Krause, Karl-Heinz; Müller, Hans-Joachim; Mußlick, Michael and Linke, Stefan

Animal welfare, environmental protection and energy saving going together by intelligent ventilation

Filter plants against emission of dust and harmful gases of husbandries are expensive in initial costs and use. In the following a cost saving concept is presented that started in great existing animal plants and has been realized in several new buildings. The narrow kind of stable construction requires a space-saving solution. A part of the stable air is sucked beneath the slatted floor and transported to filter that is lower dimensioned than such one for the whole volume stream. Apart from this the flow behavior is altered above the slatted floor by a special guidance of the air so that much less ammonia is taken away. Measurements in practice show: The filtering of the continuously sucked volume stream, which amounts to 25 % of the whole volume stream, allows a whole efficiency degree of 70 %. As well the concentrations of harmful gases go down considerably.

Keywords

Reduction of emission, environmental protection, animal protection, energy saving, filter technique, simulation

Abstract

Landtechnik 65 (2010), no. 1 pp. 15-19, 7 figures, 1 table, 6 references

The conservation principles for maintaining mass and energy are addressed in DIN 18910-1 [1]. However, they are commonly recognized as a construction norm rather than guideline, adequate for animal welfare. Among other things, a third conservation principle is needed, namely the law for the conservation of momentum. If the first two principles named for the stable serve as the so-called stirrer-tank, the third principle is the first to be appropriate to the local conditions in the stable. The concentrations of ammonia, odors, carbon dioxide, dust and water vapors occurring in the stable result constantly from the difference of inwardly and outwardly flowing materials $\dot{M}$ [2], which cause the temporal changes in the mass in the stable:

$$\frac{d}{dt}M = \dot{M}_{in} - \dot{M}_{out} \qquad \text{(Eq. 1)}$$

The mass M generally results from the product of the concentration C and the volume V:

$$M = CV \qquad \text{(Eq. 2)}$$

The discharging mass is determined from the inward volume flow $\dot{V}$ which is loaded with the concentration C

$$\dot{M}_{out} = C\dot{V} \qquad \text{(Eq. 3)}$$

And the inwardly flowing mass flow in the floor area of the stable from the source concentration C_q and the production flow $\dot{k}$

$$\dot{M}_{in} = C_q \dot{k} \qquad \text{(Eq. 4)}$$

The result is the differential equation

$$\frac{d}{dt}C = C_q K - CN \qquad \text{(Eq. 5)}$$

With the air flow rate N and the production rate K

$$N = \frac{\dot{V}}{V}, \quad K = \frac{\dot{k}}{V} \qquad \text{(Eq. 6)}$$

The linear inhomogenous differential equation leads in a stationery case (t → ∞) to the solution

$$\frac{C}{C_q} = \frac{K}{N} \qquad \text{(Eq. 7)}$$

Due to the approach-related homogenous distribution of the concentration C in the stable, the concentration at which the discharge air volume flow leaves the stable is also given. Specification of the source concentration C_q and the production rate K are open.

These result from interaction data from open stables and stables with forced air ventilation obtained in the research project [3] used to develop a simple emission model. Using the dimension analysis [4], the following interactions became evident in the results, differing from those in the conservation principle

$$\frac{C}{C_q} = e^{B\frac{K}{N}} \quad \text{with} \quad C_q = \frac{M_T}{V} e^{-A} \qquad \text{(Eq. 8)}$$

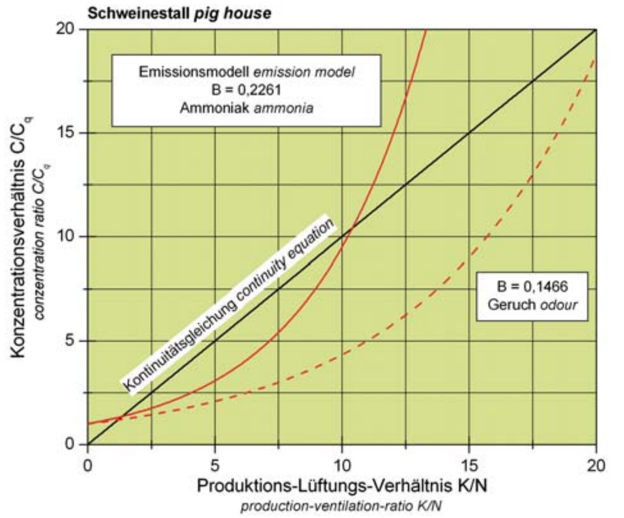
as seen in the definition of C_q. M_T stands for the animal mass in AU (1 AU = 500 kg live animal mass). The coefficients A and B depend on the type of animal and the released substances, see **table 1**. **Equation (8)** shows that the reduction of the exponents in the sense of (B K/N) → 0 presents a proven way to reduce the stable concentrations. Factor B takes over an increasing portion of the free ventilation, as in the trend in **table 1**. Factor B can, in an ideal situation, take the value 0, meaning that one thus obtains C/C_q = 1 (**figure 1**). In the most extreme case C = C_q.

