Environmental Engineering and Management Journal

October 2024, Vol. 23, No. 10, 2061-2070
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu
http://doi.org/10.30638/eemj.2024.166

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MONITORING, ACCEPTANCE LIMITS AND HEALTH CONSEQUENCE OF ODOUR NUISANCE: A SHORT LITTERATURE REVIEW ON THE STATUS OF THE ART

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Abstract

The increased sensibility of people occurred in the last years towards the environment and the quality of life have led to the classification of odours as harmful atmospheric pollutants. Exposure to odours, pleasant as unpleasant, can generate different effects in peoples ranging from emotional reactions annoyance up to indirect health consequences due to stress reactions, affecting to a not negligible extent the overall quality of life. The monitoring of odour nuisance is then one of the growing environmental issues affecting the human life in industrial, rural, and residential areas. The main methodological approaches for odour detection developed in the past decades includes odour impact criteria and field inspections. The former typically relies on the use of physic-mathematical models for odour dispersion, able to consider both meteorological and topographical features of the area, returning the odour concentration (ou_E/m^3) in the surrounding area. The latter involves the use of panels of assessors for detecting the effective exposure to odour and the extent of odour plumes. By the way significant differences exist in the worldwide regulations concerning the odour limit concentration, the percentiles of yearly hours, the averaging time and the peck-to-mean factor. Additionally, epidemiologic study concerning health consequences on people exposed to odour, resulted affected by several methodological biases. This makes the finding reported in the different studies not always fully reliable and meaningful.

Key words: exposure assessment, health effects, impact criteria, international regulations

Received: May, 2024; Revised final: September, 2024; Accepted: October, 2024; Published in final edited form: October, 2024

1. Introduction

According to Hangartner et al. (1989), odorants are defined as those substances able to stimulate the human olfactory system leading to the perception of an odour. Meanwhile, an odour can be defined as an organoleptic attribute of certain volatile substances once these are sniffed and hence perceived by olfactory organs (ISO, 2008).

The perceiving of odorous phenomena represents a matter of potential harassing for local population that requires adequate responses by local authorities. Inhalable volatile chemical species able to generate the olfactory perception are well known (*e.g.* sulfides, mercaptans, ammonia, ammines, ketones, alcohols) (UNI, 2022). Based on the current level of knowledge, it is not possible to establish absolute odorants concentrations thresholds able to prevent the risk of annoyance. The reason of this difficulty is addressable to many factors among which: the high level of subjectivity of each individual in being sensible to the specific odorants; the habituation of individual to given odours (Conti et al., 2020); the synergic effect that the mixture of the different volatile

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chemical species can have in emphasizing the odour perception; the specific urban, industrial and/or rural context (DEPA, 2002, 2009; MASE, 2023; Pringer et al, 2015).

While EU legislation has clearly identified the best available techniques (BAT) for at-source odour emission control in each industrial sector (EU, 2010), odour annoyance continues to be reported by local populations in several areas. The determination of the effective exposure of the local population to odorous phenomena and whether these phenomena can be effectively deemed acceptable or unacceptable represent a complex issue. In general, the approaches exploited for this purpose are based on two main concepts: the assessment of the concentration of the odorous compounds; the duration and the frequency of the odorous perception (EN, 2016a, 2022).

The determination of the first aspect is based on the application of atmospheric dispersion models (UNI, 2000) able to consider both the meteo-climatic and orographic characteristic of the area under study, once the amount of odorous emission has been determined according to the EN (2016 a, b). The determination of the second aspect, *i.e.* the frequency and duration of the odorous perception represents a quite complex task. Many approaches have been proposed mainly based on simulation models and on the exploitation of human assessors panel, experts, able (*i.e.* appositely trained) to recognize the presence of odours and their features (EN, 2022).

Based on what discussed above, the present paper provides an overview of the main methodologies and acceptance limits related to odour detection and control currently employed worldwide. Additionally, due to its significance, an investigation into the health consequences associated with odour nuisance has been also conducted, and the detected finding discussed.

