dimensions.

Further ventilation of the dairy stable is done by openings in the side walls and top of the stable. The total ammonia emission is determined by emission though the top of the stable in addition to the yield of the chemical air scrubber (efficiency over 90 %). The ammonia capture of the chemical air scrubber is determined by measurements. The results show that the ammonia capture is strongly related to the ratio of natural ventilation (dependent on wind direction and speed) and chosen cellar extraction flow rate.

The amount of captured ammonia can be determined and adjusted by measuring the CO_2-concentration in the manure cellar and the top of the stable. The ratio of the CO_2 mass flow rate in the manure cellar and the total CO_2 production (natural and cellar ventilation) is a measure for the effectiveness of the cellar ventilation compared to the natural ventilation. The average ammonia emission for the investigated stable with manure cellar ventilation and chemical air scrubber is 8.4 and 5.1 kg/animal/year for 35 % and 60 % of the maximum cellar ventilation flow rate respectively. The year-round average ventilation of a natural ventilated dairy stable is approximately 1200 m^3/hour/animal (WUR report 1285[2]). This means that an ammonia emission reduction of 60 % can be achieved by extracting and scrubbing a relatively small amount of (10 %) of the total amount of ventilated air.

Keywords: emission reduction dairy stable.

1. Introduction

Mulkzeewolde BV commissioned Envivice to measure the ammonia emission of naturally ventilated dairy stable (test stable) with manure cellar ventilation and chemical air washer. The advantage of the setup is the extraction of ammonia from the source (cellar), which allows for a relatively small ventilation rate. The small ventilation rate results in the subsequent air washer to be of relatively small dimensions. This setup consequently requires a relatively low amount of power per kilogram of avoided ammonia. Furthermore, the setup can effectively control and assure its emission reducing principle. A description of the emission reducing principle and the executed measurements is given below.

2. Materials and Methods

The stable under investigation is of the cubicle type and is designed to house 185 adult dairy and calf cows. To reduce the ammonia emission of the stable the following technique is used. The air from the stable is sucked through the manure cellar using the grid floor as the air intake. The air is then directed through the chemical air washer. This ventilation system aims to collect the air with a high ammonia concentration, which is present just above the grid floor and manure layer in the cellar (see five, in figure 1). The maximum average ventilation rate of the cellar is 200 m^3/hour/animal. During the measurement period the maximum ventilation rate was between 60 – 110 m^3/hour/animal, which is roughly 60% of the maximum possible ventilation rate. Meaning that the ammonia emission can possibly be reduced further for increased ventilation rates. The stable also allows for natural ventilation via the sidewalls and top of the stable. The natural ventilation is controlled to ensure animal welfare by a closable curtain in the sidewall. The ammonia is emitted through the top and sides of the stable (see 2, figure 1). As well as through the top of the air washer (see 4, figure 1). This means that the total emissions are determined by the ordinary emission through the stable's top and sidewalls in addition to the efficiency results of the chemical air washer. The chemical air washer used in the investigated setup is accepted for dairy cows and has an efficiency of at least 90 % (BWL2012.02). However, the actual ammonia reduction is strongly determined by the effectiveness of the cellar ventilation, the homogeneity of the ventilation rate over the grid floor surface and the effectiveness of the ammonia capture above the grid floor surface. To ensure correct operation of the chemical air washer during measurement, all required parameters are registered conform the prescription of the manufacturer. To monitor the cellar ventilation system, a flow control with alarm is installed in each of the 5 air intake channels. Figure 2 schematically shows the grid floor and 5 sections with separate air intake channels.