Table 1

The constants A and B of the emission model are listed for animal houses of turkey, cattle and pig plants

	Konstante A *Constant A*	Konstante B *Constant B*
Putenstall/*Turkey house*		
Ammonia/*Ammonia*	13.6533	0.1133
Geruch/*Odour*	11.7474	0.0164
Rinderstall/*cattle house*		
Ammonia/*Ammonia*	14.3096	0.1344
Geruch/*Odour*	12.2386	0.0323
Schweinestall/*Pig house*		
Ammonia/*Ammonia*	14.0766	0.2261
Geruch/*Odour*	10.4369	0.1466

Fig. 1



The concentration ratio C/Cq is plotted versus the production-ventilation ratio K/N. In the piggery, C/Cq levels are lower than with the continuity equation up to K/N = 10 for ammonia and K/N for odour

A so-called source concentration will always be present. This statement does not deliver the continuity equation with the hypothetical approach according to **equation (4)**. According to **equation (8)**, C could equal 0, which proves not to be realistic. How to really set the physical proportions between B and K/N requires more intensive studies. It has been established that a non-effectiveness of the exponents should be targeted in that the penetration of material releases, i. e., of ammonia and odorous substances in the stable rooms is to be minimized by suction. And also with intelligent flow of stable air over the slatted floor to prevent a pressure gradient, since the discharge of the released substances above the slatted floors is promoted.

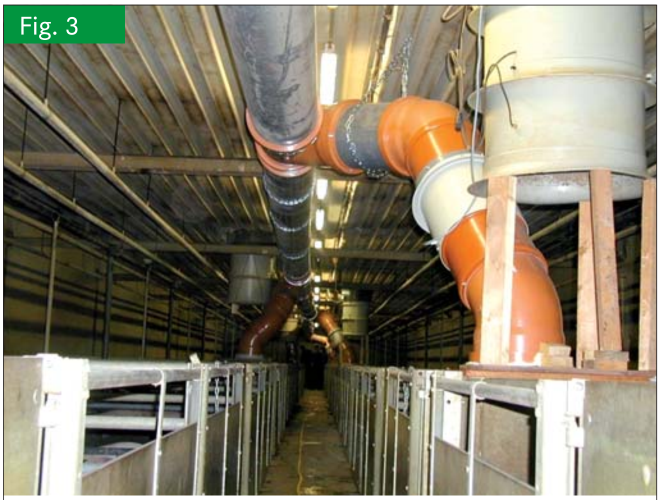
Odor reduction under given circumstances

In this study, the possibilities for reducing the odor levels from a large animal husbandry facility into its surroundings shall be investigated (**figure 2**). The authors used a partial under-floor suction system since a filtering system for the total stable was not possible for space and cost reasons. Actually, in a one month on-site study (**figure 3**), a reduction in the odors on the work-

Fig. 2

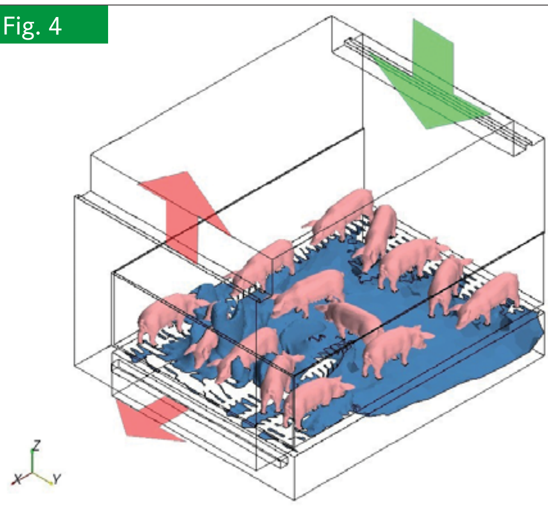
Example of a large animal husbandry facility. The plant is comprised of numerous single stables which are joined under a common roof into long rows and are marked on the roof by many chimneys. Odourous substances carried atmospherically to the outskirts of a large city and caused massive complaints