2. Odour impact criteria

Based on the current impact assessment techniques, the dispersion of odour at different distances from a specific source is determined through dispersion models, which can predict calculate the odour concentration at designated receptors by considering the effects of topographic and meteorological conditions. This result can be obtained once the odour emission rate (*i.e.* odour concentration multiplied by the whole flow rate) per each given source in the area under investigation was determined. Once calculated, the concentrations are compared against the odour impact criteria (OIC) which are represented by the legal limits and parameters imposed by local authorities. In general, OIC consists of the following main elements (Tables 1-2):

1) threshold of odour concentration;
2) level of percentile compliance;
3) averaging time adopted for the calculation of the concentrations returned by the atmospheric dispersion models;
4) peak phenomenon.

Level of percentile indicates, in general, the number of hours on yearly basis during which the average odour concentration has to be lower than the threshold limit. In other words, for the number of hours exceeding the percentile level, an odour concentration higher than the odour concentration limit is considered acceptable. In general, percentile level adopted is ≥ 98%.

Time periods considered for averaging the concentration include usually the single hour of the year, *i.e.* 8760 h/year, but also lower periods like second and/or minute are exploited.

Finally, another important aspect associated with the odour concentration is the peak phenomenon that can occur in periods < 1 h causing the momentary sensation of odour. For considering this phenomenon, a multiplicative factor named peak-to-mean ratio is generally used for correcting the hourly average odour concentration (Conti et al., 2020).

2.1. Odour concentration

Odour concentration, together with its detectability, is a widely exploited approach in regulations for indicating the acceptance limits for local populations also based on the destination of the area and on the distance of the receptors from the emission source. Due to the large variability in the sensibility of individuals against olfactometric stimulations, the concept of detectability is associated to a given percentage of individuals able to perceive the presence of odour.

The determination of odour concentration at the emission source is performed in specific laboratories by the dynamic olfactometry procedure exploiting as sensor human noses of appositely trained panel of assessor. This because there are no other instruments or analytic procedure able to return satisfactory information about the olfactometric responses of humans. The procedure for the dynamic olfactometry has been standardized in different countries by apposite technical notes: for the EU UNI EN 17325:2022 (UNI, 2022); for Australia and New Zeland AS/NZS 5323.3:2001 (AS/NZS, 2001); for US ASTM E679-04 (ASTM, 2011).

In the EU 1 odour unit (ou_E) is defined as the specific concentration of a reference odorant, n-butanol. The concentration of n-butanol corresponding to 1 ou_E/m^3 is 0.04 mol/mol of n-butanol in neutral gas. This definition is then used to trace the odour unit of any odorant or mixture of odorants in ambient air. Briefly, the analytic procedure of the dynamic olfactometry consists of determining the odour perception threshold (OPT) by submitting to the assessor's panel diluted mixture of a given volume of the sample of odour air. The dilution is performed by given volumes of pure (*i.e.* deodorized) air, expressed in m^3, and at the sample is conventionally assigned the values of 1 ou_E. This mixture is submitted to the assessor's panel at decreasing dilution ratios.

The OPT is then defined as the dilution ratio (ou_E/m^3) that is perceived by 50% of the exposed populations and, for the dynamic olfactometry procedure, by 50% of the assessors (UNI, 2022). For a given sample of odorant or mixture of odorants, the higher is the ou_E/m^3 the stronger is its olfactive impact. The standardized procedure also indicates procedure for the odour air sampling as the other conditions and criteria to be respected during the dynamic olfactometry test. Additionally, as largely describe in the study of Hayes et al. (2023), the composition of the odours mixtures can also be determined by the exploitation of gas chromatography coupled with mass spectrometry or similar techniques. However, in practice, this is primarily useful for assessing the potential presence of harmful compounds even if this approach results of particular interest also for a deeper investigation of odour nuisance. In fact, as also reported in the study of Barczak et al. (2017), humans have a very different response and perception when exposed to the same volatile substances. The so-called hedonic tone of the odour can be perceived as pleasant by someone and unpleasant by others or the odour cannot be perceived at all. Furthermore, the different substances can have also very different effects on individuals depending on the concentration and on mixtures compositions. In other words, the hedonic tone can be classified as pleasant even if the substances generating this perception can be harmful and *vice versa*.

