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Measuring of ammonia emission and determination of an emission factor in animal production

Part 1: Laying hen husbandry as an example of a forced ventilated animal house

Ammonia measurements in animal houses do not only serve for characterization of the system behavior but also for generation of boundary conditions for atmospheric dispersion calculations. In contrast to measurements of odour, dust and germs, ammonia measurements, in principle, have the advantage to lead to self-contained time series. The measurements even could be expanded to last for a year, if the financial support is granted. Due to the high costs and the large variety of stables the question arises, whether it is possible to come to conclusions on the basis of shortened time series. For the given case of a laying hen husbandry it is shown how it is possible to generate emission statements on the basis of a time series of only a few days. This applies both for the measuring time span and the whole year – despite measuring deficiencies.

Keywords

laying hen husbandry, measurements of ammonia, determination of emission, preparation of data with regard to dispersion simulations

Abstract

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The ammonia measurements in the exhaust of a laying hen stable (**Figure 1**) were taken in March 2011. The measurements were taken in the exhaust duct since emissions are only released there. The laying hens were kept in a Natura Nova Type 260 TWIN aviary with a front gate. The measurements took place continuously over two days.

To determine the emitted mass flow it is necessary to measure the concentration and flow volume simultaneously at the same place. The concentrations were measured with an Innova 1302 Multigas monitor. The measurement principle permits an almost continuous measurement of the ammonia concentration.

The flow volume measurements can be described as rudimentary: they use the visual notations from the stable climate computer, given as a percentage of maximum air turn- over. The percentage display of the equipment is synchronized with the concentration measurements.

The stable climate construction is aligned with the DIN 18910 [1], meaning that the interior stable temperature is adjusted to the external air temperature via ventilation. The inner temperature in the stable during the study was about 4 °C above the outdoor temperature.

Figure 2 presents the time series of the concentration measurements (black curves and points). The ammonia concentration is sampled with a time interval of three minutes. The course of the curve shows shifts whereby the maximal concentrations were found during cleaning of the excrement conveyor. The excrement removal acts as a disturbance because the increased concentration of ammonia is not based on animal activity. It also does not lead to a higher ventilation rate, but rather, it is typical for the system. In comparison to other types of husbandry, these influences must be considered.

Approximations can be established for the measurement curves (red curves and points). The approximations are based on causality, which, in contrast to the time series, allow a "further treatment" of the initial data. The old principle "Measure – Analyse – Evaluate" is applied here.

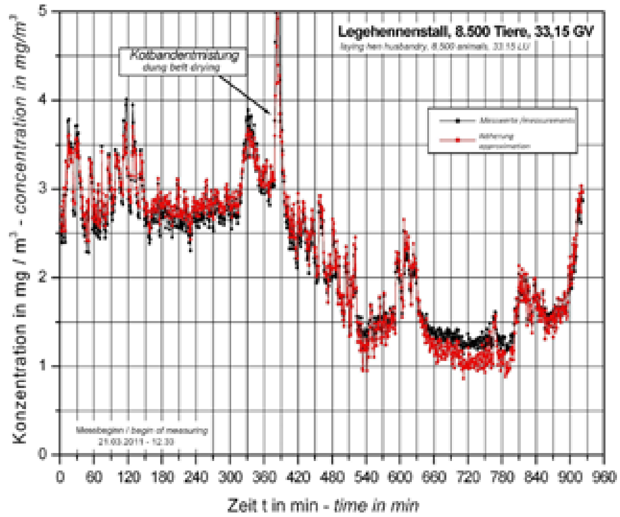
Data analysis

The sampled time series of concentration and volume flow (**Figure 2**) can not be continued, since one cannot predict the current time behaviour. However, the time series provide information on how other factors react to each other and how often such situations arise. In other words: the time dependency is eliminated in favour of a frequency distribution of certain factors. Dimensional analyses [2] lead to the observation

Fig. 1

Laying hen husbandry with suction of fresh air from the ridge and the side

Fig. 2



Time series for ammonia measurements and approximation

that emission behavior can be reduced to two dimensionless characteristics:

a) the dimensionless mass $C_0\, V_R / M_T$ and

b) the dimensionless concentration $X = C_B / C_0 - 1$

The terms "Mass proportion" or "Concentration ratio" describe the concept of dimensionlessness more adequately.