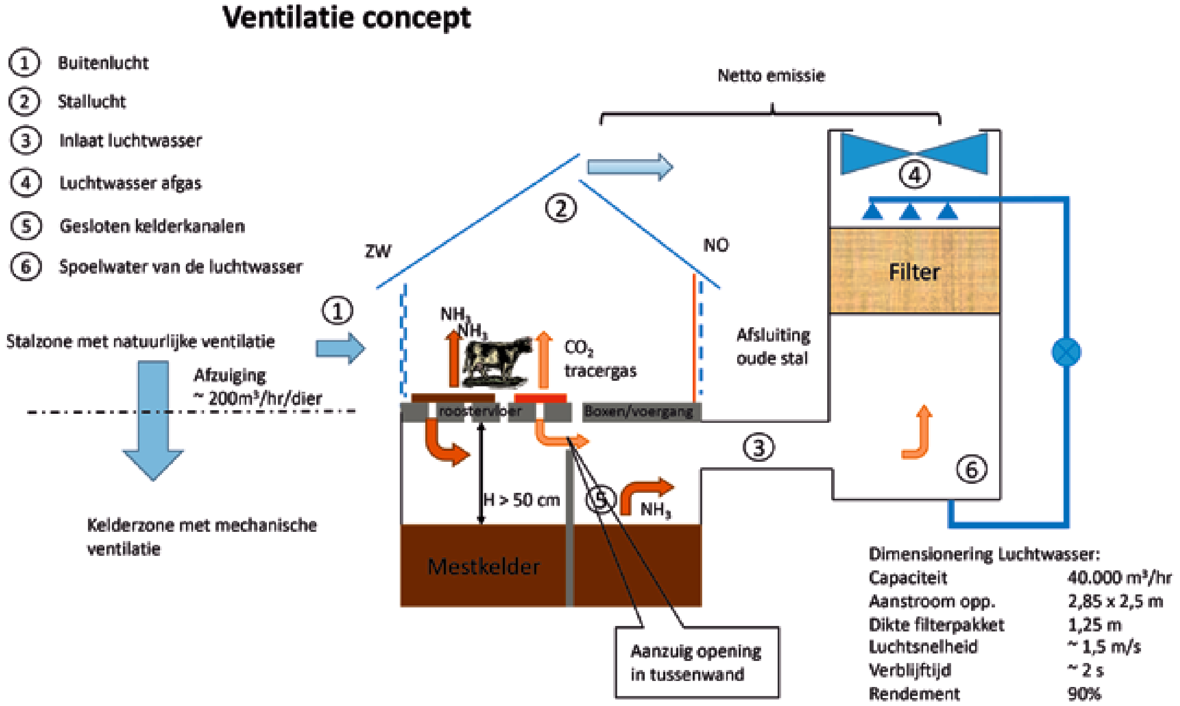

Figure 1. Schematic drawing of the air flow in the dairy stable, showing the cellar ventilation system (3 and 5) and subsequent air washer (4 and 6). Fresh air is supplied to the stable via the sidewall (1), natural ventilation occurs both via the sidewall (1) and top of the stable (2).

