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# Quantification of Odour Annoyance-Nuisance

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This paper analyzes the state of the art of the methods and models used for the characterization of odour annoyance and it preliminary advances proposals for the evaluation of the olfactory nuisance.
The use of a sensorial technique, such as dynamic olfactometry, is proposed for the analysis of odour concentrations, odour emission rates and odour dispersions. Secondly a simple model for the quantification of environmental odour nuisance, based on the use of FIDOL factors, i.e. frequency, intensity, duration, hedonic tone and location, is developed.

## 1. Introduction

Odours do not directly represent a problem for human health, but they create problems of nuisance, adversely affecting the wellness of citizens. The olfactory nuisance actually is the biggest cause of public complaints initiatives in North America and in Europe. Prolonged exposure to odors may cause negative effects on humans, including emotional stress, anxiety, discomfort, headaches, depression, eye irritation, respiratory problems, nausea and vomiting (Wilson, et al., 1980), (Brennan, 1993). Consequently, the presence of odours can lead to the loss of dwelling amenity (Freeman, et al., 2002) and to a lowering of the corresponding real estate value (Environmental Agency, 2011).
Both the loss of amenity and physical disorders, can lead to complaints, especially when the presence of an odour sensation is often repeated over time.
The interest of the scientific world with respect to the problems related to odour pollution has therefore increased over the years. As an example, Figure 1 shows the trend of the publications regarding the topic of odour nuisance.

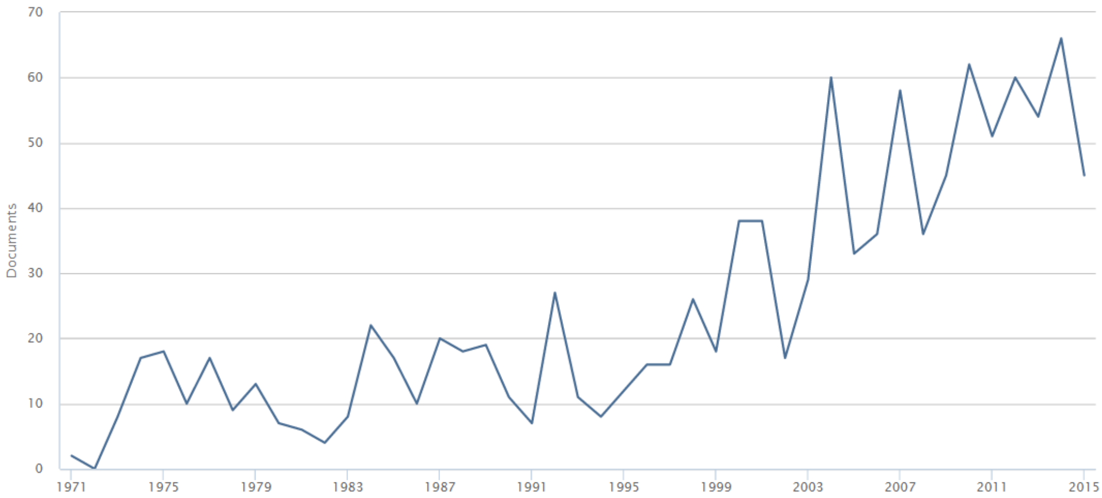


*Figure 1: Number of documents in SCOPUS using as key words “odour annoyance” or “odour nuisance”*

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In order to design appropriate strategies for odour emissions control, it is necessary to develop suitable scientific methods to univocally quantify odour (Hobson, 1995), thereby eliminating the mentality for which odor characterization should be treated more as an art than as a science (Jiang, 1996). The use of chemical analysis for odour quantification has proven to be scarcely reliable or not representative of the real situation (Brennan, 1993), (Preti, et al., 1993), (Cain, et al., 1995), ( Zhao, et al., 2014).
Instead, it is more and more frequent to apply sensorial techniques, based on the responses of a selected panel of assessors, in order to quantify odour (Hair, et al., 2010). Among those, dynamic olfactometry is the most diffuse, because of its repeatability, especially after the introduction of the EN 13725:2003 (CEN, 2003). Since the introduction of a standardized method for odour measurement, many academic studies focused on the evaluation and quantification of odour emissions from industrial facilities. Most of these studies generally aimed to evaluate solely the amount of odour emitted and eventually apply dispersion models to assess to which extent these emissions impact on the surroundings.
However, it is currently widespread opinion ithat this kind of assessment only represents one of different aspects that, when combined, may cause olfactory nuisance. As it is known from the literature, there are five factors, said FIDOL (Watts, 1995; Freeman, et al., 2002; Nicell, 2009; Griffiths, 2014), which are the frequency, intensity, duration, offensiveness and location of odor perception, that play a role in the definition of odour nuisance. For these reasons, the exclusive study of odor concentration cannot be fully representative of the environmental nuisance caused by an odour emissions, as this neglects various parameters that have to be considered in order to quantify the effective discomfort.
The purpose of this study is to explore the topic of objectification and quantification of odour nuisance. The aim of this study is therefore to make a proposal of a method for discomfort evaluation, which involves the evaluation of the contribution of FIDOL parameters to increase the reliability and completeness of the evaluation.

