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Modelling of Odour Emission Rates for Fattening Pigs as Time-resolved Input for Dispersion Models

Günther Schauberger[a*], Martin Piringer [b], Albert J. Heber [c]

[a]WG Environmental Health, Unit for Physiology and Biophysics, University of Veterinary Medicine, Vienna, Austria
[b]Central Institute of Meteorology and Geodynamics, Vienna, Austria
[c]Agricultural and Biological Engineering Department, Purdue University, West Lafayette, Indiana
* gunther.schauberger@vetmeduni.ac.at

For the calculation of the separation distance to avoid odour annoyance, the odour emission rate of the livestock building has to be known as input for the dispersion model. In general, an annual mean value is used although the influence of the live mass growth of the animals as well as of indoor air temperature and ventilation rate on the emission rate is known. This simplified approach was compared with various emission scenarios for a continuous fattening system with a constant live mass of 75 kg and an all-in/all-out system. For the last one a Monte-Carlo based model (inverse transfer sampling technique) was used to avoid an interaction between the growth of the animals and the annual variation of the outdoor temperature. The variation of the emission factor was taken into account twofold, first by a schematized diurnal emission pattern for the various seasons and second by a steady state simulation of the indoor climate to calculate indoor temperature and ventilation rate which both influence the odour release. The results indicate an underestimation of the odour emission rate of a livestock building during summer compared with winter when using an annual mean value. For the all-in/all-out system, this effect is superposed by an overestimation at the beginning of the fattening period and an underestimation at the end. Using emission models which take into account the growth function and/or the indoor climate, a more realistic description of the odour emission characteristics can be achieved. This will help to increase the goodness of the assessment of environmental odour by dispersion models.

1. Introduction

For dispersion modelling of environmental odour, the emission rate is typically estimated as an annual constant value (e.g. Guingand, 2003; Hayes et al., 2006; Nicolas et al., 2008; VDI 3894 Part 1, 2011). In general this annual mean is calculated as a product of the mean live mass of the animals and the odour emission factor. In reality, however, the two parameters show distinct variations over time. This was discussed in detail in Schauberger et al. (2013a) for fattening pigs.

Therefore the use of an annual mean to represent livestock odour emission rates is inappropriate for dispersion model inputs. For fattening pigs, an emission model is used with the indoor temperature, the ventilation rate which are calculated by a simulation model (Schauberger et al., 2000b) as well as the animal activity as predictors (Schauberger et al., 2013a).

As a reference, a constant odour emission rate is used, which is conventionally calculated by an annual mean live mass and a constant odour emission factor. Then, step by step, this constant value is substituted by a live mass which increases during the fattening period using an animal growth model and/or the emission model which takes into account the influence of the indoor temperature, ventilation rate, and animal activity. Six emission scenarios with increasing complexity are thus obtained and presented in the paper.

2. Materials and Methods

2.1 Growth model

For an all-in/all-out (AIAO) production system, an animal growth model describes the increase of emissions by the growing of the animal live mass of the herd. If the AIAO production system is applied only to individual pens within the building, a constant mean live mass value for the entire livestock building is used over time. This is called the continuous flow production system (CONT).

We used a growth model with a constant average daily gain (linear increase) of the live mass m (kg) as a function of time t (days), applied here to fattening pigs reared in an AIAO system. The live mass values at the beginning and end of the fattening period were selected to be m_{start} = 30 kg and m_{end} = 120 kg, respectively. The average daily gain is assumed to be ADG = 0.780 kg d^{-1}. This results in a duration of the fattening period of t_f = 116 d. The duration between two consecutive fattening periods, when the livestock building is empty, is assumed as t_e = 10 d. In this period, the odour emission is set to zero. Hence the overall duration of a fattening period is $t_p = t_f + t_e$ with 126 d or 18 weeks. The growth function is given by $m = m_{start} + ADG \; t$.

