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Continuous odour measurement from fattening pig units

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HIGHLIGHTS

- We carried out odour concentration measurements in experimental pig barns.
- Gas monitoring in the same barns suggested a daily variation of odour emission factor.
- We used an electronic nose calibrated against odour measurements to monitor continuously the odour in the fattening pig units.
- We predicted the diurnal evolution of the odour emission factor.
- We shown that its daily pattern could be explained by the circadian activity of pigs.

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ABSTRACT

A study in experimental slatted-system fattening pig units was conducted with the aim of estimating the odour emission factor (in ou s.pig^{-1}), which can subsequently be used in dispersion models to assess the odour annoyance zone. Dynamic olfactometry measurements carried out at different development stages of pigs showed a logical trend of the mean assessed odour emission factor with the pig mass. However, the variation within the same mass class was much larger than variation between classes. Possible causes of such variation were identified as the evolution of ventilation rate during the day and the circadian rhythm of pig. To be able to monitor continuously the daily variation of the odour, an electronic nose was used with suitable regression model calibrated against olfactometric measurements. After appropriate validation check, the electronic nose proved to be convenient, as a complementary tool to dynamic olfactometry, to record the daily variation of the odour emission factor in the pig barn. It was demonstrated that, in the controlled conditions of the experimental pens, the daily variation of the odour emission rate could be mainly attributed to the sole influence of the circadian rhythm of pig. As a consequence, determining a representative odour emission factor in a real case cannot be based on a snapshot odour sampling.

1. Introduction

Intensive livestock buildings are associated to environmental nuisance like emissions of ammonia, greenhouse gases and odorous compounds (Philippe et al., 2011, 2012; Hayes et al., 2006; Schauberger et al., 2013). Odour emission from pig barns adjacent to residential areas causes frequent conflicts between farmers and their non-farming rural neighbours.

Some countries or regions apply odour regulatory systems based on distance zones. Early guidelines proposed pure empirical formulas to calculate a reasonable separation distance between the agricultural enterprise and the first neighbour. They were based on common sense and on field surveys. A more quantitative basis is now provided with the recent broader use of dispersion modelling and chiefly with the standardization of odour determination by dynamic olfactometry. Guidelines are now validated against accurate methods and are compatible with odour units, odour rate and percentiles usually applied to assess the odour annoyance zones (Nicolas et al., 2008). The implementation of this proposed framework would rely on using emission factors per animal, which can be defined specifically for piggeries as the odour emission rate

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(ou s^{-1}) released to the atmosphere by a (finishing) pig. It has to integrate the annual mean emission from housing and manure storage/treatment (Aneja et al., 2008). Of course, the emission factor method is the only one applicable for future projects of pig barns, but, even for existing livestock buildings, it is a convenient way of avoiding expensive measurements which could only be afforded for large units or production systems (Van Harreveld et al., 2001).

As finishing pigs are the dominant source of odour emissions on intensive units, it is important to use accurate odour emission rate in atmospheric dispersion models and in setback distance formulas. Due to the lack of data, none of the existing models consider diurnal or seasonal variations in odour emission rates and the use of the mean value may result in great uncertainty in assessed results. In real barns, uncontrollable variables, such as temperature, relative humidity, season or hazards of pig behaviour and of manure management are important factors influencing odour emissions, although the story of the interrelationships of these uncontrollable variables is quite complex (Ogink and Groot Koerkamp, 2001; Van Langenhove and De Bruyn, 2001; Schauberger et al., 2003; Miller et al., 2004; Hayes et al., 2006; Guo et al., 2007). Hence, some studies are conducted in experimental facilities, where most of the ambient and process parameters are controlled. Some of them concern pure gases (Blanes-Vidal et al., 2008) and few studies of this type add the odour to their concern (Wang et al., 2011). Among the variables analysed, the floor system, the ventilation and the season are the most often cited, but some papers investigate also the diurnal variation of emissions (Schauberger et al., 1999; Jeppsson, 2002; Guo et al., 2007; Blanes-Vidal et al., 2008; Blunden et al., 2008; Wang et al., 2011). All their results show a big variation (factor 3–5) of the emissions during the day, mainly due to the animal activity and to the adaptation of the ventilation rate to keep a constant temperature in the barn. To take this diurnal variation into account in the dispersion models, Schauberger et al. (1999, 2013) propose behaviour of the emission based on empirical models.

Measuring the odour concentration by sampling and dynamic olfactometry implies a quite heavy and expensive procedure which precludes the possibility of a high frequency monitoring. On the other hand, the absence of a relevant key-chemical-compound correlated to the odour prevents a continuous estimation of olfactory emissions by classical analytical instruments. Now, the electronic nose (e-nose) represents a promising emergent technique which could be used to monitor in real time the odour emission from a pig barn.

The first step of the present study consists in measuring the odour emissions by dynamic olfactometry during the whole growing period of pigs kept in experimental pig barns, where most of external parameters are controlled. Then, these data will be used to achieve the main objective of the paper, i.e. calibrating an electronic nose to monitor the variation of odour emission factors on daily and long term basis. By the way, some influencing factors could be pointed out.