## 2. Methods

### 2.1 Current methods for odour impact assessment

One common method for the prediction of odour emissions from an activity is the use of OEFs Odour Emission Factors). OEFs are developed in analogy with the emission factors defined by the United States Environmental Protection Agency (1995) according to which an Emission Factor is a representative value relating the amount of a pollutant released into the atmosphere to a certain type of related activity. Numerous studies deal with this type of assessment factors for different types of plants (Hair, et al., 2009; Mielcarek, et al., 2015; Sironi, et al, 2005; Sironi et al, 2007). OEFs are typically evaluated upstream of abatement systems, for this reason, in order to estimate odour emissions into the atmosphere from non-existing plants it is necessary to hypothesize the efficiency of such systems.
Instead, when making evaluations about an existing plant, the best strategy to use is direct emission sampling and analysis. The parameter that is used is the OER (Odour Emission Rate), calculated as:

$$\mathrm{OER} = \mathrm{Q} \cdot \mathrm{C_{od}} = \left[\frac{\mathrm{ou_E}}{\mathrm{s}}\right] \qquad (1)$$

where Q is the airflow coming from an emission point, normalized at 20 °C [$m^3$/s] and $C_{od}$ is the odour concentration of the emission [$ou_E/m^3$] measured by dynamic olfactometry according to the EN 13725:2003.
An older approach for some regulations was based on the definition of limit values at emissions in terms of odour concentration or odour emission rate (e.g., D.G.R.n.7/12764, 2003; D.G.R. n.1495, 2001; S 2205-1, 1997), which is the reason why some odour impact assessment approaches involved only the quantification of emissions. However, the evaluation of the OER alone doesn’t give any information about how an emission will affect potential receptors.
In order move in the direction of evaluating odour impact at receptors instead that at the source, the use of dispersion models has been spreading out recently. Models allow to simulate how odour emissions disperse in the atmosphere and thus to evaluate the ground odour concentration in a defined space-time domain. Currently most of the regulations in the world in the field of odour are based on a dispersion modelling approach (Capelli et al., 2013).
Input data required for this kind of models are meteorological, orographical and emission data. The output is the ground odour concentration in each point of the sampling grid, estimated in each time interval considered, averaged over the integration time. In order to avoid to increase too much the computation time and the input data complexity, the time step on which the model runs is generally one hour. For this reason, the ground odour concentration values calculated by the model on evry cell of the simulation domain is an represents the odour concentration averaged over one hour. Since the odour event can have a lower duration with respect to an hour, the use of corrective so called “peak-to-mean” factors becomes necessary. These factors are

multiplied by the 1-h averaged odour concentration value, thus giving the peak odour concentration within the hour (Schauberger, et al., 2012). The peak-to-mean factor is defined as

$$F = \frac{Cp}{Cm} \quad (2)$$

where F is the peak-to-mean ratio, $C_p$ is the peak concentration and $C_m$ is the 1-h averaged (mean) concentration.

Therefore, the output data obtained by means of odour dispersion modelling are typically the "peak" odour concentration values at all points of space-time domain obtained through the application of this "safety" factor F. The applied peak-to-mean factors vary widely from country to country (Nicell, 2009).

Finally, being odour a pollutant that is not constantly present at the receptor, it is common that odour impact is assessed by evaluating not the average odour concentration over the simulation period, but a given percentile of the odour concentration values estimated over the time domain. This means that odour impact is defined through the frequency with which a given odour concentration values is exceeded in the simulation domain. The authorities and regulators usually use these parameters to set odour impact limits. However, they are often different from one jurisdiction to another, thereby referring to different integration times or percentile values, giving that this kind of evaluations are hardly comparable from country to country (Nicel, 2009; Jeong 2012). Up to now, odour impact is mostly quantified by means of the above mentioned series of assessments and parameters.