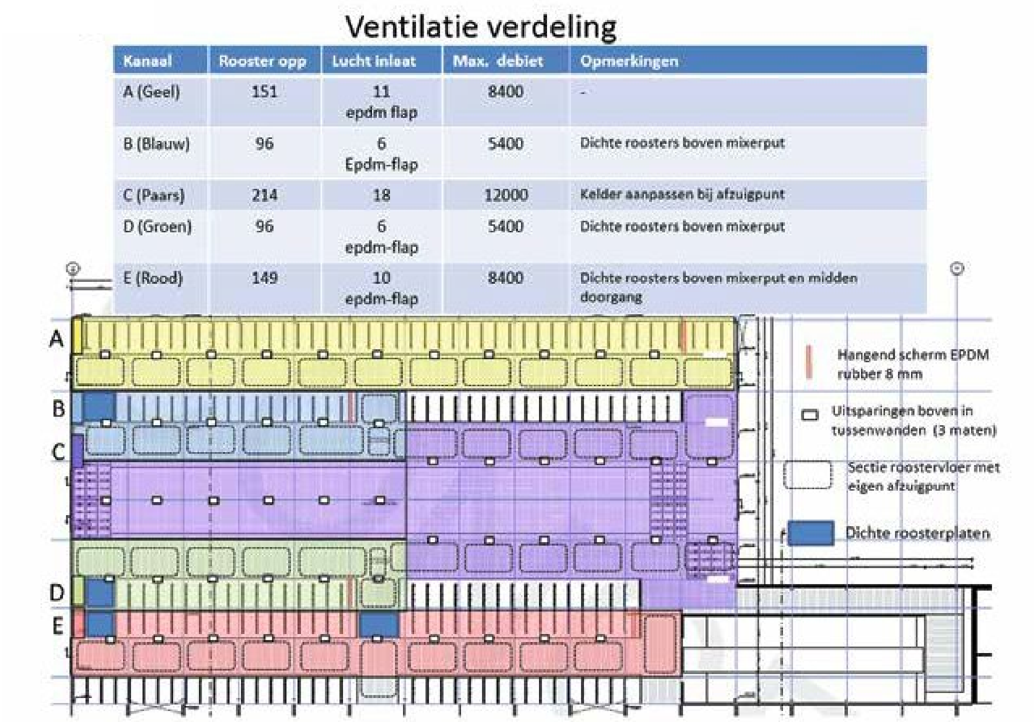

Figure 2. Schematic drawing of the 5 cellar ventilation intake sections, represented by the different colors.

The ammonia measurements are performed according to the guidelines of the standard measurement protocol [1]. In total 6 ammonia measurements are performed; every measurement takes 24 hours. The individual ammonia measurements are equally spaced in time over 1 year, so that seasonal effects are considered. To measure the natural ventilation/emission a measurement duct was installed in the top of stable. The duct consisted of 12 orifices equally spaced along the length of the stable (80m), this was done to take a volume proportional sample of the stable. To measure the air washer both the NH_3 and CO_2 concentration are determined before the air washer. After the air washer only the NH_3 concentration is determined. The CO_2 concentration before the washer is required to determine the total ventilation rate of the stable (CO_2 mass balance method, GIGR calculation rules 6,8,9). Table 1 shows an overview of the executed measurements.

Table 1. Executed measurements.

Measured components/ parameters	Location description			
	1. Stable air	2. Cellar air (Before washer)	3. Air after washer	4. Ambient air (outside stable)
NH_3	X	X	X	X
Ventilation rate through CO_2 measurements	X	X		X
Ambient temperature (outside)				X
Stable temperature (inside)		X		

The ammonia concentrations are measured using the wet-chemical method. The CO_2 concentrations are measured using a NDIR monitor. CO_2 concentrations are used in a mass balance method to calculate the total ventilation rate. The ambient (outside) measurement location is chosen upwind for each of the measurement sessions. The equations to determine the ventilation rate are discussed below,

$$In - Out = Accumulation + Production \qquad (1)$$

CO_2 does not accumulate in the stable, which simplifies the equation to,

$$In - Out = Production \qquad (2)$$

The intake of CO_2 by the stable is the product of the outside CO_2 concentration (C_{in}) and the ingoing air flow ($\emptyset_{in}$). The loss of CO_2 by the stable is the product of the CO_2 concentration before the air washer (C_w) and the ventilation rate through the air washer ($\emptyset_w$) in addition to the product of the CO_2 concentration in the stable (C_s) and the air flow out of the stable ($\emptyset_s$). The production term in equation (2) can be calculated using the CIGR calculation rules [3]. Equation (2) takes the following form,

$$\underline{C_{in}} * \emptyset_{in} - (\underline{C_w} * \underline{\emptyset_w} + \underline{C_s} * \emptyset_s) = \underline{P_{CO2}} \qquad (3)$$

The unit on both sides of the equation is mg/h. The underlined terms in the equation above are measured or calculated and thus known. Since the total inflow of air must be equal to the total outflow of air,

$$\emptyset_{in} = \emptyset_s + \underline{\emptyset_w} \qquad (4)$$

substituting equation (4) in equation (3) results in the final formula,

$$\underline{C_{in}} * (\emptyset_s + \underline{\emptyset_w}) - (\underline{C_{vw}} * \underline{\emptyset_w} + \underline{C_s} * \emptyset_s) = \underline{P_{CO2}} \qquad (5)$$

This equation only has one unknown, the air flow out of the stable ($\emptyset_s$). Solving for $\emptyset_s$ results in the following formula,

$$\emptyset_s = \frac{P_{CO_2}}{C_{in} - C_s} + \emptyset_w \left(\frac{C_w - C_{in}}{C_{in} - C_s} \right) \qquad (6)$$

3. Results

Figure 3 shows the measurement results (24-hour averages) of the ammonia emission for each of the six measurements. The percentage in the brackets shows the percentage of cellar ventilation with respect to the maximum possible cellar ventilation rate. This shows that the first three measurements are conducted at 35 % of the maximum ventilation rate and the last three at 60 % of the maximum ventilation rate.