2. Material and methods

2.1. Animal housing and conditions

A batch of 36 pigs (Piétrain × Belgian Landrace) was fattened in an experimental farm in Liège (Belgium), from 34 to 122 kg on average, during a 3 months period from October 22nd, 2011 to January, 23rd, 2012, corresponding to fall and winter seasons in Belgium. The batch was divided into 3 homogeneous groups of 12 animals according to the sex and the body mass. Groups were kept separately in three identical rooms (30 m^2, 103 m^3) equipped with a 9 m^2-pen (0.75 m^2 per pig) with concrete slatted floor.

The manure was collected under the flooring surface and evacuated only at the end of the finishing period. Each pen was equipped with two feeding troughs with free and unlimited access.

Each pen was ventilated using an extraction fan whose flow was automatically adapted to keep constant the ambient temperature. The fresh air entered by an opening which communicated with the service corridor. Ventilation rates and ambient temperature were continuously monitored and recorded with an Exavent apparatus (Fancom, Panningen, The Netherlands). The pigs were weighted individually once a month. The average daily gain (ADG) is supposed to be constant between weightings.

2.2. Gas emissions

The experimental facility was originally designed for a measurement campaign aiming essentially at assessing the contribution of pig breeding to the emission of different gases, and particularly greenhouse gases. The concentrations of NH_3, N_2O, CH_4, CO_2 and H_2O were measured during three periods of six consecutive days (weeks 5, 8 and 12 of stay). The research groups took the opportunity to use the same facility to measure odour emission.

2.3. Dynamic olfactometry

A total of 37 measurements of odour concentration were carried out by dynamic olfactometry on the basis of samples collected in 60 L-Nalophan® bags. However, each measurement value was calculated as the geometric average of at least 2 replicates and the total number of collected bags is 84 in the three pens, of which 23 concerned pen 2, also monitored with an electronic nose (see below). Odour bags were collected during three sampling periods corresponding to three different development stages: 36 samples between 46 and 52 kg (low), 28 between 70 and 78 kg (medium) and 20 between 97 and 106 kg (high). The bags were filled by evacuating the surrounding air from a rigid container by a pump. Dynamic olfactometry was conducted with the Odile 2010 olfactometer (Odotech, Canada) in the laboratory of the research group "Environmental Monitoring" at Arlon, Belgium, in full compliance with the European standard EN13725. The odour concentration (in $ou_E\ m^{-3}$) is the dilution ratio of the odorous sample in odour-free air which corresponds to the odour perception threshold, averaged for a panel of 6 assessors. The odour emission rate (in $ou_E\ s^{-1}$) is then obtained by multiplying the odour concentration by the ventilation flow rate (in $m^3\ s^{-1}$). The odour emission factor ($ou_E\ s^{-1}$.pig) is the odour emission rate divided by the number of animals in the room. The subscript "E" in ou_E stands for "European" as the European standard is applied for this measurement. However, later on, as other methods are also used to assess the odour concentration, the subscript E will be avoided. The inlet of the sampling tube was located in the pen, just in front of the ventilation shaft before the fan. The ventilation flow rate is assessed on the basis of the measurement of rotational speed of the impeller through an empirical model calibrated against air velocity measurements conducted in an accurate test installation. The flow rate is measured every 5 min, but to avoid spotty extreme values, the hourly average is used in the further discussion.

2.4. Electronic nose

In one pen (pen 2), a sample tube was also dedicated to an electronic nose (e-nose) measurement. The signals were recorded at a sampling frequency of 1 measurement each 5 min during the

whole campaign. An electronic nose is an intelligent device based on an array of non-specific gas sensors and a signal processing system. When sensors responses are put together, they form a pattern, which is typical of the gas mixture presented to the array, like a signature. Hence, e-nose is not an analytical instrument, aiming at measuring the concentration of various chemical compounds. In the signal processing step, the whole signal pattern is always used as a global response. The instrument was developed in the university research laboratory and consisted in a six-sensor metal-oxide sensor array (Figaro™) arranged in a PTFE 200 ml-chamber. The ambient air is sucked with a pump placed after the sensor chamber at a flow rate of 200 ml min^{-1}. The useful signal of each sensor is its electrical conductance, which is recorded, on-board saved and off-line processed by statistical package (Statistica). For this work, the six used sensors are listed in Table 1 with the application suggested by the manufacturer. Remembering that sensors have only partial specificity to those compounds (sometimes odourless), they were chiefly selected from the experience of the research group within the domain of odour monitoring.

2.5. Animal activity

Animal activity, defined as the number of standing pigs divided by the total number of pigs (in %), was monitored using video cameras placed in each room. Recordings were made during 24 h-periods on November 22nd and 24th, 2011, December 13th and 15th, 2011 and January, 17th and 19th, 2012, corresponding to the first, second and third periods of gaseous measurement, respectively. Animal activity was measured every 5 min.

2.6. Statistical analyses

Three data processing techniques are mostly used in this work.

The analysis of variance (ANOVA) was used to appreciate the influence of categorical factors on the measured odour.