2.2. Atmospheric dispersion modelling

The presence of several technical and analytical obstacles for direct experimental determination of the odour concentration in the ambient air, requires the exploitation of dispersion modelling able to return the values of the ou_E/m^3 in the selected receptors once the odour emission at the source have been defined.

Qualitatively, dispersion modelling of airborne particles and/or aerosols aims to describe and predict the fate of chemicals in the atmosphere from a given source to given points (receptors). These last can also be represented by lines characterized by the same concentration of chemicals, isolines. From the quantitative point of view these models can return the concentration of chemicals and, in the specific case, of odours (ou_E/m^3), once the meteorological parameters, sources feature, and topography of the analysed area were defined.

Simulation of atmospheric dispersion of pollutants can be performed by the following main approaches:

- Lagrangian approach, in which the variation of concentration is related to the fluid in movement;
- Eulerian approach, in which the concentration is related to a fixed system of coordinates;
- Gaussian approach, in which the distribution of pollutants and hence their concentration is determined by using a normal probabilistic distribution of fluctuation of wind vectors;
- Semi-empirical approach, mainly based on empirical parametrization;
- Stochastic approach, in which semi-empirical and statistic models are used to analyse periodicities, trends and interrelationships of air quality measurements and to forecast episodes of air pollution;
- Receptor approach, in which starting from the concentration observed at the receptor the contribution of different emission sources is estimated.

More recently, also computational fluid dynamics (CFD) was proposed (Yeo et al., 2020) as an approach for analysing the odour dispersion from pig house with complex terrain.

In general, the most widely used models for the determination of odours are represented by the AERMOD and CALPUFF for the Gaussian approach and AUSTAL2000 for the Lagrangian approach (Capelli et al., 2013). In any case, in Table 1 are reported the most diffused software available on the market with brief indications about the features, advantages and disadvantages.

2.3. Peak-to-mean factor

As already described in the previous paragraphs, calculation models are largely indicated by regulations as the most suitable method for the determination of the dispersion of odour emitted in the surrounding area of a given source.

Table 1. Software, approaches used and mean features

Software	***Approach***	***Features***	***References***
AERMOD (U.S.)	Gaussian	Enable to point, volume and areal sources	Baawain et al. (2017); Schulte et al. (2007),
LODM (Canda)	Gaussian	Oriented for livestock facilities	Yu et al. (2013a), Yu et al. (2013b)
STINK (Australia)	Gaussian	Specific for ground level areal sources	Galvin et al. (2004); , Smith (1995)
OdiGauss (Italy)	Gaussian	Enabled for odour from multiple sources	Danuso et al. (2015)
INPUFF-2 (U.S.)	Gaussian	Emission from semi-instantaneous and continuous points sources	Asadollahfardi et al. (2015); Zhu et al. (2000),
CALPUFF (U.S.)	Lagrangian	Multi-layer, multi-species, non-steady-state, evaluating the effect of time- and space-varying meteo conditions	de Melo et al. (2012);, Ranzato et al. (2012)
CALGRID (U.S.)	Eulerian	Photochemical, transport and dispersion model, three dimension temperature and air velocity	Scire et al. (2000);, Yamartino et al. (1992)

By the way, the hourly average odour concentrations in the air (ou_E/m^3) returned by these models resulted not adequate to account for the fluctuations of the odour concentration that is usually characterize by a sequence of peaks and null ou_E/m^3 values (Conti et al., 2020). The shorter is the averaging period considered, the higher are the concentration (ou_E/m^3) fluctuations. Considering that a typical human inhalation occurs every 1.6 seconds, the exploitation of the hourly average can result in inadequate method for assessing the presence of olfactometric nuisance. In other words, olfactometric nuisance could be masked by the hourly average.

To account for this phenomenon, the peak-to-mean approach has been proposed, aiming to calculate the short-term odours concentration starting from the hourly average (Drew et al., 2007). According to Smith (1968), Schauberger et al. (2012) and Piringer et al. (2015), the calculation of short-term concentration can be calculated starting from the long-term ones by using the correlation reported in Eq. (1).

$$C_p = C_m * (t_m/t_p)^n \qquad (1)$$

In Eq. (1) Cp and Cm represents the short-term and the long-term concentrations, respectively, t_p and t_m the shorter and the longer averaging time, respectively, to whom the previous concentrations are referred whereas n is an empirical dimensionless exponent ranging from 0.2 to 0.5.