However, as discussed in the Introduction, the five FIDOL parameters exists that can be used to define the odour nuisance at a receptor. The above described odour impact assessment approach based on the application of dispersion modelling, which calculates the frequency of exceedance of an odour concentration value in the area surrounding the source, only accounts for 3 of the 5 factors: frequency, intensity and duration.

As a matter of fact, the choice of the percentile value univocally fixes the frequency of the odour events. The intensity value is linked to the ground odour concentration. The duration is linked to the software integration time, usually an hour. The duration of the odour event can then be represented by the choice of a fixed peak-to-mean factor F, or by the use of variable factors expressed as functions of different parameters, such as distance from the source or atmospheric stability (Smith, 1973) (Schauberger, et al., 2012).

The above described methos for odour impact assessment by means of the simulation of emission dispersion, is one of the most used, however, it does not consider the remaining two FIDOL parameters: offensiveness and location. This means that odour dispersion modelling cannot be considered as completely exhaustive, as it ignores two fundamental parameters for impact quantification.

### 2.2 The "offensiveness" parameter

Numerous studies invite to consider the offensiveness of certain odours (Sucker, et al., 2008. Miedema, et al., 1998, Miedema, et al., 2000)

Already today, in the United Kingdom, different concentration limits at the receptor, for different types of plant and processing, are set depending on the relative expected offensiveness (UK Environmental Agency, 2011).

Sucker et al. (2008) carried out a comparison among results of a survey through questionnaires, filled out by residents, and a field inspection, where the correlations between the hedonic tone assessments by the panel and by residents were highlighted. In the second part of this study, the impact of hedonic tone on the perception of odour nuisance is again underlined, and a good correlation between frequency and nuisance using a logarithmic scale is also shown.

A subsequent study (Miedema, et al., 2000) tries to investigate a correlation between olfactory nuisance and odour concentration and states a relationship between the percentage of residents who declare to be highly annoyed and the odour concentration at the 98th percentile (C98) obtained by a dispersion model. This analysis was carried out for different installations, characterized by different types of odour offensiveness. Performing a single generic assessment that includes all the sites, it should be noted that the percentage of people who declare high nuisance is closely related to the C98 through the logarithmic equation:

$$\%\mathrm{HA} = \mathrm{a} \cdot (\log\mathrm{C}_{98})^2 \quad (3)$$

where %HA is the percentage of residents annoyed (considered by Miedema, et al., 1998 upper then 72/100), "a" is a multiplicative coefficient, "log$C_{98}$" is the logarithm of the odour concentration at the receptor.

By differentiating the various plants with different degrees of unpleasantness and regressing the curves of Miedema for the calculation of the coefficient "a", very different values can be obtained between a plant and the other. This fact highlights that offensiveness is a key parameter for the definition the odour nuisance.

To quantify the degree of nuisance resulting from an odour emission, it is possible to use the same equation by Miedema and to define an Odour Nuisance Index, ONI (O) that takes into account the odour offensiveness:

$$\mathrm{ONI}\ (\mathrm{O}) = \mathrm{a}(\mathrm{O}) \cdot (\log\mathrm{C}_{98})^2 \quad (4)$$

In order to obtain an Odour Nuisance Index depending from odour offensiveness, the coefficient “a(O)” has to be fixed. Obviously, the greater the odour unpleasantness, the greater will be the odour nuisance and the corresponding value “a(O)”.
The UK Environmental Agency already classifies odour emissions into the three categories: pleasant, neutral or unpleasant. The differentiation can be made on the value of the odour hedonic tone, measured by a suitable sensory technique (VDI 3882, 1994). According to the VDI 3882 standard, the quantification of the hedonic tone occurs in a binary way to differentiate pleasant odours, marked with a + sign, from unpleasant ones, marked with a sign -. The concept of neutral odour would therefore apply to hedonic tones that are equal to zero. The proposal of this study is to divide the whole scale of hedonic tone levels (+4 to -4) into three intervals, with similar magnitude, and to define in this way uniquely the multiplication factor “a(O)”. The values defined for this coefficient maintain the ratio 1: 2: 4 of the line English guideline (UK Environmental Agency, 2011). This ratio is also comparable to those found in the coefficients of concavity regressed from Miedema, et al. 2000.