A regression procedure aimed at creating a global indicator, which is a linear combination of the 6 sensor signals and which is able to assess, with sufficient accuracy, the odour concentration at the moment of the e-nose observation. Among all the possible linear combinations, the one built by the multiple linear regression (MLR) generally gives the best results in terms of least squares fitting of the calibration set. The resulting model however is a pure mathematical construction, which is convenient to assess concentration values inside the training sample, but which is less adapted to the assessment of new data. Using as explanatory variables, in place of raw sensor signals, the results of an unsupervised classification method, such as Principal Component Analysis (PCA) has a good chance to produce a more physical model, making more "sense" from a physical standpoint (Wise and Gallagher, 1998). Indeed, the Principal Component Regression (PCR) tries to assess the odour concentration by including in the model the first principal components (factors) which explain most part of the data variability. However the regression is made *a posteriori* and remains an artificial construction.

Table 1
Six metal-oxide sensor from Figaro(TM) used for the present application.

Sensor type	Application suggested by the manufacturer
TGS2610	Combustible gases
TGS822	Alcohols, solvents
TGS2620	Alcohols, solvents
TGS842	Methane
TGS2180	Water vapour
TGS880	Alcohols and vapours from food

Finally, Partial Least Square regression (PLS), captures the greatest amount of variance, like PCA, while also achieving correlation with the predictor variable (here the odour concentration), but during the sensor matrix decomposition process itself. By combining the advantages of several other chemometrics methods, PLS should probably provide the most adapted model for the odour concentration assessment.

Of course PCR or PLS models converge towards MLR one when all factors are included in the model. Selection of the optimum numbers of factors is a very important step before using the model, as if the number of factors retained is more than required, noise will be fitted also, resulting in overfitting. On the other hand, if the number of factors retained is low, meaningful data may be discarded. So, the Partial Least Square regression (PLS) was used in this work to build a model able to assess the odour concentration on the basis of the 6 sensor signals.

A third statistical method is applied to quantify the odour level: the Mahalanobis distance with respect to a "non-odour" reference group in the space of the 6 sensor signals.

Finally, as usual in the domain of environmental odours, the odour annoyance zone in the surroundings is estimated on the basis of odour concentration percentiles prevailing for typical climatic conditions. That long-term exposure is quantified in terms of a frequency of occurrence of hourly averaged concentrations above a certain limit odour concentration. In the present study, 98th percentile for 1 ou m^{-3} is used as a possible annoyance zone for pig odour. It is calculated using a typical Belgian climate and the Gaussian dispersion model Tropos Impact (Odotech, Canada).

3. Results and discussion

3.1. Ambient parameters

Table 2 summarizes the ambient conditions in the three experimental rooms.

Despite a large variation of outdoor temperature, the indoor temperature remained in a narrow interval. Such stable conditions were respected by a suitable ventilation system, with a flow rate exhibiting some exceptional values under 600 $m^3\ h^{-1}$ or above 1100 $m^3\ h^{-1}$, but with a standard deviation only around 150 $m^3\ h^{-1}$. This range was kept under excessive limits since the air came from the service corridor which acted as a buffer zone.

3.2. Olfactometric measurements

The analysis of the influence parameters on odour concentration and emission factor was performed by combining the samples from the three experimental rooms, and all the replicates, i.e. by using all the 84 olfactometric measurements.

As ANOVA results show, odour emissions allocated to three pig mass classes differed significantly (Fig. 1; p value lower than 0.05).

Table 2
Range and standard deviation of ambient parameters in the three experimental rooms.

Ambient parameter	Range	Mean	Standard deviation
Outdoor temperature (°C)	−1.0 to 18.4	7.7	3.5
Indoor temperature (°C)			
Pen 1	17.8–21.5	19.7	0.4
Pen 2	17.3–21.0	19.4	0.4
Pen 3	17.1–20.8	19.0	0.4
Ventilation flow rate ($m^3\ h^{-1}$)			
Pen 1	210–2529	867	132
Pen 2	145–2477	843	167
Pen 3	152–2272	827	121

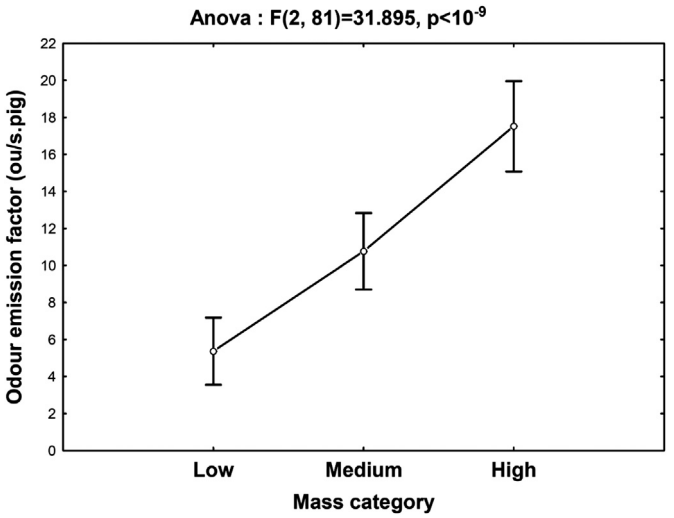

Fig. 1. ANOVA result testing the influence of mass category on odour emission factor – Illustration of average values and 95% confidence intervals.