- C_0 stands for the concentration of ammonia in the exhaust duct, given here in mg/m³
- VR stands for the inner stable volume in m³
- MT gives the animal weight in kilograms, whereby due to the standard use of the term "Live Animal Unit (1 AU = 500 kg)", AU is used here as well for purposes of completeness
- CB stands for the ammonia concentration near to the floor, given also in mg/m³

C_B describes the intrinsic inner stable emission behavior. Via the mass balance for a stable area, one can also find a relation to link C_B and C_0 with the production rate K and the ventilation rate N. Thus it holds that

$$\frac{N}{K} = \frac{C_B}{C_0} - 1 \qquad \text{(Equation 1)}$$

with

$$N = \frac{\dot{V}_0}{V_R} \quad \text{und} \quad K = \frac{k}{V_R} \qquad \text{(Equation 2a, b)}$$

k gives the production rate of ammonia, for example expressed as the product of the emission area multiplied by the exit speed of ammonia.

The exhaust concentration C_0 increases with the size of the ground concentration of C_B if either the ventilation rate N strives against 0 or K becomes infinitely large. In both cases the animals have no chance of survival in the stable. As a consequence N and K are finite values.

a) Substitution process

For the average emission mass flow in one year the following relation exists:

$$\overline{\dot{M}_0} = \frac{1}{t_{Jahr}} \int_0^{t_{Jahr}} C_0(t) \dot{V}_0(t)\, dt \qquad \text{(Equation 3)}$$

Since the time series (t) are not completely available for integration, one can replace them with a summation over i classified pairs of data:

$$\overline{\dot{M}_0} = \frac{1}{n} \sum_{i=1}^{n} C_{0,i} V_{0,i} \qquad \text{(Equation 4)}$$

In forced ventilation the classes ai are oriented on the summer ventilation rate, the maximal volume flow with i = 1...5:

$$\dot{V}_{0,i} = a_i \dot{V}_{0,\max} \qquad \text{(Equation 5)}$$

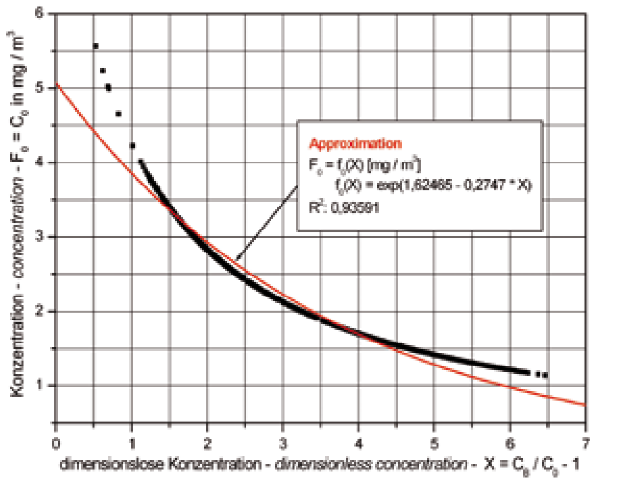
The frequency of occurrence H_i of the volume flow classes ultimately leads to the average emission mass flow for the year (n = 5)

$$\overline{\dot{M}_0} = \frac{\dot{V}_{0,\max}}{n} \sum_{i=1}^{n} C_{0,i} a_i H_i \qquad \text{(Equation 6)}$$

For the calculation of the mass flow it is necessary to allocate concentrations $C_{0,i}$ to the classified volume flows, according to **Figure 3**, and to assign the class limits to the dimensionless concentration X.