Starting from Eq. (1) a peak to mean factor F has hence been introduced, Eq. (2), also at regulatory level, for accounting C_p based on the C_m generally calculated on hourly average. The longer is t_m the higher is F.

$$F=C_p/ C_m \qquad (2)$$

2.4. A glance to main world regulatory frameworks

Table 2 summarizes the values reported by the main regulations in some countries around the world for the parameters associated with the odour impact criteria described in the previous paragraphs. These data have been retrieved both from the specific regulations of each country and area and from the work of Bokowa et al. (2021) and Conti et al. (2020). As it is possible to note there are some relevant differences among the countries but also among the different jurisdictions of the same country. For example, Australia showed a wide range of both odour concentrations limit but also of percentile and average time values, ranging from 1s up to 1h, based on the jurisdiction (*e.g.* Queensland, Tasmania, Victoria) and on other factors as the destination of the urban/industrial/rural areas considered. Similar considerations are also valid for other countries as Canada, Belgium and Netherlands.

3. Field inspection

Before the implementation of more relevant activities for preventing and decreasing the odours annoyance reported by the local population, the adoption of preliminary activities aimed to understand the importance and the extension of the problem is usually recommended. According to the current legislation (Table 2), the initial approach to be adopted in case of odours annoyance reported by the local populations, is represented by field inspections. In fact, the only presence of odour is not enough for being classified as a nuisance, but it is also necessary to establish its frequency.

For this reason, the objective of field visits is not to determine if the acceptance threshold has been exceeded but primarily to assess whether the frequency at which local populations are exposed to an odour result in a nuisance.

The methodologies adopted for this purpose are the grid and the plume methods (EN, 2016a, b). Both methods used a panelist of variable number of assessors depending on the number of measures to be performed. The grid one is more oriented to characterize odour exposure in a given assessment area whereas the plume one is more oriented to assess the extension of the odour impact (*i.e.* where the odour is perceived and where not) under specific emission and meteorological conditions (e.g. wind direction, rain, humidity, temperature, pressure). In the grid method the area under investigation is divided in a grid of a given number of squares with minimum side of 250m. The vertex of each square represents the point in which the panel of expert assessors makes the measurement. One measurement consists of 10 measurements performed over 10 minutes. Every 60 seconds the members of the panel are requested to sniff for 10s and note on a specific form, according to a preordered scale of values, the intensity and the quality of the odour perceived. For considering the different meteorological conditions and the odour fluctuation, the whole duration of the field inspection is generally established in 1 year. Grid methodology can be applied also in presence of several odours emission sources.

In the plume method two different approaches can be adopted: static and dynamic. For the static approach, the panel of experts moves upwind the source along parallel lines that are perpendicular to the plume extent. The goal is to determine the presence and the absence of odour along these lines. For the dynamic approach the panel of expert moves according to a zig-zag pathway with the same aim of determining the extension of the plume.

The plume method is applicable only when there is a given source of emission. In both methods the panel of expert have to be appositely trained according to what reported in the UNI (2022).

Table 2. Averaging time, limits for odour concentration (ou_E/m^3), associated percentile level (%) and peak to mean factor (F) for some countries

