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Odour emission scenarios for fattening pigs as input for dispersion models: A step from an annual mean value to time series

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ABSTRACT

For the assessment of odour annoyance by dispersion models, the odour emission rate of the source has to be known. In general, an annual mean value is used, although the live mass of the animals increases dramatically during the fattening period and odour emission from the building is known to depend strongly on indoor air temperature and ventilation rate. This annual mean value of the odour emission rate was compared with various emission scenarios for a continuous flow production system with a constant live mass of 75 kg and an all-in/all-out system. For the last one an inverse transfer sampling method 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 model that employs a sensible heat balance 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 the emission model which takes into account a time series of the odour emission rate, a more realistic description of the odour emission characteristics can be achieved compared with an annual mean value.

1. Introduction

Livestock buildings near residential areas can create public nuisance due to the annoyance potential of odour. To protect residential areas from excessive odour exposures, reasonable separation distances can be estimated using dispersion models with hourly meteorological input data (Guo et al., 2006b; Pullen and Vawda, 2007; Yu et al., 2010, 2011a,b; Capelli et al., 2013). Together with the meteorological data describing the dilution in the atmosphere, the odour emission rate is the major input variable for such calculations.

For the purpose of dispersion modelling, the odour 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 based on the mean live mass of the animals and a mean body mass related odour emission factor. In reality, however, the two parameters show distinct variations over time. Pigs and broilers, in particular, increase in live mass over their growing periods by factors of 4 and 70, respectively. The temporal development of the live mass during the fattening period can be described by growth functions for the animals. For the determination of the odour emission factor, the influence of various parameters has been previously studied. The parameters evaluated in the literature include indoor temperature (Nicholas et al., 2002; Le et al., 2005b; Guo et al., 2006a), air velocity above the release surface (Le et al., 2005b; Nimmermark and Gustafsson, 2005; Zhang et al., 2005), animal activity (Nicholas et al., 2002; Guo et al., 2007), humidity, diet (Le et al., 2005a), and cleanliness (Miller et al., 2004). This was discussed in detail in Schauberger et al. (2013a) for fattening pigs.

Therefore the use of annual means to represent livestock odour emission rates is inappropriate for dispersion model inputs. In this paper we describe the method to calculate a time series of the odour emission rate on an hourly basis. For fattening pigs, an emission

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Table 1
Characterization of the production of fattening pig in several countries described by the live mass at the beginning m_{start} (kg) and the end of the fattening period m_{end} (kg), the average daily gain *ADG* (kg/d), and the duration between two consecutive fattening periods, when the livestock building is empty (service period) t_e (d).

Country	m_{start} (kg)	m_{end} (kg)	*ADG* (kg/d)	t_e (d)
US	25	128	0.750	9
		124	0.780	
Germany				
Survey	30	118	0.701	
Planning data	28	118	0.780	14
Austria	32	119	0.790	18
EU mean	30	117	0.780	
Australia		120	0.790	
Belgium		113	0.659	
Canada		122	0.875	
Denmark		107	0.905	
France		117	0.789	
Germany		121	0:780	
Great Britain		103	0.822	
Ireland		105	0.838	
Italy		166	0.640	
Netherlands		116	0.795	
Spain		108	0.689	
Sweden		119	0.913	

Source: BPEX (2013); Germany: KTBL (2012) and KTBL (2009).

model is used with the indoor temperature, the ventilation rate and the animal activity as predictors (Schauberger et al., 2013a). Values for indoor temperature and ventilation rate are obtained from a simulation model of the indoor climate (Schauberger et al., 2000b), taking into account the sensible heat release of the livestock, the thermal characteristics of the building, and the ventilation system.

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. The application of such a time-series based empirical emission model will improve the outputs of dispersion models via process-based emission estimates (Tong et al., 2012).

2. Materials and methods

2.1. Growth model for pigs

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). The kind of production system predominantly used depends strongly on the national agricultural system. Also the boundary conditions like the starting live mass of the fattening pigs and the slaughter live mass can differ considerably (Table 1).

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 (Table 1). The average daily gain is assumed to be $ADG = 0.780\,\mathrm{kg\,d^{-1}}$. 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 linear growth curve represents a uniform distribution of the live mass between m_{start} and m_{end}.

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. Wilks, 2011; Schauberger et al., 2013b). There are many techniques for generating a random sample which is distributed according to a pre-selected cumulative distribution function CDF. Here we used the inverse sampling technique. Using this method, a pseudo-random number RN from a uniform distribution [0; 1], is transformed by $F^{-1}(RN)$, where F is the CDF of the live mass for the AIAO system. The selected CDF F has to be available in a closed form, here:

$$F = \left| \begin{array}{ll} f_e & \text{for} \quad m = 0 \\ k \quad m + d & \text{for} \quad m_{start} \le m \le m_{end} \end{array} \right.$$

with the portion of the empty livestock building $f_e = t_e/t_p$, and the two parameters $k = (1 - f_e)/(m_{end} - m_{start})$ and $d = f_e - k\ m_{start}$.

If RN is a uniformly distributed random number in the interval [0;1], then the live mass $m = F^{-1}(RN)$ is a random variable, distributed according to the CDF F. In this case we get

$$m = \left| \begin{array}{ll} 0 & \text{for} \quad RN \le f_e \\ \dfrac{(RN - d)}{k} & \text{for} \quad RN > f_e \end{array} \right.$$

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). 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 $d\Theta_i/dt = 0$.

The sensible heat balance is given by

$$c\,m \frac{d\Theta_i}{dt} = Q_{A,sens} + Q_B + Q_V$$

with the sensible heat release of the animal $Q_{A,sens}$, the loss of sensible heat caused by the transmission through the building Q_B, the sensible heat flow rate caused by the ventilation system Q_V, and the specific heat capacity c of the mass m.

The sensible heat release of the animal is part of the total heat production Q_A (CIGR, 2002) which depends on the live mass of the animal m (kg) by $Q_{A,m} = 5.06\,\mathrm{m}^{0.75}$. The total heat production Q_A depends on $Q_{A,m}$ (taking into account the average daily gain of live mass of $ADG = 0.780\,\mathrm{kg\,d^{-1}}$) and the indoor temperature Θ_i and reads as

$$Q_A = \{Q_{A,m} + Q_{A,m}(n - 1)[1 - (0.47 + 0.03m)]\}[1 + 0.012(20 - \Theta_i)]$$

where n presents multiples of the daily feed intake, normalized by the maintenance $Q_{A,m}$, calculated as a function of the live mass m by $n = -0.00157\ m^2 + 0.0123\ m + 2.9882$. This function was derived from data collected in Denmark, The Netherlands, and Sweden (CIGR, 2002).