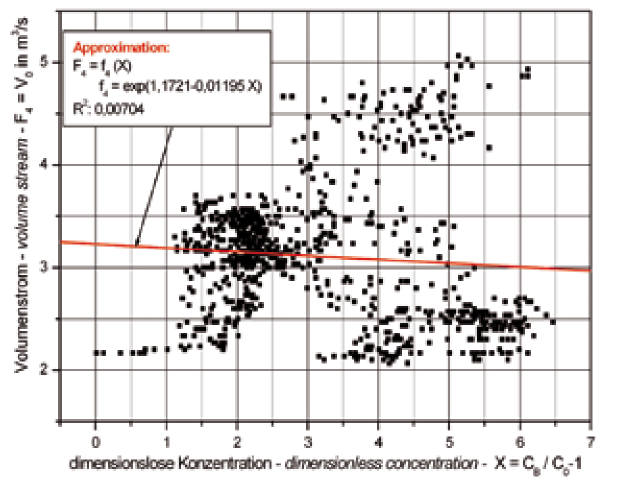
It can however be seen, that the class limits of the volume flows in the transformation to X_i can not be represented well (**Figure 4**). This can be seen, for example, at i = 1 with 0.1 • 1,400 m³/h / 3,600 s/h = 1.29 m³/s, at i = 2 with 2.58 m³/s and also for i = 4 and i = 5 (**Table 1**). This means that the measurement time series are not adequate to present, via X, a functional context for the entire year. If in the studies in March had shown hours of cold nights and very warm days, a different

Fig. 3



Ammonia concentration versus the dimensionless concentration X. F_0 determines the approximation function

Fig. 4



Volumetric flow rate versus the dimensionless concentration X. F_4 determines the approximation function

Table 1

Calculation steps for determination of the average emission mass flow, a = 1.3326 and b = 0,1974

i	H_i	a_i	A_i	B_i	$M_{0,i}$ mg/s	$M_{0,i}$ H_i mg/s
1	0,1	0,1	0	1,29	1,1089784	0,1108978
2	0,2	0,2	1,29	2,58	1,4155026	0,2831005
3	0,4	0,4	2,58	5,16	4,1816452	1,6726581
4	0,2	0,8	5,16	10,30	18,482386	3,6964772
5	0,1	1	10,3	12,89	19,329321	1,9329321
Σ	1					**7,696066**

picture would have resulted. The temporal average over the period of measurement can only be seen as any one episode in the annual activity. This is evident in **Figure 5** in which the emission flow level is presented as a function of the volume flow. The measurement points serve to calculate the emission mass flow. If all volume flow classes are occupied, then the frequency of their occurrence is documented. If, however, measurement points are only available for certain areas, the integration of the mass flow and the inclusion of the frequency of occurrence can only take place in sections. This is unsatisfactory, particularly if important areas are not documented. Further measurement campaigns are thus necessary. The view should be directed toward closing the gaps in data.

b) Extrapolation process

In order to classify the emissions from laying hen husbandry, the sectional calculated mean emission mass flow levels can give speedy information. The averaged emissions mass flow level for the year results from the summation of the classified, meaning sectional, mass flows and their frequency of occurrence H_i. The sectional mass flow levels are determined by means of the approximal function F_7 through integration (**Figure 5**).

$$\overline{\dot{M}_0} = \frac{1}{5}\sum_{i=1}^{5} \dot{M}_{0,i} H_i \qquad \text{(Equation 7)}$$