Mean values for the emission factor are 5.4, 10.8 and 17.5 ou s.pig^{-1} respectively for low mass (mean mass = 49 kg), for medium mass (mean = 74 kg) and for high mass (mean = 103 kg). Related to body mass, the mean values of the odour emission factor are 0.108, 0.146 and 0.172 ou s.kg^{-1} respectively for low, medium and high masses. A linear regression provides a slope of 0.21 ou s.pig^{-1} per kg live-mass between 40 and 110 kg, but with a rather high variability inside the same mass category ($R^2 = 0.42$), which could be due to other influence factors.

As the odour emission rate is the product of odour concentration and ventilation flow rate, it should be influenced by both factors. However, for the whole data set, the coefficient of variation is 20.8% for the flow rate and 67.4% for the odour concentration. So, in the studied case (winter period and air entering through a buffer zone), the variability of the odour emission rate was essentially driven by the variation of odour concentration ($r = 0.96$) and is less dependent on ventilation rate ($r = 0.13$) as shown on Fig. 2. The odour emission factor related to body mass was poorly correlated with ventilation rate ($r = 0.29$, Fig. 3). Besides, the ventilation rate does not depend on the pig mass ($r = -0.11$). For those statistical parameters, rare ventilation rate values exceeding 950 m^3 h^{-1} were discarded to insure data normality.

As a consequence, it could be expected that the dependence of the odour emission factor with ambient parameters, including the ventilation, should be limited and that its variation should chiefly be due to the pigs themselves (growing, activity, defecation).

Diurnal evolution of emitted gases generally showed a first peak in the morning, between 8:00 and 10:00 and a second peak or plateau between 15:00 and 20:00 or 21:00.

As expected, the signals of the electronic nose sensors show variations during the same hours, although presenting different patterns, more typical of TGS sensors (see Fig. 4 for two examples of sensor signals, plotted as mean differences from daily average). Hence, the odour emission should also be likely to present peaks or plateaus at the same hours.

3.3. Odour assessment model

Considering the cost and the constraint of the dynamic olfactometry method, the monitoring by electronic nose is fully justified to get information on the diurnal odour variation.

However, the metal oxide sensors in the e-nose react to various chemical compounds, whether they smell or not. It is thus essential during the data processing phase to make an unquestionable link between the sensor signals and the odour concentration.

Odour concentration was used as dependant variable of a regression with the 6 sensor signals as explanatory variables. The calibration set consisted in 23 olfactometric measurements performed in pen 2 where the e-nose was installed and in the sensor signals recorded at the same time as bag sampling, i.e. around 9:00.

As awaited, the multiple linear regression gave the best fitting from the calibration set ($R^2 = 0.90$), but it was not suited for prediction of new data. It was definitely discarded. Partial Least Square regression was then applied and considered afterwards as the best regression procedure. But to finally define the most reliable model, one has still to select the optimum number of factors from PLS regression (from 1 to 6). To test the reliability of the 6 PLS models, a leave-three-out cross-validation procedure was used. With only 23 observations, it was unwise indeed to discard 7 or 8 observations from the calibration set for validation purpose. Leave-three-out cross-validation consists in removing 3 observations from the calibration set, calibrating the model with the rest, and validating upon the 3 discarded data. Then rotating through the data set to choose each time 3 other observations for subsequent calibration sessions will provide a series of 21 figures of merit to appreciate the model quality. Calculating the average of the 21 figures of merit will

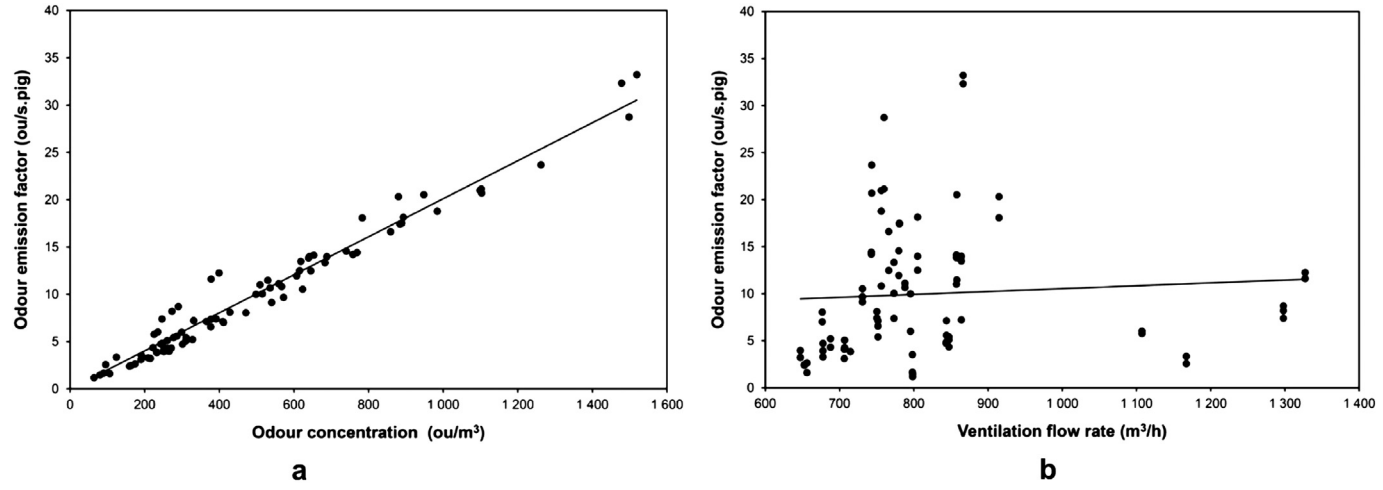

Fig. 2. Relation between odour emission factor and odour concentration (a) and ventilation flow rate (b).