Fig. 3



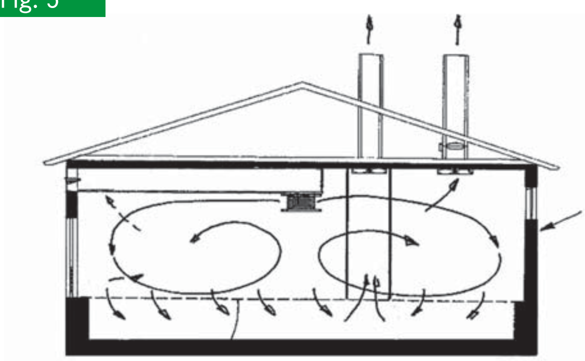
Study design with simultaneous above- and under-floor suction. Air is withdrawn both beneath and above the floor (at a set distance from the ceiling)

Fig. 4



Ammonia cloud of 0.1 ppm in one compartment. Fresh air flows into the room through a channel on the ceiling (above right) and flows out (above left) with substance releases during under-floor suction (bottom left) at the same time. The concentration at the manure surface amounts to 20 ppm (Program STAR-CCM+ from CD-Adapco)

Fig. 5



P. Rieth: Registered Design DE 296 14928 U1. Announced in Patent Paper: 19.02.2006

ing farm were observed, so that deeper and systematic analyses were introduced with physical and numerical models.

Physical and numerical models to document farm processes can effectively help to discern trends and establish whether a model project is worth carrying through. The measurements in the model confirm that the above-floor concentrations are less in simultaneous- below-floor suction than without sub-floor suction, and that even in the case of minimal air diversion. This interaction was to be optimized. Here, numerical models grasp the detail of documentable flow courses in the slatted floor area (**figure 4**) [5].

Known similar approaches

Many ventilation concepts with under-floor suction exist and many approaches were preceded by experiments in animal husbandry in the former GDR. The suction pipes or pressure pipes are implemented under the flooring, as in, for example, beef cattle husbandry [6]. In the following, example is shown for pig husbandry. **Figure 5** shows a vertical section of the planned flows in the stable area. At the horizontal level, radiation effects are noticeable, especially from source points (meaning radial fans), since the transfer from the initial radial distribution of the rectangular stable area can only take place if circulatory flows are developed. Seen spatially, we are far from homogenous flow patterns, as one would desire in the positioning of temperature sensors for climate control until now. The concepts maintained by the authors (**figure 6**) are based on the idea of "ordered" flow behavior in the entire length area of the stable.