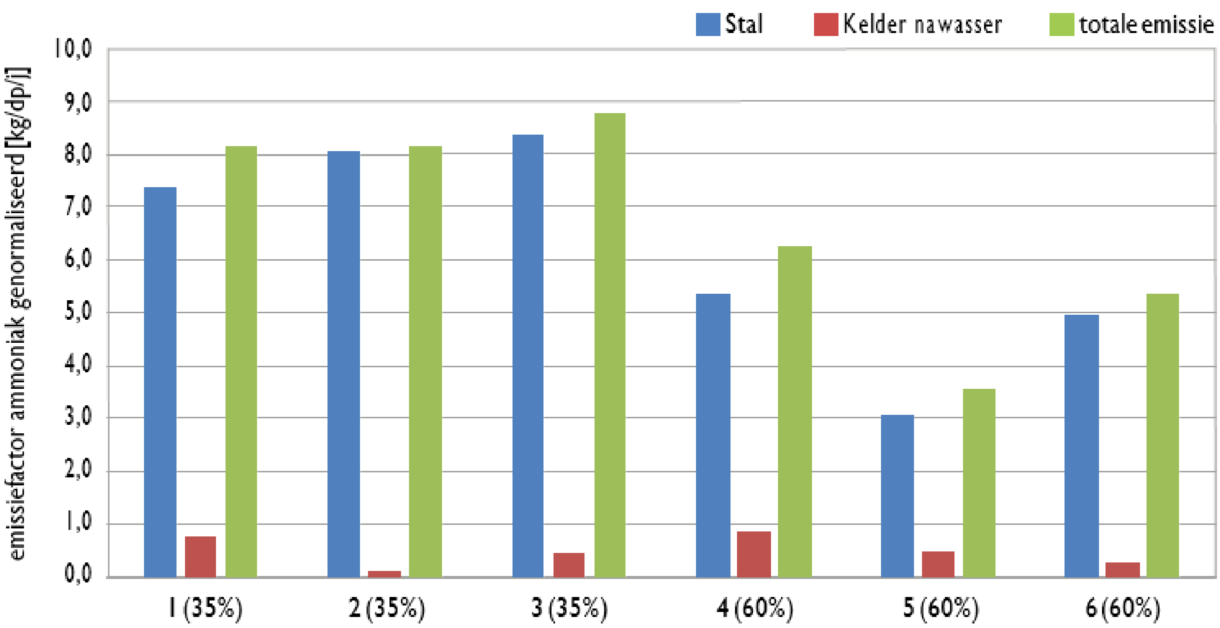

Figure 3. Graph showing the standardized ammonia emission factor for each of the six measurements. The percentage in brackets shows the percentage of cellar ventilation compared to the maximum possible cellar ventilation rate. The green bar shows the total emission, the red bar the emission from the washer and the blue bat the emission from the (top of the) stable.