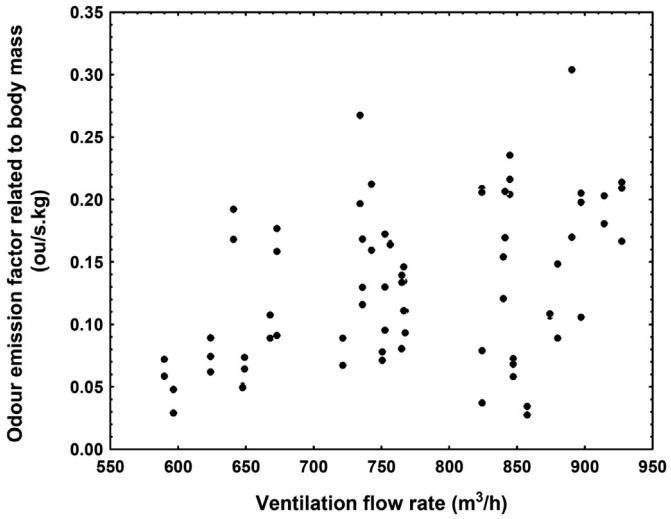

Fig. 3. Scatterplot of odour emission factor related to body mass versus ventilation flow rate.

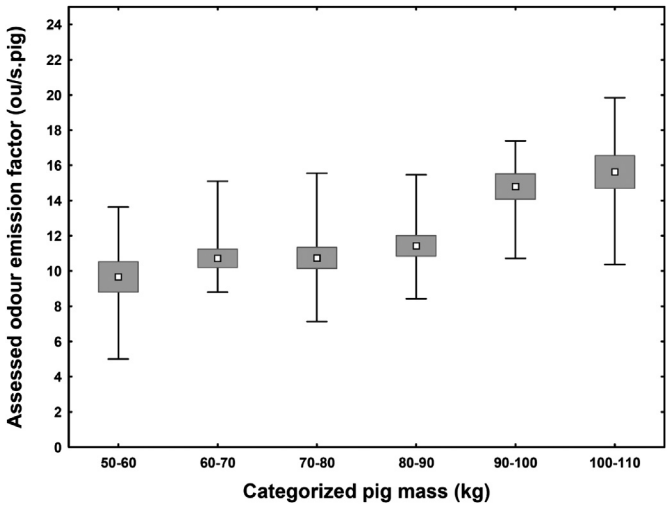

Fig. 5. Box-and-whiskers plots of assessed daily mean value of odour emission factor in function of categories of pig mass (the central square dot is the mean value, the grey boxes are limited by one standard error on both sides of the mean and the limits of the whiskers are minimum and maximum of the assessed concentration).

provide a single criterion for the model. The figure of merit selected in this work is the mean prediction error sum of square (PRESS) for the 3 validation moving observations.

In the present case, the PRESS value is minimum when introducing only the first factor in the model, 1 is thus the optimal number of factors.

This first factor alone represents 71% of the variance of the sensor signal and the coefficient of determination R^2 of the model with only this factor is 0.72, which is less than MLR model, but with better performance in terms of validation. Hence, the linear combination of sensor signals corresponding to the first PLS factor will be considered thereafter as the best indicator of the odour concentration. So, the result of its implementation on recorded signal sensors will be called "assessed odour concentration", and "assessed odour emission factor" when divided by the number of pigs in the barn.

3.4. Odour evolution

Applying the PLS model to the whole data recording period in pen 2 provides interesting information about the long-term and short-term evolution of the assessed odour concentration. Fig. 5 shows box-and-whiskers plots of the assessed daily mean value of odour emission factor categorized according to classes of pig mass.

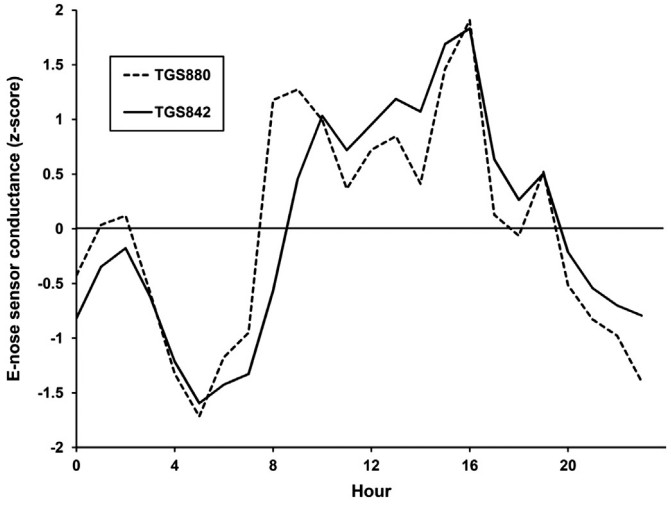

Fig. 4. Typical diurnal evolution of two gas sensors of the electronic nose (scaled values).