The time course of the live mass of fattening pigs behaves like a saw tooth wave with a period duration of 18 weeks (about 1/3 year). These growth periods are superimposed and interact with the time course of the outdoor temperature. To avoid this interaction we calculate the live mass on the basis of a Monte Carlo method, called inverse transform sampling, a useful tool for environmental sciences (e.g. Schauberger et al., 2013b; Wilks, 2011). This method was applied to the growth function (Schauberger et al., 2014). For each half hour mean value, a live mass m for AIAO pig production systems is calculated using this Monte-Carlo approach.

2.2 Simulation of the indoor climate

We adapted a simulation model for the indoor climate of a livestock building which calculates inside air temperature and the ventilation rate. The model is reduced to the sensible heat balance of a livestock building in a moderate climate (Schauberger et al., 2001). To reduce the complexity of the simulation, the influence of the latent heat balance to the sensible heat balance is neglected. The two parameters indoor air temperature Θ_i (equal to the temperature of the exhaust air) and the volumetric ventilation rate V are calculated as a function of the outdoor temperature under the assumption of steady-state conditions. The simulations were conducted for an AIAO system, taking into account the growth of the animals, and for a continuous flow production system CONT with a constant live mass of m = 75 kg.

2.3 Meteorological data

The air temperature for the simulation of the indoor climate was measured at Wels, a site representative of the Austrian flatlands north of the Alps, with a temporal resolution of 30 minutes over a 2 year period between January 30, 1992 (JD=30) and January 31, 1994 (JD=761).

2.4 Odour release model

In general, the odour emission rate of a livestock building is calculated by a live mass specific emission factor (ou s^{-1} LU^{-1}) and the total live mass (LU, 1 LU is equivalent to 500 kg) of the animals inside the building. The odour release is also modified by the indoor climate (e.g. temperature, ventilation rate and time of the day) of the livestock building described in the Sections above. Therefore we developed an odour release model to describe the modifications based on these parameters.

The live mass specific odour emission factor e (ou s^{-1} LU^{-1}) is calculated by multiplying the standardized live mass specific odour emission factor e_0, by the release modification factor R, which modifies the odour emission due to the indoor climate

$$e = e_0 \cdot R \tag{1}$$

In this paper two different release modification factors R were selected. The first one R_1 is derived from Nicholas et al. (2002) in a schematic way using rectangular functions with different durations of the day/night cycles and different emission levels to describe the diurnal variations for winter, summer, and spring/autumn (Figure 1).

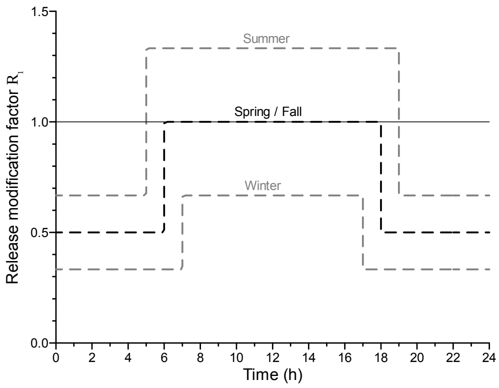

Figure 1. Diurnal course of the release modification factor R_1 for winter, spring/autumn, and summer time derived from Nicholas et al. (2002).

Second we use the emission model of Schauberger et al. (2013a) to calculate the release modification factor R_2 on the basis of the indoor air temperature Θ_i, ventilation rate V, and physical activity of animals A as a function of daytime t. The release modification factor R_2 is calculated by

$$R_2 = F_\Theta \; F_V \; F_A \tag{2}$$

with F_Θ for indoor temperature, F_V for ventilation rate and F_A for relative animal activity.
The release modification factor R_2 is thus given by

$$R_2 = \exp\left(0.0314\left(\Theta_i - \Theta_R\right)\right) \cdot V_n^{0.318} \cdot \left(1 + 0.25 \sum_{i=0}^{1} \frac{\sin\left(\frac{2\pi}{\tau} \cdot (2i+1) \cdot \left(t+\varphi\right)\right)}{2i+1}\right) \tag{3}$$

with the reference temperature Θ_R = 20°C, the the normalized ventilation rate V_n per animal place. The ventilation rate per animal place V is normalized to unity by V_d, according to $V_n = V / V_d$. This ventilation rate is the maximum ventilation rate for growing pigs of V_d = 200 m^3 h^{-1} (55.6 10^{-3} m³ s^{-1}) per animal place (MWPS-32, 1990). The relative animal activity depends on the period τ = 24 h, time of day t (h), and the time lag φ = -6 h.

