Odours have become a priority concern for facility operators, engineers and urban planners who deal with waste and industrial treatment plants. The subjectivity of smell perception, its variability due to frequency and weather conditions, and the complex nature of the substances involved, has long hampered the regulation of odour emissions. This book provides a comprehensive framework for the assessment, measurement and monitoring of odour emissions, and covers:

- Odour characterization and exposure effects
- Instruments and methods for sampling and measurement
- Strategies for odour control
- Dispersion modelling for odour exposure assessment
- Odour regulations and policies
- Procedures for odour impact assessment
- Case studies: Wastewater treatment, composting, industrial and CAFO plants, and landfill

Intended for researchers in environmental chemistry, environmental engineering, and civil engineering, this book is also an invaluable guide for industry professionals working in wastewater treatment, environmental and air analysis, and waste management.
Odour Impact Assessment Handbook
Odour Impact
Assessment Handbook

Editors

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Preface

Odour emissions are considered to be the main cause of disturbance noticed by the citizens living near some facilities. Even though a real toxicological-sanitary risk is hardly ever associated to the odour impact from sources connected to the activities of waste management and similes, due to the rarely dangerous nature of the smells as well as the generally very low concentrations, the collective imagination often associates the bad smell to conditions of ‘non healthy’ air. In fact, a valence higher than the one related to more dangerous contaminants, but not directly perceptible from our senses, is often attributed to them.

Odour emissions affect quality of life leading to psychological stress and symptoms such as insomnia, loss of appetite and irrational behaviour. Odours have become a priority concern for facility operators, engineers and urban planners that deal with waste and industrial treatment plants. Odour complaints can shut down facilities and prevent the expansion of existing facilities. The particular and complex nature of the many substances being dealt with in these facilities results in a ‘smell impact’. The extent of this impact depends on a variety of factors, most notably these factors are time, weather conditions and the subjectivity of each individuals’ perception of a specific smell. When combined, these factors have delayed progress in odour regulation.

The difficulties in resolving these controversies are also the result of an absence of universally recognized standards for objectively determining the negative effect induced. Only a few countries, in fact, have odour quality criteria or odour emission thresholds for industrial sources. On the European scale, standard EN 13725:2003 makes reference to the sampling and quantification of odours using dynamic olfactometry from sources. USA, Australia, Canada and Japan are following similar approaches.

Offensive odours are not only a direct threat for human health and welfare, but also represent a significant contribution to photochemical smog formation and particulate secondary contaminant emission. In this context, a cost-effective and environmentally friendly abatement of odours is crucial in a world increasingly concerned about sustainability and environmental preservation, but also increased life quality standards. Physical/chemical technologies have been widely used due to their low footprint, extensive experience in design and operation and rapid start-up, however, they exhibit significant environmental impacts and high operating costs. On the other hand, biotechnologies have been marketed as low-cost, environmentally friendly odour abatement methods.

The aim of this book is to provide a theoretical and practical basis for responding to the problem of sampling and measuring odours using olfactometric, analytical and mixed techniques to assess the impacts. This is in order to provide a realistic response to the demand for information from the population and from the technical-scientific world, while at the same time providing an objective instrument for the authorities managing and monitoring
environment and the professional figures who are becoming more and more involved in this type of problem.

This handbook contains the work of 28 contributors from 13 different countries. The experience behind the authors stems from years of technical activity and scientific research in assessing odour environmental impact. The applicative approach that this handbook adopts in Part 8 is coherent with the numerous applications in the methods and processes field, in which the progress made in international scientific research has been integrated with the applicative limits and the need to supply results.

V. Belgiorno, V. Naddeo and T. Zarra
Fisciano, Italy (August 2012)
Glossary and Abbreviations

**Acute odour effect:** the effect due to short-term exposure to odours sufficiently intense to cause adverse effects.

**Adaptation:** the phenomena of reduced sensitivity to a stimulus after prolonged exposure. Unlike habituation this refers to a reduced physiological as opposed to psychological response to a stimuli.

**Annoyance:** (1) when used in relation to an odour’s character or pleasantness, annoyance is akin to the hedonic rating of an odour’s pleasantness. (2) When used in conjunction with population annoyance surveys, it is a function of the attitude and feelings of the community towards a source (or sources) of ongoing odour impacts.

**Area Source:** a surface-emitting source, which can be solid for example, the spreading of wastes, material stockpiles, surface of a biofilter, or liquid for example, storage lagoons, effluent treatment plant.

**Assessor:** somebody who participates in odour testing.

**Delayed olfactometry:** measurement of an odour with a time-lag between sampling and measurement. The odour sample is preserved in an appropriate container.

**Detection Threshold:** the point at which an increasing concentration of an odour sample becomes strong enough to produce a first sensation of odour in 50% of the people to whom the sample is presented. The measurement of odour concentration is based on determining the detection threshold. This is a laboratory-based test and should be conducted according to the EN13725 European standard. The odour concentration at the detection threshold is one odour unit (per cubic metre).

**Diffuse Sources:** sources with defined dimensions (mostly surface sources) which do not have a defined waste air flow, such as waste dumps, lagoons, fields after manure spreading, un-aerated compost piles.

**Dilution factor:** the dilution factor is the ratio between flow or volume after dilution and the flow or volume of the odorous gas.

**Direct olfactometry:** measurement of odour concentrations without any time-lag between the sampling (operation) and the measurements; equivalent to dynamic sampling or on-line olfactometry.