Country	***Aver. Time***	***ouE/m³/ Percentile (%)***	***F***	***References***
Austria	5s	1/92 and 5/97	Variable	OAW (1994)
Australia	-	5/98 (Queensland)	10 (stack)	EHP (2013), DAFF (2012); DEC (2006), DEP (2002), SAEPA (2007), EPA Victoria (2001), EPA Tasmania (2004)
		5/99.5 (Queensland)	5 (ground)	
	3s	-(logD-4.5)*0.6^{-1}/99 (New South Wales)	1.9-2.5	
	3min	2/99.5 (West) 4/99.9 (West) 4/99.9 (Victoria)	-	
	-	2.5/99.5 ((Queensland)	2	
	3min	-(logD-4.5)*0.6^{-1}/99.9 (South)	-	
Belgium	1h	6/98 (pigs) 10/98 (poultry)	1	Government Walloon (2009) LNE (2008) VITO (2012)
Canada (Ontario)	10min.	0/95	1	MDDEP (2011, 2012)
Denmark	1min.-1h	5-10/99 (residential) 10-30/99 (industrial, rural)	7.8	DEPA (2002,2 009)
France	1h	5/98 (Composting plant) 5/99.5 (at 3km new animal by-product processing plant) 5/98 (at 3km existing animal by-product processing plant) <5 (at 500m for populated areas for other activities)	1	JORF (2003, 2008)
Germany	1s	0.02-0.1-0.15	-	GOAA (2008) , TA-Luft (2002)
	1h	0.5 (pleasant odours) 1.5 (poultry) 0.75 (fattening ptig) 0.5 (milking cow, fattening bulls, horses)	-	
Hong Kong	5s	5	N.A.	EPD (2016)
Italy	1h	1/98 (residential, hospital) 2/98 (market, offices, turistic) 3/98 (rural, leisure, sport) 4/98 (industrial, farm) 5/98 (country, unpopulated)	2.3	ARPAP (2014); MASE (2023); Provincia di Trento (2016); Regione Lombardia (2012)
Israel	5s-10min	1.5-10	N.A.	IMEP (2013)
Netherlands	1h	5/98 (existing situations) 1.5/98 (new situations) 0.5/98 (new sources)	1	InfoMil (2014, 2016); VROM (2006, 2007)
Spain	1h	3-7/98	1	DMAV (2005)
UK	1h	1.5 (most offensive odours) 3 (moderately offensive odours) 6 (Less offensive odours)	1	Bokowa et al. (2021); EA (2011)
New Zeland	1h	1/99.5 (high sens./unstable) 2/99.5 (semi unstable) 3/99.5 (high sens./stable)	1	NZMOE (2003)

Another preliminary approach available consists in the direct engagement of the same individuals, populations, reporting on the presence of odor. These are requested to note on a specific preset form record each odour nuisance episodes perceived, its intensity together with a description of the type of odour. This represents a less expensive approach, useful for the determination of the annoyance, but lacking scientific stability of the data due to psychological effect of citizens.

4. Odour pollution and human health

The toxic effect that specific odorant compounds, as H_2S, NH_3, COS can have if inhaled above the chronic reference dose (RdF) (mg/m^3) (Barczak et al., 2022) is a well know aspect. Les clear appears what effects can indirectly generate on human health the short and the long-term exposure of odours due to stress reactions. In fact, odour nuisance can also be generated by synergic effect of mixtures of different compounds even if the single concentration of each compound is largely below the odour perceiving and toxic thresholds. According to Guadalupe-Fernandez et al. (2021), this is due to a lack of standardized methods usable for environmental epidemiology studies able to include also specific psychological aspects and life quality of each single individual.

Several sources of bias have influenced the overall quality and reliability of the studies reported in the literature. Key biases include the identification of exposed and non-exposed populations, confounding factors such as lifestyle and exposure to other sources, the completeness of outcome data, and the application of appropriate statistical methods. Many of these studies are based on self-compiled questionnaires on which the engaged subjects report both the perceiving of odour annoyance and their symptoms.

Based on the discussion above, the already mentioned study of Guadalupe-Fernandez et al. (2021) identified five high-quality epidemiological studies, four of which consider the exposure of populations to odour emissions from animal feeding and one from a waste landfill. Table 3 summarizes the main health outcomes self-reported by the subjects exposed/engaged along with the main biases detected for each study.

The lack of other objective or clinical methods other than questionaries' (Wroniszewska and Zwozdziak, 2020) reported by Guadalupe-Fernandez et al. (2021) as a limiting factor for the assessment of odour annoyance, appears suitable of improvement by its integration with new promising methods combining questionary with electronic nose and specific trained staff for on-site surveys (Valli and Immovilli, 2008).

