ASSESSMENT OF SEPARATION DISTANCES TO AVOID ODOUR ANNOYANCE: INTERACTION BETWEEN ODOUR IMPACT CRITERIA AND PEAK-TO-MEAN FACTORS

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Abstract: The assessment of the impact of environmental odour emissions is based on four steps: (1) the determination of the odour flow rate of the source, (2) the dilution in the atmosphere, described by dispersion models, calculating time series of one-hour mean values, (3) short-time peak concentrations derived from one-hour mean values, to mimic odour sensation of the human nose, and (4) odour impact criteria, defined by the odour concentration threshold and its exceedance probability. The procedure of the determination of odour annoyance by the last two steps (peak-to-mean factor and odour impact criteria) is compared for various national jurisdictions showing a great variety of criteria. To reach a better comparability for separation distances, calculated by impact criteria for different countries, an alignment of the peak-to-mean factors and the odour impact criteria should be aspired. An important requirement to improve the reliability of the calculated separation distances is the use of a peak-to-mean factor, which decreases with distance from the source. The separation distances calculated for the same protection level but with different national odour impact criteria, contrary to expectation, are very different and show a stronger dependence on wind direction for higher exceedance probabilities. It must be concluded that the concept of odour impact criteria used in various jurisdictions should be harmonized. It is obvious that separation distances, calculated for an identical protection level, should be similar.

Key words: *odour impact criteria, odour, annoyance, peak-to-mean factor,*

INTRODUCTION

The assessment of the impact of environmental odour emissions is based on four steps: (1) the determination of the odour flow rate of the source, (2) the dilution in the atmosphere, which is described by dispersion models, calculating time series of one-hour mean values, (3) short-time peak concentrations to mimic odour sensation of the human nose, which are derived from these one-hour mean values, and (4) the odour impact criteria, defined by the odour concentration threshold and its exceedance probability which enable to assess the environmental impact of the odour source, e.g. by (direction-dependent) separation distances around the source under investigation.

The first two steps are internationally better established by reliable odour emission measurements and well documented dispersion models than the last two steps. Therefore we can assume comparable results independent from the selected dispersion model. This investigation focuses on the last two steps. The approaches chosen differ from country to country, prescribed by the environmental protection agencies and influenced by national jurisdictions, e.g. in the form of guide lines, often resulting in different separation distances for the same protection level (e.g. pure residential areas).

Therefore, the last two steps (peak-to-mean factor and odour impact criteria) are analysed in detail to discuss a new approach which can harmonise the incomparable situation in different national jurisdictions.

PEAK-TO-MEAN FACTORS AS A CONCEPT TO ASSESS HUMAN ODOUR PERCEPTION

Contrary to most air borne pollutants odour is not a feature of a certain chemical species but a physiological reaction of humans. The sensation and perception of odorants depends on sniffing as an active stage of stimulus transport.

For the assessment of peak values, describing the biologically relevant exposure, often the so called peak-to-mean concept is used. This is a way to adopt dispersion models to short-term odour concentrations. The goal of the use of peak-to-mean factors is to mimic the perception of the human nose in a better way as it can be achieved by long term mean values.

The step from the one-hour mean value (as output of the dispersion model) to an instantaneous odour concentration is shown in Fig.1. For the one-hour mean value, the threshold for odour perception (here taken as 1 ou_E /m^3) is not exceeded. Taking mean values over 10 minutes, one concentration value exceeds the threshold. For the short term mean values of 12 s, concentrations in the range of 5 to 6 ou_E /m^3 can be expected, which means a distinct odour perception over several breaths. Fig.1 shows that the shorter the selected time interval, the higher the maximum concentration. For the shortest period of 12 s, a new feature of the time series can be seen. Besides 12 s intervals with odour concentrations above zero, a certain percentage of zero observations can be expected. The frequency of non-zero intervals is called intermittency γ defined by the conditional probability $\gamma = prob\{C | C > C_D\}$ with the concentration of the detection limit C_D (Chatwin and Sullivan, 1989).

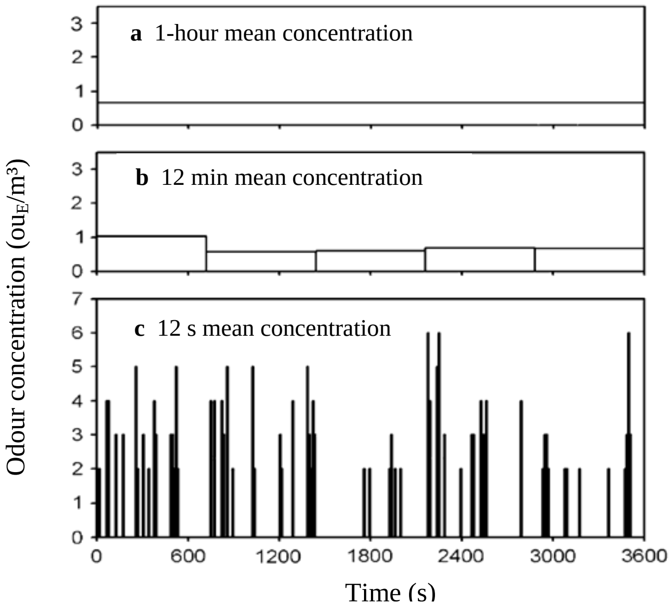

Fig. 1: Time course of the odour concentration (ouE /m³) for three time intervals. (a) one-hour mean value (e.g. output of a dispersion model), (b) 12-min and (c) 12-s mean odour concentrations observed at a single receptor point during a field study. The 12-s mean values were recorded and subsequently used to calculate 12-min and one-hour mean concentrations (source: Schauberger et al. (2012), modified from Nicell (2009)).