*Tab 1: Proposal for the a(O) values in function of the hedonic tone values*

| Offensiveness | Hedonic Tone | a(O) |
|---|---|---|
| Pleasant odours | +4 → +1.5 | 0.5 |
| Neutral odours | +1.5 → -1.5 | 1 |
| Unpleasant odours | -1.5 → -4 | 2 |

**2.3 Location**
Another crucial parameter for the quantification of the odour nuisance is the place where the odour is perceived. This variable is closely linked to the prediction and expectation of the amenity of a certain urban or geographical location.
The degree of discomfort is significantly lower if the odour is perceived in a rural area or in an industrial area compared to the case in which it is perceived in a sensitive area as in the surroundings of a hospital, or in particular places of artistic or historic interest.
Differentiating zones in an urban area thus means giving them a different value that also reflects the economic value of the real estate. Normally the local administration is responsible for providing this differentiation.
For this reason, for the evaluation of the odour nuisance, another parameter that has to be considered for the contextualization of the location parameter is the population density: the odour nuisance, measured as numbers of complaints, will undoubtedly be greater in a highly populated area than in a less populated area. This is because, when analysing not just the odour itself, but rather the nuisance arising from it, the population density indicates how many people can potentially be annoyed. For this reason, also the population density will be proportional to the risk that the complaint effectively occurs.
The proposal for an area differentiation weighing the odour nuisance is not new. Some authors have proposed a method providing different odor concentration limits at the 98th percentile in function of the sensitivity of the receptor (Rossi et al, 2015). In this case, two different types of receptor classifications are considered: a classification by area and a classification per building (or unit).
The classification by area is, for sure, the most simple and practical approach. However, there are cases in which it is as important to protect sensitive buildings, or historical/architectural buildings inserted in a rural area.
Considering therefore that what we want to quantify is not the odour but the public odour nuisance that originates from odour, we can consider the odour nuisance as the risk that receptors suffer an odour problem originating from a plant.
The concept of risk quantification (R), already used in safety-related fields, is calculated as the product of the probability (P) of event occurrence and its magnitude (M) (Rota et al., 2007).

$$\mathrm{R} = \mathrm{P} \cdot \mathrm{M} \tag{5}$$

This concept can be applied to the specific field of odour nuisance evaluation by considering the risk “R” as the risk of public annoyance-nuisance, the magnitude “M” as a function of intensity and hedonic tone, and the probability “P” as a function of the place linked to quantity of receptors and their expectations.
Using this approach, even in cases in which the magnitude is important, if the odor is present in an uninhabited area, the probability of creating nuisance or complaints will be almost equal to zero (P ~ 0). Similarly, in the case the receptors are located in a densely populated area or are particularly sensitive (in this

case P assumes important values), but the odour intensity is very low (M ~ 0), the risk of annoyance would be negligible.
In this way, the equation for the odour nuicance index can be written as:

$$\mathrm{ONI} = \mathrm{P(L)} \cdot \mathrm{M(I, O)} \quad (6)$$

The function M (I, O), which represents the magnitude, could be represented by the equation (4) previously reported.
The equation that defines the odour nuisance index becomes:

$$\mathrm{ONI} = \mathrm{P(L)} \cdot \mathrm{ONI\ (O)} = \mathrm{P(L)} \cdot \mathrm{a(O)} \cdot (\mathrm{LogC_{98}})^2 \quad (7)$$

To define P (L) values, the reciprocal data of the odour concentration limits proposed by Rossi et al. 2015 can be used.
In doing that, the coefficient P (L) qualifies a place as the moderating factor; i.e. an area that is considered sensitive and to be preserved can be considered as a standard situation with a unitary coefficient. If an odour is perceived in a different place, then this can only have a minor effect on the receptor.

*Tab 2: Proposal for the P(L) values on the function of area sensibility*

| Sensibility Class | Odour concentration limits (Rossi, 2015) | P(L) |
|---|---|---|
| Areas with low population density but that need stillness (hospitals, schools, churches etc free of industrial activity) | 1 | 1 |
| Little villages without highway-rural area | 2 | 0.5 |
| Towns with some industrial activity | 3 | 0.333 |
| City | 4 | 0.25 |
| Mainly industrial areas | 5 | 0.2 |
| Exclusively industrial areas | 10 | 0.1 |

## 3. Conclusions

This study outlines a methodological approach which can promote the study and research of methods and models that characterize the odour nuisance.
In this work, a formulation of the equation that includes all FIDOL parameters for the definition of an odour nuisance index is proposed
In the formulation of this expression, in addition to traditional parameters as frequency, intensity (concentration), and dose, we hypothesized, as the initial estimate, some coefficients to be used within the equation considering the hedonic tone a(O) and the localization of the receptor P(L).
As a final result, a proposal is given of how to link these parameters in order to obtain an expression for the odour nuisance index: $\mathrm{ONI} = \mathrm{P(L)} \cdot \mathrm{a(O)} \cdot (\mathrm{LogC_{98}})^2$.

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