For the graded or sectional mass flows one finds:

$$\dot{M}_{0,i} = \int_{A_i}^{B_i} \exp(a + b\dot{V}_{0,i}) d\dot{V}_{0,i} = -\frac{1}{b}[\exp(a+bA_i) - \exp(a+bB_i)] \qquad \text{(Equation 8)}$$

and thus

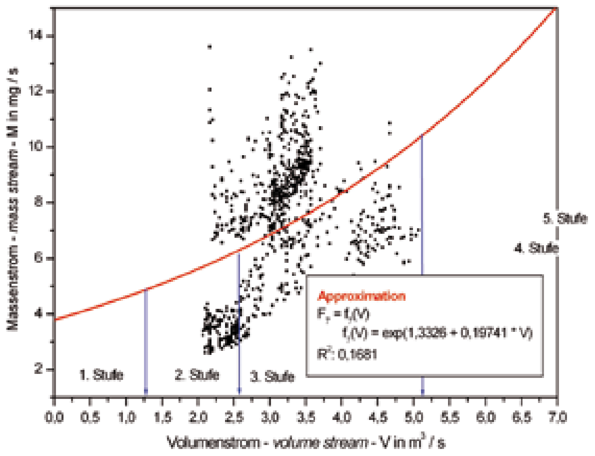
$$\dot{M}_{0,i} = \frac{1}{5b}\sum_{i=1}^{5} -H_i[\exp(a+bA_i) - \exp(a+bB_i)] \qquad \text{(Equation 9)}$$

When considering 1/(5b) = 1.01312 in **Equation 9** the emitted average annual emission mass flow level after the extrapolation process results in 7.7 mg/s. The mean of the measured time series is 7.05 mg/s. Studies from 2007 to 2009 confirm the order of magnitude, but show large variations in the practical operation [6]. Thus in regard to the animal weight of M_T = 33.15 AU for the emissions factor a value of $f_{e,vTI}$ = 2.35 • 10^{-4} g/(s AU) results. The values in the guideline VDI 3894 show from group keeping with ventilated manure belt up to floor keeping with inside manure storage a span of $f_{e,VDI}$ = 3.25 • 10^{-4} g/(s AU) to 2.6 • 10^{-3} g/(s AU), while the conversion from animal place (AP) to the animal weight takes place with the relation 1 AP = 3.9 • 10^{-3} AU. The value $f_{e,vTI}$ is lower than the limits set by $f_{e,VDI}$.

Evaluation

The process described under point a) in the presented procedure permits the measured time series to be illustrated in an acceptable form and in dependence on the dimensionless concentration relation X. If X also includes all conditions as they

Fig. 5



Emission mass flow rate versus the volumetric flow rate.
F_7 *denotes the approximation function*

Table 2

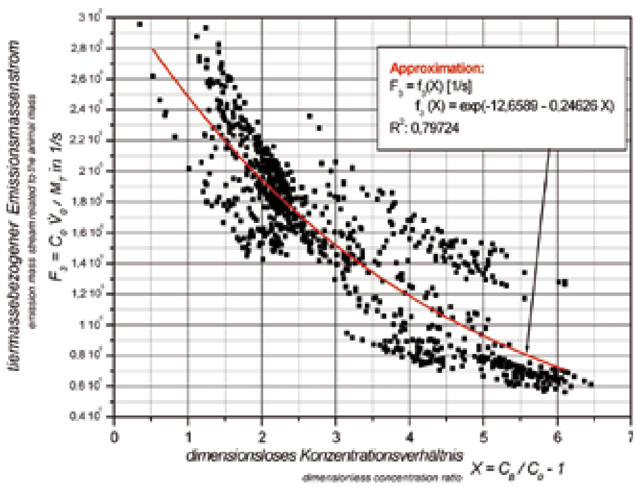
Values of A and B

A		B	
Ammoniak ***Ammonia*** **[mg/m³]**	**Geruch/*Odour*** **[GE/m³]/*[OU/m³]***	**Ammoniak** ***Ammonia*** **[mg/m³]**	**Geruch/*Odour*** **[GE/m³]/*[OU/m³]***
Putenstall/*Turkey stable*			
-13,65	-11,75	-0,1133	-0,0154
Rinderstall/*Cattle stable*			
-14,31	-12,24	-0,1344	-0,0323
Schweinestall/*Pig stable*			
-14,08	-10,44	-0,2251	-0,1466