According to the relationship above, the peak-to-mean factor is defined by $F = C_p / C_m$. The open question is the definition of the peak value C_p. It can be defined manifold (Gross, 2001; Klein and Young, 2010). The following definitions are used frequently: (1) $C_p = C_M + \sqrt{\sigma}$, i.e. the peak value is defined by the mean value and the standard deviation $\sqrt{\sigma}$. The quotient between standard deviation and the mean value C_m is called fluctuation intensity *i*, therefore the peak-to-mean factor on the basis of the fluctuation intensity is $F_i = i + 1$; (2) the peak value is defined by the 90-percentile C_{p90}, so $F_{90} = C_{p90} / C_m$; (3) the peak value is defined by the 98-percentile C_{p98} or the 99-percentile C_{p99}, and (4) the peak value is defined by the maximum C_{max} , then $F_{max} = C_{max} / C_m$ (Klein and Young, 2010).

Especially for Germany, the peak value C_p is well defined by the comparison between empirical field measurements (VDI 3940 Part 2, 2006) and dispersion model calculations. If we assume that the assessor sniffs every 10 seconds to decide if the sample smells, then 360 breaths (sample size) during one hour are obtained. In the German jurisdiction an hour is counted as a so called odour hour if at least 10% of the 360 breathes can be evaluated as odourous. For practical reasons (VDI 3940 Part 2, 2006), only a period of 10 minutes (60 breaths) is used as a sample to judge a certain hour. If 6 out of 60 periods (10 minutes) are assessed as odourous by a panelist, this defines an odour hour. Therefore the 90-percentile is used to define the peak value C_p with t_p = 1 s to assess the incidence of an odour hour.

The following predictors are discussed, which influence the concentration fluctuation and thereby the peak-to-mean factor (Hanna and Insley, 1989; Olesen et al., 2005):

1. Stability of the atmosphere
2. Intermittency
3. Travel time or distance from the source
4. Lateral distance from the axis of the wake
5. Geometry of the source (emission height and source configuration)

The details for the parameterization of these five predictors can be found in Schauberger et al. (2012). A post-processing tool for dispersion calculations was developed by Schauberger et al. (2000) showing a decrease of the peak-to-mean factor with distance from the source. Further downwind the peak-to-mean factor is modified by an exponential attenuation function depending on the Lagrangian time scale (Piringer et al., 2007).

Figure 2 shows the distance depending function of the peak-to-man factor for all stability classes. In addition, the constant factor $F = 4$ applied by the German dispersion model AUSTAL2000 is shown by a thin straight line. It is obvious that a constant factor $F = 4$ as with AUSTAL2000, will lead to an underestimation in the near field compared to the far field and vice versa.

As indicated in Figure 2, also constant peak-to-mean factors are in use, which do not take into account the above mentioned predictors. Some examples: $F = 10$ for the pervious regulatory Gaussian dispersion model in Germany (Rühling and Lohmeyer, 1998), the Danish model with $F = 7.8$ (Olesen et al., 2005), and $F = 4$ for AUSTAL2000. A peak-to-mean factor $F = 1$ means that the long term mean value (e.g. 1-hour mean value) is selected to evaluate the sensation of environmental odour. Countries using constant peak-to-mean factors $F > 1$ are listed in Piringer and Schauberger (2013).

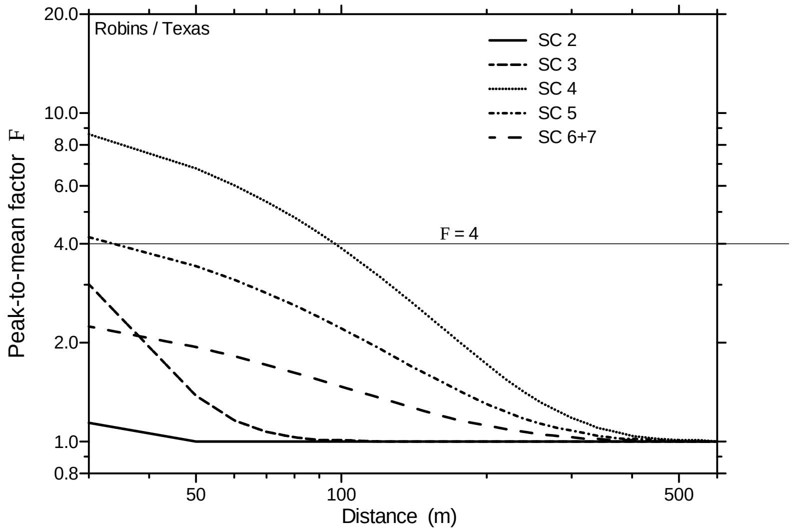

Figure 1 Distance depending peak-to-mean factor F for all stability class used by the AODM. The constant factor F = 4 applied by AUSTAL2000 is shown as a thin straight line (source: Piringer and Schauberger (2013)).