5. Discussions

The information reported above highlight large differences at world level concerning the criteria exploited for setting the dispersion model (*e.g.* OPT, F, percentile, averaging time) (Bokowa et al, 2021). Such differences were justified by several factors as the destination of the area, e.g. residential, industrial, rural, and of the activities performed, e.g. livestock, chemical industries, waste management, water management, and other similar activities.

Other differences can also be found on the minimum distances from the odour sources. In general, in Asia and China the odour issue resulted more focused on specific sectors like the waste management one whereas other country showed a particular attention to livestoks (Conti et al., 2020). Another difference noted was related to the models and approaches exploited for odour dispersion and concentration. For this aspect, a combination of different techniques including questionary, dispersion models and chemical analysis appears the one indicate as the most suitable by several authors (Baczak et al., 2017; Bokowa et al., 2021; Conti et al., 2020). A particular critical situation was detected for the EU area. In fact, EU aims to homogenize the legislation of the different member states (MS) in many sectors by the adoption of EU directives. The environmental sector is one of the most relevant in which the EU is more active since the late 50' and in which there is continuous implementation of new and advanced legislation. In the case of odour, several aspects require further understanding and regulation to prevent significant disparities among Member States.

Similar considerations can also be done for the field inspection approaches. In fact, despite the presence of specific technical notes able to standardize and to homogenize the methodologies and procedures to be adopted for the inspections, there is a lack of indications on threshold values (EN, 2016a). Such lack represents a matter of possible biases causes some bias for in assessing whether or not a population resulted exposed.

Table 3. Emission source, methodology used for the exposure assessment, health outcome assessment and main biases for the five epidemiologic studies classifies of higher quality by Guadalupe-Fernandez et al. (2021)

Author	***Emission source***	***Exposure assessment***	***Outcome assessment***	***Main bias***
Avery et al. (2004)	Animal feeding	Self-reported questionnaire	Clinical measurements: Immune functions and allergy	Exposure assessment Confounding factor (other exposure)
Heaney et al. (2011)	Waste landfill	Self-reported questionnaire	Self-reported questionnaire: Gastrointestinal Mucus irritation Respiratory Skin	Exposure assessment Outcome assessment
Horton et al. (2009)	Animal feeding	Self-reported questionnaire	Self-reported questionnaire: Mood states Odour nuissance	Exposure assessment Outcome assessment
Schinasi et al. (2011)	Animal feeding	Self-reported questionnaire	Sel-reported questionnaire: Gastrointestinal Mucus Respiratory Skin	Exposure assessment Outcome assessment
Wing et al. (2013)	Animal feeding	Self-reported questionnaire	Cardiovascular	Exposure assessment Confounding factor (other exposures)

Furthermore, this can also represent a matter of weakness of the odour exposure assessments that can generate criticism by the different actors involved in such investigations.

Finally, more research appears necessary for a definitive assessment of the impact of odour on human health. In fact, excluding the toxic effect of some well-known chemical compounds already regulated by specific legislations, the epidemiologic studies performed on the health consequences of individuals exposed to odour, in general, are characterized by the presence of several biases as: not proper consideration of confounding factors; absence of analytical results (large use of self-questionnaire); lack of adequate description of the source of the emissions; absence of adequate procedure able to give a clear and more deterministic indication about the effective exposure of population to odour.

6. Conclusions

The review performed in the present study highlighted that more research activity resulted necessary for a definitive solution of the different aspects involved in odour nuissance. Despite the quite extensive availability and reliability of physico-mathematical models and procedures, the assessment of the effective level of exposition and of the acceptable limits of odour concentration still remains a matter of discussion.

Many social, cultural and individual factors influence these aspects justifying the large differences of the values of the main odour impact criteria adopted worldwide. A decisive contribution to the definition of appropriate values for the above-mentioned criteria can be represented by scientific results concerning epidemiologic studies on population exposed to such nuisance.

Based on the state of the art, these studies are often influenced by numerous biases and methodological flaws, rendering the associated findings less reliable and challenging to utilize for this purpose.Among these drawbacks, the lack of clinical methodologies, other than questionnaires, able to definitively asses the exposure of the population to odor, represents one of the main limitations even if new integrated approaches seems able to give adequate response to this aspect.

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