A clear trend of the mean assessed odour concentration is observed with the pig mass, confirming the olfactometric measurements illustrated in Fig. 1. But the within day variation is much larger than the variation between mass classes. The standard deviation within a same day can reach 200 ou m^{-3} for the assessed odour concentration, i.e. 4.5 ou $s.pig^{-1}$ for the odour emission factor, and presents a trend to increase with the pig mass. The assessed odour emission factor patterns are different from day to day, but typical ones are shown in Fig. 6 for November 22nd, 2011 (Fig. 6a, mass = 59 kg) and for January 17th, 2012 (Fig. 6b, mass = 105 kg).

The assessed odour emission factor is lower during the night and exhibits a peak in the morning, typically between 8:00 and 10:00. Then, after 12:00 and chiefly after 15:00, the odour increases again and presents a plateau until 20:00 or 21:00. The causes of this daily evolution of odour could be either the circadian rhythm of pig or the evolution of ventilation rate.

As above mentioned, the variability of the ventilation rate is quite low and, for the two days considered in Fig. 6, its coefficient of variation is less than 10%. As a consequence, the assessed odour emission factor follows about exactly the pattern of the assessed odour concentration. So, for this particular experiment, the circadian rhythm of pig is likely to be the main reason of the diurnal evolution of odour emission factor.

Fig. 7 shows, for the whole measurement period, the histogram of the hours for which the maximum odour concentration occurs during the day. It confirms the peak in the morning (generally between 10:00 and 12:00) and the higher level in the end of the afternoon (generally between 17:00 and 21:00).

Regarding the minimum of the assessed odour concentration, it generally occurs during the night period, between 22:00 and 8:00.

Fig. 8a and b show the circadian evolution of the animal activity for the two days corresponding respectively to Fig. 6a and b.

The similarity of patterns between Figs. 6 and 8 could explain that the circadian activity of the pigs induces a big evolution of odour release. Considering the assessment of the PLS model as reliable, the odour emission factor could vary by a factor up to 5 during a typical day.

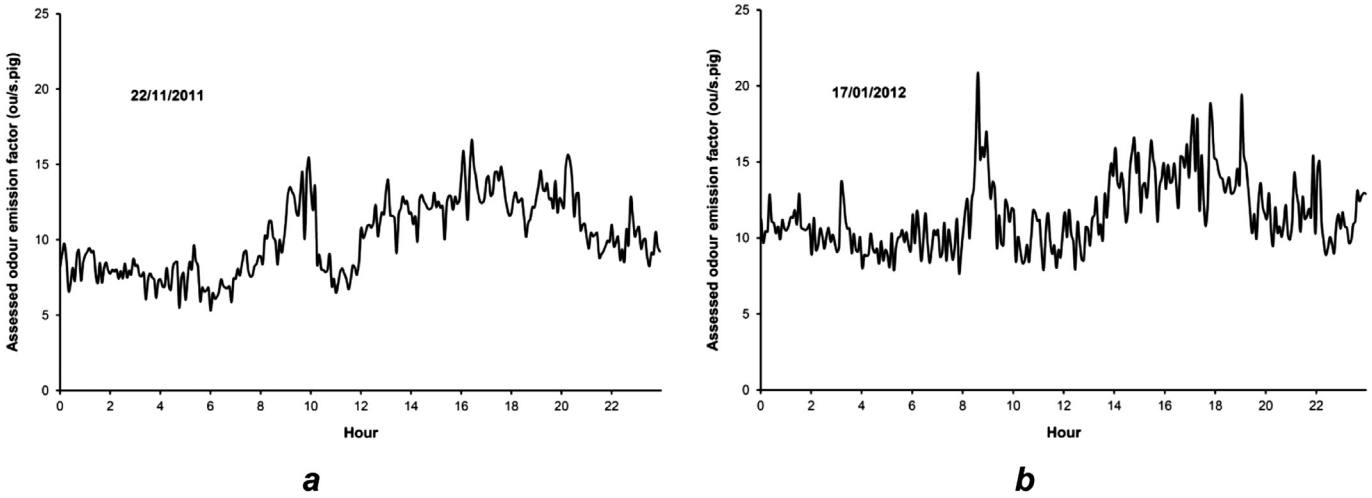

Fig. 6. Diurnal patterns of assessed odour emission factor for two typical days.

3.5. Relevance of electronic nose

Obviously, the link between electronic nose response and odour concentration is not straightforward. However with some precautions in the design and in the use of sensor arrays, it is possible to approach the human nose perception of the odour level.