2.5 Odour emission scenarios

The odour emission rate E (ou s^{-1}) is calculated for one animal place with a time resolution of one half hour according to

$$E = e_0 \cdot R \cdot m \tag{4}$$

with the standard live mass specific odor emission factor e_0, the live mass of one animal m (LU; 1 LU = 500 kg), and the release modification factor R. The entire emission rate of the livestock building can be calculated by multiplying this emission rate E by the number of animals N.

Table 1. Input parameters for odour emission scenarios with growing complexity to calculate the odour emission rate E (ou s^{-1}) per animal place by the standard live mass specific odour emission factor e_0 (ou s^{-1} LU^{-1}), the release modification factor R, and CONT (m = 75 kg) and AIAO pig production systems.

Scenario	Release modification factor R	Pig production system
SC_0	R = 1	CONT
SC_m	R = 1	AIAO
SC_{R1}	R_1 = f (season, t)	CONT
SC_{R1+m}	R_1 = f (season, t)	AIAO
SC_{R2}	R_2 = f (Θ_i, V, A)	CONT
SC_{R2+m}	R_2 = f (Θ_i, V, A)	AIAO

The input parameters of the scenarios are summarized in Table 1. The standard live mass specific odour emission factor e_0 is selected from Schauberger et al. (2013a) with e_0 = 48 OU s^{-1} LU^{-1}. For the first two emission scenarios, the release modification factor is set to R = 1. For scenario SC_0 a continuous pig production system is assumed, which means that the live mass of the pigs is constant over the year with m = 75 kg or m = 0.15 LU. For scenario SC_m, the odour emission rate per animal place is calculated for an AIAO pig production system where the live mass is calculated by the Monte Carlo based growth model (Section 2.1). The next four emission scenarios differ by the way the release modification factor is calculated, either R_1 (Nicholas et al., 2002) or R_2 (Schauberger et al., 2013a). Both are applied either to a continuous flow (m = 75 kg) or to an AIAO production system.