In general, a constant peak-to-mean factor (even if $F = 1$) will underestimate the predicted odour sensation in the near field. In the far field the peak-to-mean factor reaches the value $F = 1$ (Schauberger et al., 2012).

ASSESSMENT OF ANNOYANCE BY THE ODOUR IMPACT CRITERIA

For practical use separation distances are calculated to reduce or avoid odour annoyance depending on a certain protection level. At such a distance the frequency of odour sensation over a certain odour concentration threshold C_T does not exceed a pre-selected level, called the exceedance probability p_T. The exceedance probability can be defined as a conditional probability $p_T = prob\{C | C > C_T\}$. This concept is based on investigations of Miedema and Ham (1988) and Miedema et al. (2000) who found a strong relationship between the odour concentration threshold for an exceedance probability of $p_T = 2\%$, $C_{2\%}$ (respectively the 98 percentile) and the percentage of the highly annoyed neighbors, using an integration time of 1 hour ($F = 1$).

The determination of the separation distance depends on the protection level, which is established in various jurisdictions in different ways. The odour impact criterion for a certain protection level depends on three parameters. The first parameter defines the integration interval of the ambient odour concentration. In many cases this is calculated by the peak-to-mean factor F which fixes the integration time of the ambient concentration in relation to the outcome of the dispersion model. The other two parameters are the exceedance probability p_T of a certain odour concentration threshold C_T which together form an odour impact criterion.

Table 1: Odour impact criteria defined by the odour concentration threshold C_T (in ou_E /m³) and the exceedance probability p_T (in %) for various countries which use peak-to-mean factors $F > 1$. The ambient odour concentration is determined by the peak-to-mean factor. The impact criteria were applied to this (modified) concentration (modified from Piringer and Schauberger (2013)

Country / Protection level	Peak-to-Mean factor *F*	Odour impact criteria (C_T / p_T)
Germany		
irrelevance criterion	4	1 ou_E /m³ / 2%
residential areas:		
poultry	4	1 ou_E /m³ / 6.7%
fattening pigs	4	1 ou_E /m³ / 13.3%
milking cows	4	1 ou_E /m³ / 20%
other animals	4	1 ou_E /m³ / 10%
rural areas:		
poultry	4	1 ou_E /m³ / 10%
fattening pigs	4	1 ou_E /m³ / 20%
milking cows	4	1 ou_E /m³ / 30%
other animals	4	1 ou_E /m³ / 15%
Austria residential areas	variable	1 ou_E /m³ / 8% **and** 5 ou_E /m³ / 3%
Denmark		
residential areas	7.8	5 to 10 ou_E /m³ / 1%
industrial and rural areas	7.8	10 to 30 ou_E /m³ / 1%
Australia, Queensland		
stacks	10	5 ou_E /m³ / 0.5%
ground-level or down-washed	5	5 ou_E /m³ / 0.5%
Australia, Queensland residential areas	2	2.5 ou_E /m³ / 0.5%
USA, Pennsylvania residential with highway	2	4 ou_E /m³ / 0.57%
USA, California plant fence-line	2.29	4 ou_E /m³ / 0.5%

The odour impact criteria can be adapted to the required protection level in two ways. (1) The exceedance probability varies, keeping the odour threshold constant. E.g. in Germany the exceedance probability $p_T = 10\%$ for pure residential areas and $p_T = 15\%$ for rural sites, whereas the odour concentration threshold remains constant with $C_T = 1$ ou_E/m³. (2) The odour concentration threshold is variable, whereas the exceedance probability is kept constant (e.g. Australia).

In Table 1 only those criteria in different countries are listed which use a peak-to-mean factor $F > 1$, which means that the integration time of the ambient odour concentration, which is evaluated by an odour impact criterion, is shorter than one hour. An overview of impact criteria using $F = 1$ can be found in Piringer and Schauberger (2013). In Europe, Germany, Denmark and Austria a factor $F > 1$ is used to assess the expected odour concentration in the range of several seconds. All other European countries use a factor $F = 1$. In Austria, a method is used to calculate the factor F (here a peak-to-mean factor dependent on meteorological conditions, i.e. wind speed and stability class) as a function of the distance to avoid the disadvantages of a constant factor which was discussed above. The consideration of the hedonic tone (pleasant/unpleasant) for the odour impact criteria can be seen for Germany, Ireland, and Belgium with increasing protection needs for poultry, pigs, and milking cows.

An important requirement to improve the reliability of the calculated separation distances is the use of a peak-to-mean factor, which decreases with distance from the source. The separation distances, which are calculated for the same protection level but with different national odour impact criteria, contrary to expectation, are very different. It must be concluded that the concept of odour impact criteria, used in various jurisdictions should be harmonized. It is obvious that separation distances, calculated for an identical protection level, should be similar.

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