result in the classified flow volumes, the statements on annual emission behavior can also be obtained via the shortened measurement time series. In some cases it becomes apparent why a shortened measurement time series does not prove to be appropriate. The variant shown for data analysis under b) – calculation of a mass flow via the classed volume flow on the basis of sectional data – always carries the risk that errors may be made in the extrapolation. However, it is very difficult to follow data back to its genesis. Information on measurements in a broiler farm and a beef farm is found in [5]. The evaluation takes place in accordance with a scheme presented here as a) with an adequate breadth of data.

The results show that this is not always the case (**Figure 3–5**). Since the substitution approach has been used in many studies with different species of animals [2] this approach is maintained for comparative purposes.

Fig. 6



Mass stream F_3 *of emission of ammonia related to the animal mass versus the dimensionless ratio of concentration*

The substitution process used in a) is contained in its most simple form in the DEMAP model [4]. Accordingly the following context was found for the concentration via the dimension analysis:

$$\frac{C_0 V_R}{M_T} = \exp(A + BX) \qquad \text{mit} \quad X = \frac{C_B}{C_0 - 1} = \frac{N}{K} \qquad \text{(Equation 10)}$$

From this, the relation

$$\frac{C_0 \dot{V}_0}{M_T} = N \exp(A + BX) \qquad \text{(Equation 11)}$$

is found for the animal mass related emission mass flow.

If one holds the measurements as they are shown in **Figure 2** as representative for the year, then the relation can be quantified according to Equation 11 as presented in **Figure 6**. One comes to the parameters A = -12.6589 and B = -0.2463. **Equation 11** presents the "characteristic emission function" for the studied stable. A glance at **Table 2** makes it obvious that the data line up with results from other types of housing. The parameters A and B vary in "Odour" and "Ammonia" in the various types of animal housing.

For forced ventilation systems, the emissions prove to be almost independent from the meteorological parameters. The temperature influence is taken into account by the stable internal ventilation control with regard to the animal physiological requirements according to DIN 18910. With free ventilation, this is only successful when a surplus of atmospheric air mass flow is present. In free ventilation one can at the moment only react one-sidedly. A storage of cold air at night presents a general relief from the high temperatures for several day hours in the states located on the Mediterranean.

If various process methods are compared among themselves, then method is a) always to be given preference. The reason for this is the causality of the approach. The calculated mass flow results from the internal stable production rates coupled with the ventilation rates. In principle, this is an expression of the law of mass conservation. It holds true to the same extent for all domesticated animal species, so that it is not unexpected that one can use the same model structures for the emission behavior, see **Equation 11**. Most important here, and in serious contrast to other approaches with direct time row processing, is the independence from the meteorological time series. The locational dependence in form of the meteorology on site is not shown. This is not the case with the data of the guideline VDI 3894 [3]. Nonetheless, the data is generally declared as valid. This may be acceptable in terms of legal security, but is it not physically logical.

If other forms of stables with forced ventilation are planned than customary, then simulation techniques can help to calculate the stable specific functions addressed here.

The calculation of value X in **Equation 11** over the course of the year and via the ventilation rate with its relative occurrence frequency H, one ultimately comes to the emission factor:

$$f_e = \frac{\overline{C_0 V_0}}{M_T} = \sum_i^n H_i N_i \exp(A + BX) \qquad \text{(Equation 12)}$$

which can be used as a constant in the distribution calculations. In freely ventilated animal husbandry systems this is no longer the case. In Part 2 of the total paper a simulation method for emission behavior and a complex derivation behavior for a box stable will be presented.

Conclusions

With few measurements taken in all ventilation variations in one year, the Emission Model DEMPA shows results which permit statements on the annual emission of a stable.

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