A first condition is the right choice of the application for which the "chemical" concentration should be correlated to the odour concentration. Such condition is generally fulfilled for waste or fermentation odours, such as pig farm emissions. There is a quite linear relationship between odour concentration and chemical response, as measured by gas sensors, through that is not true for all odour sources.

A second condition is the right choice of the sensors in the array. In the present study, the 6 tin oxide sensors were selected for their good sensitivity to chemicals involved in the odour of pig barns, according to previous experience of the research team. Fig. 9 shows the relation between the odour concentration measured by dynamic olfactometry and the Mahalanobis distance, calculated in the 6D-space of sensor signals, of the observations in the pen from ones in an odour-free air.

The two variables are estimated independently one from the other, but the coefficient of determination of the linear model between them is quite high ($R^2 = 0.78$). So, in this specific case, the distance from an odour-free group of observations should already be sufficient to estimate the odour concentration.

But the third and major condition to really acknowledge the electronic nose as a "nose" is the right choice of a robust and validated mathematical model of data processing. Here, a link between sensor signals and odour concentration was obtained through a regression procedure. The 1-component PLS model gave very good results in cross-validation and can be considered as sufficiently robust to assess the odour concentration in the pig pen.

In the present study, the odour measurements conducted in the specific case of experimental barns provide results which could be regarded as almost independent of ambient parameters, such as temperature (inside and outside), humidity and even ventilation rate. As these parameters do not vary significantly, they have low influence on both the response of e-nose sensors and the odour emission itself. Hence, the time evolution of the odour emission factor can roughly be directly deduced from the variation of the odour concentration inside the pen (about independently of the

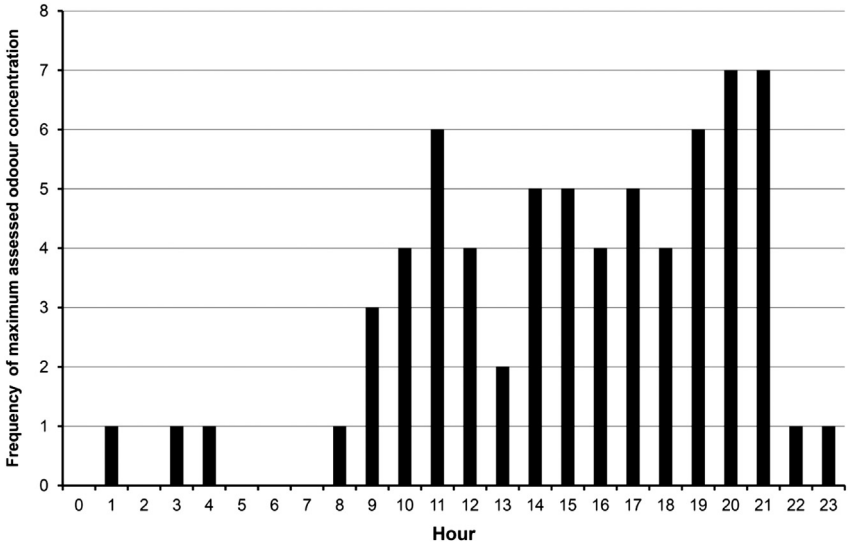

Fig. 7. Histogram of hour occurrences of the maximum assessed odour concentration during the day.

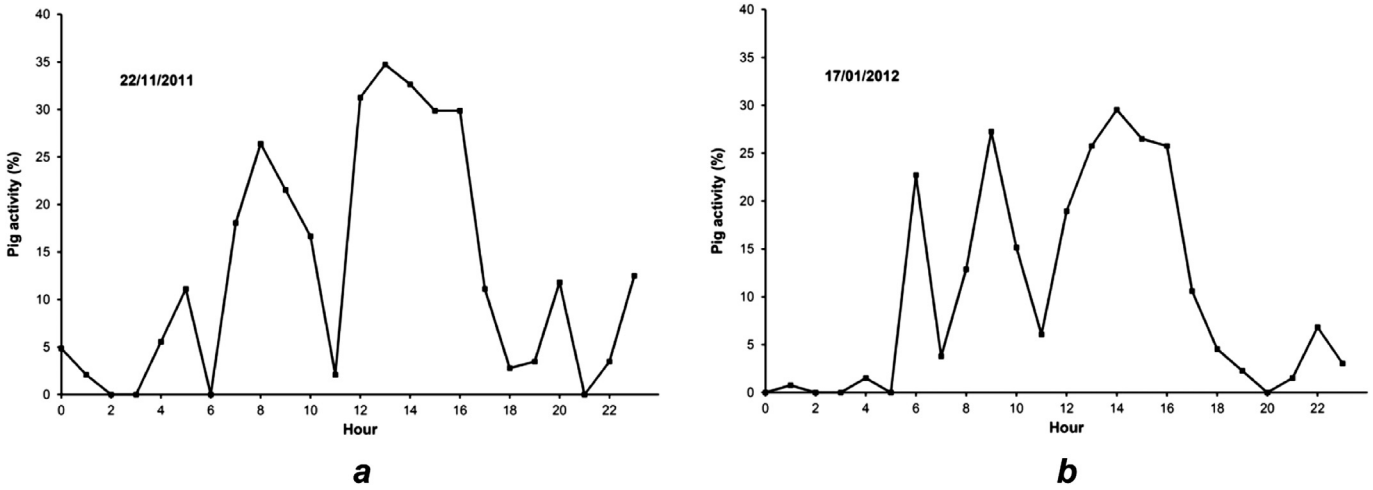

Fig. 8. Diurnal patterns of pig activity for the two days considered in Fig. 6.