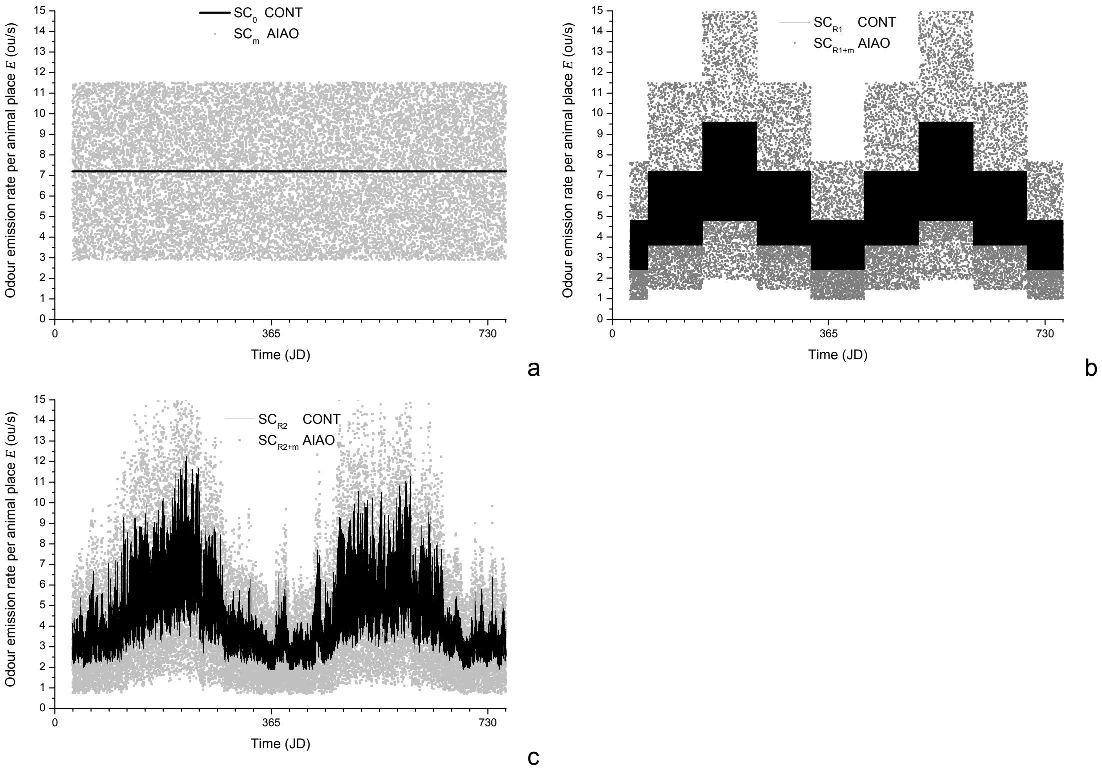

Figure 2 Time course of the odour emission rate E (ou s^{-1}) per animal place for the six odour emission scenarios, calculated for the two year period (JD Julian day; 1.1.1992 = 0) (zero values during the service period are not displayed). (a) SC_0: Continuous fattening: m = 75 kg and release modification factor R = 1, SC_m: all-in/all-out and release modification factor R = 1, (b) SC_{R1}: Continuous fattening: m = 75 kg and release modification factor R_1 (Nicholas et al., 2002), SC_{R1+m}: all-in/all-out and release modification factor R_1, and (c) SC_{R2}: Continuous fattening: m = 75 kg and release modification factor R_2 (Schauberger et al., 2013a), SC_{R2+m}: all-in/all-out and release modification factor R_2. (Source: Schauberger et al. (2014)). The CONT emission scenarios are shown as black lines, the AIAO data as grey dots.

3. Results and Discussion

The time course of the six odour emission scenarios (Table 1) with increasing complexity is shown in Figure 2. The grey dots represent the emission E, calculated by the Monte Carlo simulation. Therefore the values are randomly distributed according to the live mass. The corresponding cumulative distribution functions (CDFs) of the six scenarios are depicted in Figure 3. Whereas scenario SC_0 with a constant live mass shows also a constant emission, the odour emission of scenario SC_m changes with the changing live mass of the AIAO production system (Figure 2a). Neither the influence of the indoor climate nor the influence of the animal activity is considered.

An improvement of the odour release was reached for scenario SC_{R1} (CONT) and SC_{R1+m} (AIAO) by a schematised diurnal time pattern of the release modification factor for the winter, summer, and spring/autumn (Figure 1).

The last two scenarios (Figure 2c) CS_{R2} and SC_{R2+m} are calculated with the release modification factor R_2, which relates the odour emission to the indoor climate of the livestock building. Therefore we combined the simulation of the indoor climate of a livestock building of fattening pigs (Schauberger et al., 2000b) with an odour emission model (Schauberger et al., 2013a) using indoor air temperature, ventilation rate as well as the animal activity as predictors. In this way, the most realistic yearly odour emission cycle is obtained, with low emissions in winter and higher emissions in summer. The variability of the AIAO production system is always larger than for the CONT system.