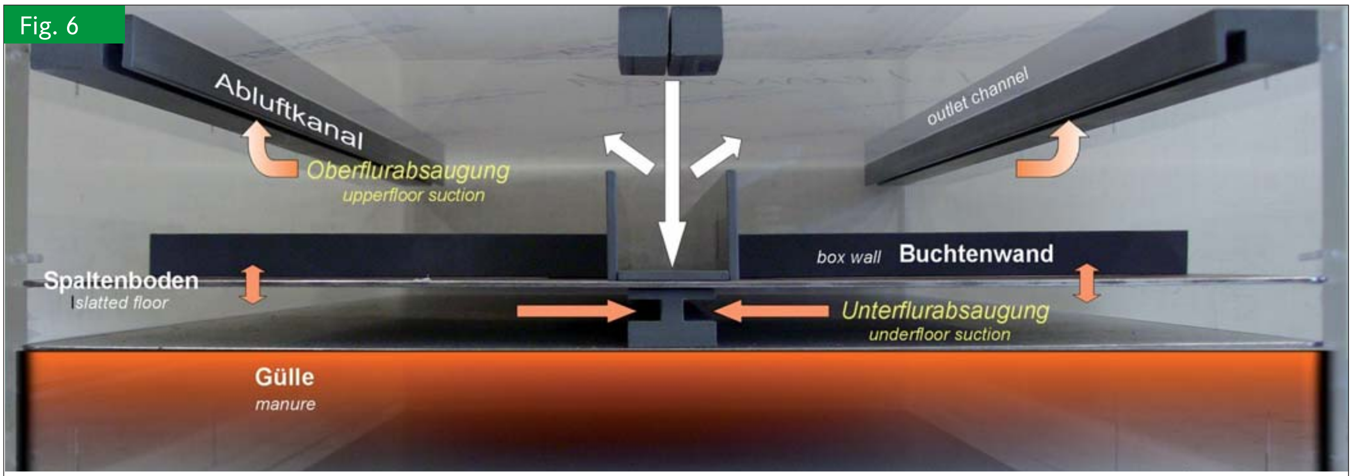
Concrete results in stable realization

A stable holding 1 400 fattening pigs (meaning M_T = 182 AU) was used for measurements. The stable ventilation was marked by constant under-floor suction. The suction was carried out at the same rate as the winter air rate. The winter air rate was 25 % (α_{UF} = 0.25) of the under-floor suction of the total flow volume, meaning the same level as the maximum volume flow at the summer air rate. The above-floor suction is 75 % (α= 0.75) of the total flow volume. In the colder seasons, only the under-floor suction operates. The goal of the study was to document the mass flows in under-floor and above-floor suction separately and to compare it to conventional stall suction (only above-floor suction). In the new section 106, the concentrations of ammonia in the exhaust compartment of the above-floor suction and in the exhaust shaft of the under-floor suction were measured (**figure 7**) In the reference section 104, in which the under-floor suction was shut off and closed, the measurement of the ammonia concentration in the exhaust shaft of the above floor suction was measured.

An Innova Multi Gas Monitor 1302 served as measuring equipment which was switched to each measurement site with a measurement setting switch.

For the total effectiveness level η_{system} for the system in regard to the discharge of ammonia in comparison the equation

Fig. 6



The stable air is drawn into channels on the side walls. Fresh air flows in via an inlet channel at the center of the ceiling. Underneath the slatted floor, the air above the manure is drawn to the centre of the stable and transported to a filter. Because of the width of the slatted floor, it is inevitable that some air is drawn in the room above the floor through the slatted floor

$$\eta_{system} = 1 - \frac{\dot{M}_{new\ section}}{\dot{M}_{reference\ section}} \qquad \text{(Eq. 9)}$$

The mass flows thus emitted above-floor are

$$\dot{M}_{new\ section,\ aF} = C_{new\ section,\ aF}\,\dot{V}_{new\ section,\ aF} \qquad \text{Eq. 10}$$

with $\dot{V}_{new\ section,\ aF} = a\,\dot{V}_{new\ section,\ max}$ and $0 \leq \alpha \leq 1 - \alpha_{UF}$

and under-floor measured only with the used filter as

$$\dot{M}_{new\ section,\ uF} = \varepsilon\, C_{new\ section,\ uF}\,\dot{V}_{new\ section,\ uF} \qquad \text{Eq. 11}$$

with $\dot{V}_{new\ section,\ uF} = a_{uF}\,\dot{V}_{new\ section,\ max}$ $\quad \varepsilon = 1 - \eta_{Filter}$

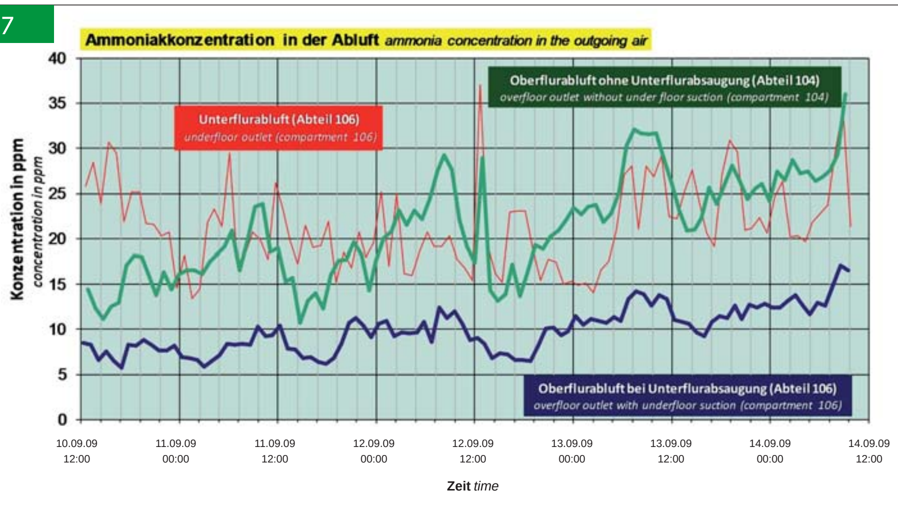
so that by using **equations 10** and **11** in **equation 9**, it follows that:

$$\eta_{system} = 1 - \frac{\tau_{aF}\,\alpha\, C_{new\ section,\ aF} + \tau_{uF}\,\varepsilon\,\alpha_{uF}\, C_{new\ section,\ uF}}{C_{reference\ section}}\,\beta$$

$$\text{with } \beta = \frac{\dot{V}_{new\ section,\ max}}{\dot{V}_{reference\ section}} \qquad \text{Eq. 12}$$