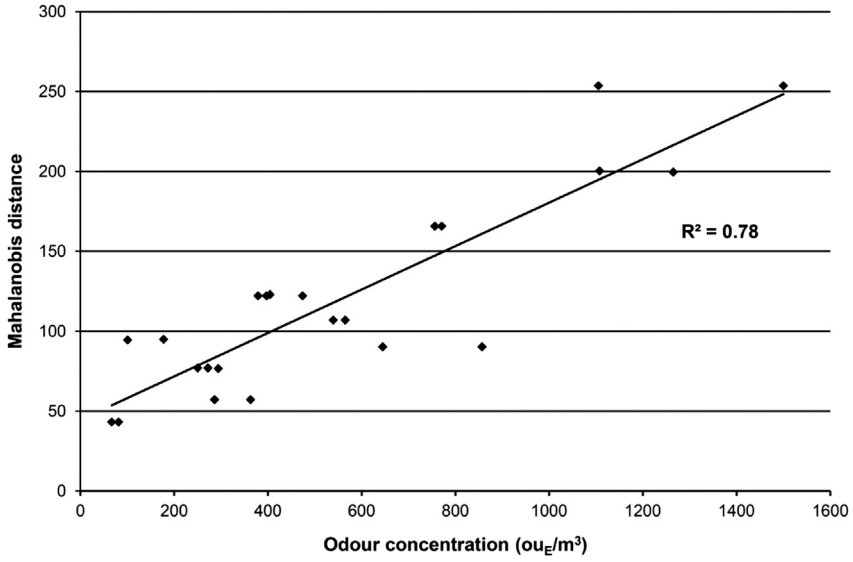

Fig. 9. Relation between the Mahalanobis distance from a non-odorous air group in the 6D-space of sensor signals and the odour concentration measured by dynamic olfactometry.

ventilation rate). Snapshot olfactometric measurements conducted at different stages of pig growth clearly indicate that the odour emission factor increases about linearly with the pig mass. The value of 20 ou s.pig^{-1} at the finishing stage, adopted in some European guidelines, appears to be credible for the breeding system considered in this study.

The most significant outcome of the present study is the confirmation of the high diurnal variation of odour emission rate, which is chiefly due in the studied case to the circadian rhythm of pig. Hence, it is unlikely that a representative odour concentration and emission rate (i.e., a daily mean) can be obtained using a snapshot measurement. As concluded by Schauberger et al. (2013), previously published odour emission rates are likely to show a bias towards higher values since most of the measurements were taken during daytime and in warm weather.

The lowest odour level is actually observed during the night, when usually more stable outdoor atmospheric conditions occur. Therefore, considering such variability of the odour emission in dispersion modelling may lead to some differences in the assessment of the area of the annoyance zone. For long term studies, e.g. on an annual time base, however, the higher odour emission rates recorded during the day should balance the shorter extend of the night-time plume. Simulating (with Tropos Impact) a 2000 pigs barn with a constant 20 ou s.pig^{-1} emission factor or with a typical diurnal pattern, but with the same daily average odour emission rate, gives rise to about the same 98th percentile shape for a typical Belgian climate. The influence of diurnal variation should be more marked when considering short term plumes, especially when night and day wind patterns are very different.

4. Conclusions

When used cautiously, the electronic nose, fitted with appropriate gas sensors and with a suitable odour assessment model, validated against acknowledged measurement methods, proves particularly convenient to continuously monitor an odour emission. In the present study, it was chiefly useful as complementary tool to dynamic olfactometry to record the daily variation of the odour concentration in the pig barn which, when multiplied by the measured ventilation rate, provides the odour emission factor. In

the controlled conditions of the experimental pens, the daily variation of the odour emission rate could be mainly attributed to the sole influence of the circadian rhythm of pig. As a consequence, determining a representative odour emission factor in a real case cannot be based on a snapshot odour sampling, even modulated by the variation of the ventilation rate. The odour emission in a pen is likely to vary up to a factor 5 between quiet periods (e.g. night) and activity periods (e.g. late afternoon). Depending on the sampling time, the average odour emission rate could be largely over or under estimated.

To improve the estimation of odour concentrations and odour annoyance zones by dispersion models, not only the annual variation of the odour release has to be taken into account, but also the diurnal one. According to the measurements conducted during this study, this time evolution should be better accounted for by a step variation (e.g. low odour before 8:00 and after 21:00 and higher between) than by a true sinusoidal function.

As mentioned, the advantage of experimental barns over real farms is that many parameters are controllable. However, essential outcomes may be extrapolated to farms as experimental conditions were as much as possible representative of real cases. So, the odour emission factor of 20 ou $s.pig^{-1}$ for the finisher pig can be considered as a plausible value, at least for slatted systems in Belgium.

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