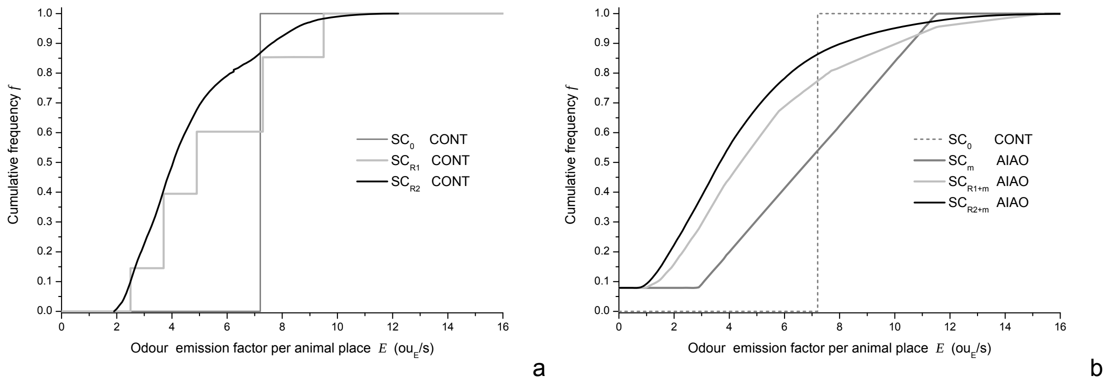

Figure 3 Cumulative frequency of the odour emission rate E (ou s^{-1}) per animal place for the continuous flow production system CONT (a) and the all-in all-out (AIAO) production system (b), calculated for the two year period. (a) CONT: SC_0: m = 75 kg and release modification factor R = 1, SC_{R1}: m = 75 kg and release modification factor R_1 (Nicholas et al., 2002), SC_{R2}: m = 75 kg and release modification factor R_2 (Schauberger et al., 2013a). (b) AIAO: SC_0: m = 75 kg and release modification factor R = 1 (as reference), SC_m: animal growth model and release modification factor R = 1, SC_{R1+m}: animal growth model and release modification factor R_1, SC_{R2+m}: animal growth model and release modification factor R_2. (Source: Schauberger et al. (2014))

Even if the scenarios calculated with R_1 and R_2 do not show much difference in the shape of the CDFs, only the release modification factor R_2, which is based on the indoor climate simulation, shows a high correlation with the meteorological situation, which is to be expected. The scenarios with the AIAO production system also deliver, in general, larger odour emissions and greater variability.
The odour emission rate of a livestock building is a major input to the calculation of separation distances by dispersion models. These model calculations are generally based on hourly weather data (Capelli et al., 2013; Schauberger et al., 2000a; Yu et al., 2009). Nevertheless, most of the calculations of separation distances are performed with constant emission rates (e.g. Hayes et al. (2006); VDI 3894 Part 1 (2011)). Due to the lack of data, none of the existing setbacks or odour dispersion models consider diurnal and seasonal variations in odour emission rates, which may result in great uncertainty in the predicted results (Guo et al., 2007). Capelli et al. (2013) pointed out the importance of the influence of meteorological parameters on the odour emission rate. They suggested the recalculation of the emission rate of an area source on an hourly basis taking into account the influence of wind velocity on the area-specific emission factor. Sun et al. (2010) suggested the use of different emission rates on a monthly basis.
For other farm animals as fattening pigs, such emission models are unavailable in detail. If empirical data on odour emission are missing then such odour emission models can also be based on other substances or gases which are closely related to odour (e.g. PM_{10} for turkeys (Li et al., 2008)), ammonia for poultry (Cheng et al., 2011). Even if such a model is only an educated guess, we are convinced that this will result in a better prediction quality compared with a constant emission rate.

4. Conclusions

The odour emission rate of a livestock building is a major input to the calculation of separation distances by dispersion models. In general, only an annual mean value is used even if it is evident that the growth of the animals and the influence of the indoor climate on the odour release are neglected thereby. In this paper we use a constant emission rate with an annual mean only as a reference. In addition, emission scenarios with increasing complexity have been developed. Calculations were carried out for a continuous flow production system with a constant live mass during the year and an all-in/all-out system with a growing live mass during the fattening period. The emission scenarios which take into account the modification of the odour release due to the indoor climate show an increasing variability of the emissions year-round. During summer the odour release will be underestimated when an annual mean value is used.
This effect will be amplified when high outside temperatures and the ends of the fattening periods coincide. In winter, using an annual mean value, the odour emission will be overestimated compared with variable

emission scenarios. The step from an annual mean value to a more realistic emission scenario will thus increase the reliability of the calculation of separation distances to avoid odour annoyance.