To evaluate the annual activity, one must observe the effectiveness periods τ. The under-floor suctions runs all year, meaning $\tau_{UF} = 1$. The above-floor suction is then switched on additionally if the required volume flow is above the winter air rate, meaning $\tau_{OF} = 8/12$ with a working period of 8 months. The various flow volumes found in the experiments are considered, while the volume flow in the reference section was somewhat smaller than in the new section $\beta = 1.1$. The effectiveness level of the filter is also modestly different at $\eta_{FILTER} = 0.8$. These conditions reduce the effectiveness of the system. If one assumes in or-

Fig. 7



Concentration time series, marked by the corresponding lettering. The concentration above the floor is much higher in those systems with no under-floor suction in comparison with under floor such systems der to show the effectiveness of the system, that the study data from high summer are valid for the entire year, one can assume $C_{new\ section\ oF}$ = 10 ppm, $C_{new\ section\ uf}$ = 24 ppm, and $C_{reference\ section}$ = 22 ppm.

Explanation

In a state of only under-floor suction, it held true for $\tau_{uF} = 1$: $\alpha=0$, $\alpha_{uF} = 0.25$ meaning $\eta_{System} = 0.95$. In a state of combination suction for $\tau_{uF} = 1$ and $\tau_{oF} = 0.7$: $\alpha=0.75$, $\alpha_{uF} = 0.25$ that means $\eta_{System} = 0.68$. With an effectiveness level of $\eta_{Filter} = 0.9$, the system effectiveness increases to $\eta_{System} = 0.71$. If one were to operate the new section for four months with a system effectiveness level of $\eta_{System} = 0.9$, and for 8 months with an effectiveness level of $\eta_{System} = 0.4$ one achieves a total of $\eta_{System} = 0.6$.

Conclusions

With a partial under-floor suction of 25 % of the total flow volume in combination with an air direction system adapted to the suction conditions, one can achieve an effectiveness level of 70 %. In terms of acquisition and operating costs such a process is less expensive than the total filtering of stall exhaust and benefits the environment. Also the concentration of ammonia in the stable is reduced by almost half. The energy consumption is significantly reduced by the major reduction in resistance with the small filter units.

Literature

[1] DIN Deutsches Institut für Normung e.V.: DIN 18910-1 - Wärmeschutz geschlossener Ställe. Wärmedämmung und Lüftung, Teil 1: Planungs- und Berechnungsgrundlagen für geschlossene zwangsbelüftete Ställe, 2004

[2] Krause, K.-H.: Strömungsvorgänge in Tierhaltungssystemen. Bauen und Technik in der landwirtschaftlichen Nutztierhaltung, Wissenschaftlicher Fachverlag Dr. Fleck, 35428 Niederkleen, 1993, S. 143-152

[3] Müller, H.-J. und K.-H. Krause: Geruchsemissionen und -immissionen aus der Tierhaltung (Beurteilungsgrundlagen und Ableitung von Emissionsminderungsmaßnahmen), Forschungsbericht, Vorläufiger Endbericht, 2002

[4] Weihs, C: Modell- und Praxisuntersuchungen zum Emissionsverhalten von zwei Schweinemastställen. Diplomarbeit. Fachhochschule Braunschweig/Wolfenbüttel, 2006

[5] Krause, K. and S. Linke: How to describe animal welfare in stable design? Proceedings of the XIV ISAH Congress 2009, International Society for Animal Hygiene, Germany, vol. I, pp. 529-532

[6] Anton, W: Tierhygiene. S. Hirzel Verlag, Stuttgart,1984

Authors

Dr.-Ing. Karl-Heinz Krause is a scientist at the Institute for Agricultural Technology and Biosystems Engineering of the Johann Heinrich von Thuenen Institute (vTI), German Federal Research Institute for Rural Areas, Forestry and Fisheries, Bundesallee 50, 38116 Braunschweig, E-Mail: karlheinz.krause@vti.bund.de

Dr. Ing. Hans-Joachim Mueller was until June 2009 a scientist at the Institute of Agricultural Engineering Bornim (ATB), Max Eyth Allee 100, 14469 Potsdam, E-Mail: hmueller@atb-potsdam.de

Dr. Michael Musslick is the officer for agricultural building, animal husbandry, site security and agricultural engineering of the Thuringia Ministry of Agriculture, Forestry, Environment and Natural Protection, Beethovenstrasse 3, 99096 Erfurt,
E-Mail: Michael.musslick@tmlfun.thueringen.de

Stefan Linke is a technician at the Institute for Agricultural Technology and Biosystems Engineering of the Johann Heinrich von Thuenen Institute (vTI), German Federal Research Institute for Rural Areas, Forestry and Fisheries, Bundesallee 50, 38116 Braunschweig,
E-Mail: stefan.linke@vti.bund.de