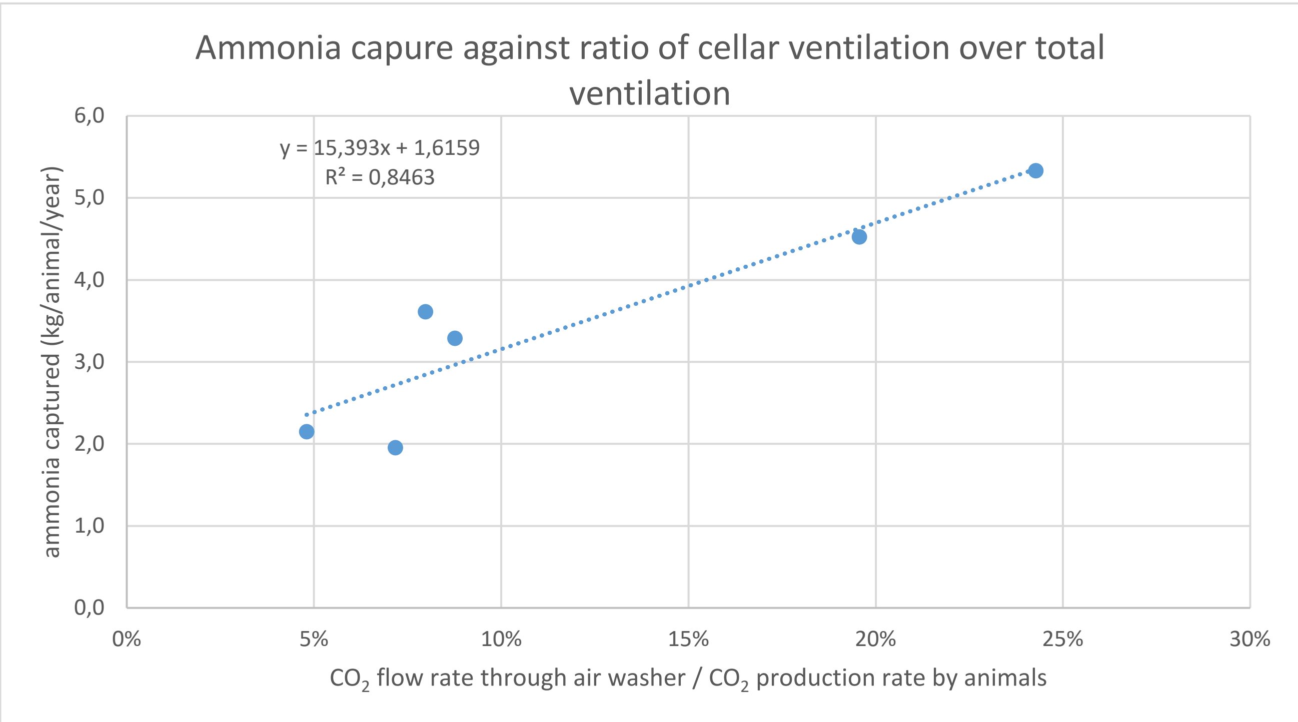

Figure 4. Relation between the ratio of cellar ventilation over total ventilation and amount of ammonia captured by the chemical air washer. (Note that the linear regression line is made to show the increasing character, it is not known if the relation is linear).

4. Discussion

During measurements of the test stable in Zeewolde all agricultural conditions are satisfied. Meaning that the measurements are conducted with representative circumstances for a dairy stable. The measurements are conducted at two different cellar ventilation rates, namely 35% and 60% of the maximum possible ventilation rate. The results suggest that increasing the cellar ventilation rate above 60% would decrease the ammonia emission even further. The results also allow for a calculation of the ammonia captured by the chemical air washer. This is done by comparing the ammonia concentration before and after the air washer. The ammonia captured by the air washer is strongly dependent on the ratio of cellar ventilation over total ventilation (cellar + natural). The natural ventilation is influenced by meteorological conditions, in particular wind speed and wind direction. Figure 4 shows the ammonia capture in kg/animal/year against the ratio of cellar ventilation over total ventilation. This ratio is equal to the CO_2 flow rate (g/h) divided by the total amount of CO_2 produced by the animals (g/h). This figure shows that the amount of captured ammonia can be estimated by measuring the CO_2 concentration in the cellar (before the washer) and in the top of the stable. This is to be expected as the ratio of cellar ventilation over total ventilation can be taken as a measure for the effectiveness of the cellar ventilation system itself. This means that during strong winds and thus increased amount of natural ventilation, the cellar ventilation system will have to work harder to maintain a high CO_2 concentration ratio and a high ammonia capture.

5. Conclusions

The average ammonia emission factor of the investigated stable with cellar ventilation and subsequent chemical air washer is 8.4 or 5.1 kg/animal/year for 35 % or 60 % of the maximum cellar ventilation rate respectively. The latter case corresponds to a cellar ventilation rate of around 120 m^3/animal/hour. The year-round ventilation rate average of a naturally ventilated dairy stable is 1200 m^3/animal/hour [2]. This means that if 10% of the total ventilated air is passed through cellar ventilation system with washer, an ammonia emission reduction of 60 % can be achieved (calculated using the emission of a category A1.100 housing system with an ammonia emission of 13 kg/animal/year [4]). The ammonia emission of 5.1 kg/animal/year (60 % cellar ventilation) is 41 % lower than the maximum allowed emission of 8.6 kg/animal/year from the low-emission housing decree [5].

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