References

Capelli, L., Sironi, S., Del Rosso, R., Guillot, J.-M., 2013. Measuring odours in the environment vs. dispersion modelling: a review. Atmos. Environ. 79, 731-743.

Cheng, W.-H., Chou, M.-S., Tung, S.-C., 2011. Gaseous Ammonia Emission from Poultry Facilities in Taiwan Environmental Engineering Science 28, 283-289.

Guingand, N., 2003. Air quality and reduction of slatted floor in growing-finishing pig units, Gaseous and Odour Emissions from Animal Production Facilities. CIGR, Horsens, DK, pp. 80-87.

Guo, H., Dehod, W.D., Agnew, J., Feddes, J.R., Lague, C., Pang, S., 2007. Daytime odor emission variations from various swine barns. Transactions of the ASABE 50, 1365-1372.

Hayes, E.T., Curran, T.P., Dodd, V.A., 2006. Odour and ammonia emissions from intensive pig units in Ireland. Bioresource Technology 97, 940-948.

Li, H., Xin, H., Burns, R.T., Hoff, S.J., Harmon, J.D., Jacobson, L.D., Noll, S.L., 2008. Effects of bird activity, ventilation rate and humidity on concentration and emission rate of a turkey barn, Livestock Environment VIII - Proceedings of the 8th International Symposium, Iguassu Falls, pp. 111-116.

MWPS-32, 1990. Mechanical ventilating systems for livestock housing. Midwest Plan Service, Iowa State University, Ames p. p72.

Nicholas, P., McGahan, E., Watts, P., 2002. Application of emission data in modelling and assessment. FSA Environmental, Australian Pork Ltd, Toowoomba, Queensland.

Nicolas, J., Delva, J., Cobut, P., Romain, A.-C., 2008. Development and validating procedure of a formula to calculate a minimum separation distance from piggeries and poultry facilities to sensitive receptors. Atmos. Environ. 42, 7087-7095.

Schauberger, G., Lim, T.T., Ni, J.Q., Bundy, D.S., Haymore, B.L., Diehl, C.A., Duggirala, R.K., Heber, A.J., 2013a. Empirical model of odor emission from deep-pit swine finishing barns to derive a standardized odor emission factor. Atmospheric Environment 66, 84-90.

Schauberger, G., Piringer, M., Baumann-Stanzer, K., Knauder, W., Petz, E., 2013b. Use of a Monte Carlo technique to complete a fragmented set of H_2S emission rates from a waste water treatment plant Journal of Hazardous Materials 263, 694-701.

Schauberger, G., Piringer, M., Heber, A.J., 2014. Odour emission scenarios for fattening pigs as input for dispersion models: A step from an annual mean value to time series. Agriculture, Ecosystems & Environment 193, 108-116.

Schauberger, G., Piringer, M., Petz, E., 2000a. Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM). Atmospheric Environment 34, 4839-4851.

Schauberger, G., Piringer, M., Petz, E., 2000b. Steady-state balance model to calculate the indoor climate of livestock buildings, demonstrated for fattening pigs. International Journal of Biometeorology 43, 154-162.

Schauberger, G., Piringer, M., Petz, E., 2001. Separation distance to avoid odour nuisance due to livestock calculated by the Austrian odour dispersion model (AODM). Agriculture, Ecosystems and Environment 87, 13-28.

Sun, G., Guo, H., Peterson, J., 2010. Seasonal odor, ammonia, hydrogen sulfide, and carbon dioxide concentrations and emissions from swine grower-finisher rooms. J. Air Waste Manag. Assoc. 60, 471-480.

VDI 3894 Part 1, 2011. Emissions and immissions from animal husbandry - Housing systems and emissions - Pigs, cattle, poultry, horses, in: Verein Deutscher Ingenieure (Ed.). Beuth, Berlin.

Wilks, D.S., 2011. Statistical methods in the atmospheric sciences: an introduction. Acad. Press, San Diego, CA.

Yu, Z., Guo, H., Xing, Y., Laguë, C., 2009. Setting acceptable odour criteria using steady-state and annual hourly weather data. Biosystems Engineering 103, 329-337.