**Dynamic dilution olfactometry (DDO):** the general procedure used to establish the relative odour concentration of a gas sample. The method establishes the extent of clean air dilution required to reduce the odour strength to a level that is at the threshold of detection for a calibrated panel. The sampling of the raw gas, dilution and presentation to the panel is undertaken in a continuous manner. The backcalculated concentration of the undiluted gas sample (OU_{E}/m^{3}) represents the number of dilutions with odour-free air required to reduce the odour of the gas down to the detection threshold.
**Dynamic olfactometer:** a dynamic olfactometer delivers a flow of mixtures of odorous and neutral gas with known dilution factors in a common outlet.

**Electronic nose (E-Nose):** an electronic device that uses an array of solid-state sensors, or synthesized protein sensors, that respond to the presence of different chemical compounds. The resulting electronic signals are processed using neural network computing techniques to help produce a two-dimensional spectral pattern that is specific to a particular mix of chemical compounds. The aim is to create different spectral patterns that can identify/fingerprint specific types of odour character.

**European Odour Unit OU\(_E\)/m\(^3\):** that amount of odorant(s) that, when evaporated into one cubic metre of neutral gas at standard conditions, elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one European Reference Odour Mass (EROM), evaporated in 1 m\(^3\) of neutral gas at standard conditions. One EROM is equivalent to 123 \(\mu\)g n-butanol.

**Exposure:** the dose received by a receptor, determined by the strength (concentration or intensity), time (duration and frequency) of a particular character odour.

**Fugitive Releases:** unintentional emissions from, for example; flanges, valves, doors, windows; that is, points which are not designated or intended as release points.

**Fugitive source:** any type of odour emission that cannot be readily quantified or defined. This usually refers to such sources as leaks in pipes, flanges, pump seals or structures, openings in buildings, floor spills, occasional sources such as uncovered truck loads or releases from pressure relief valves, and leaks in seals on covered tanks.

**Gas Chromatography:** this analytical technique is a form of chromatography that separates and detects compounds by the rate in which they move through an inert or un-reactive carrier gas such as nitrogen, helium or carbon dioxide. The time taken (residence time) to move through the glass or metal tube called a column is used to determine the type of compound present within the sample.

**Habituation:** a psychological term used to describe the process of decreasing behavioural response after repeated exposure to a stimulus such as odour over a prolonged period of time. This phenomena is particularly noticeable in commercial and industrial settings where occupational exposures to strong odours are no longer found offensive or even noticed by operational staff, for example, rendering plants, livestock, sewage and food processing.

**Hedonic Tone:** a judgement of the relative pleasantness or unpleasantness of an odour made by assessors in an odour panel. A methodology is described in VDI 3882, part 2. Odours which are more unpleasant will have a negative hedonic score whilst odours that are less unpleasant will tend towards a positive score.

**Hyposmia:** partial inability to detect odours (compare with anosmia).

**Intensity:** an assessment of odour strength based on an initial perception. This perception strength will rapidly diminish with constant exposure. The relationship between odour intensity and odour concentration depends on the specific intensity of the chemical or mixture being detected. Assessments can be made using the German method VDI 3882.

**Isopleth:** a line on a map connecting places registering the same amount or ratio of some geographical or meteorological phenomenon or phenomena. Commonly used to illustrate the output of odour models.

**Mass Spectrometry:** this is an analytical technique used to identify the chemical composition of a compound. The technique determines particles of the same type from the
principle that particles with the same mass and charge will move in the same path in a vacuum when subjected to the same electric and magnetic fields. This principle of determining electronic mass and ionic charge allows the chemical composition of a sample to be determined from a database of existing compounds or unknown compounds to be detected. Three basic components make up a mass spectrometer; an ion source, a mass analyser and a detector.

**Neutral gas:** air or nitrogen treated in such a way that it is odourless, and which, according to panel members, does not interfere with the odour under investigation.

**Odorant:** a substance which stimulates a human olfactory system so that an odour is perceived.

**Odour (or Odor):** organoleptic attribute perceptible by the olfactory organ on sniffing certain volatile substances [ISO 5492].

**Odour abatement efficiency:** the reduction of the odour concentration or the odour flow rate due to an abatement technique, expressed as a fraction (or percentage) of the odour concentration in or the odour flow rate of the untreated gas stream.

**Odour annoyance survey (Community survey):** standard survey method used to quantify the extent of population annoyance in different sectors of a community as a result of industrial odour impacts.

**Odour concentration:** the number of odour units in one cubic metre of gas at standard conditions. Note: odour concentration has a non-linear relationship with odour intensity.

**Odour detection:** to become aware of the sensation (smell) resulting from stimulation of the olfactometry system.

**Odour diary:** the systematic recording by individuals of odour events over a period of time at a defined location (normally a residential dwelling), including the date, time, duration, character, strength and weather conditions associated with each odour event.

**Odour dose-response:** the relationship derived between population annoyance and predicted odour impact concentrations, where the former is quantified via an odour annoyance survey and the latter is determined using odour emission measurement and modelling techniques.

**Odour emission:** the number of odour units per second discharged from a specific source.

**Odour flow rate:** the odour flow rate is the quantity of European odour units which crosses a given surface divided by time. It is the product of the odour concentration cod, the outlet velocity v and the outlet area A or the product of the odour concentration cod and the pertinent volume flow rate V. Its unit is OU_E/h (or OU_E/min or OU_E/s, respectively).

**Odour intensity:** the perceived strength of an odour as rated by individuals against a numerical scale, such as that contained in the German Standard VDI 3882 Odour Intensity Scale.

**Odour unit (OU):** one odour unit is the amount of (a mixture of) odorants present in 1 m³ of odorous gas (under standard conditions) at the panel threshold. NOTE See also European odour unit.

**Offensiveness:** see hedonic tone.

**Olfactometer:** apparatus in which a sample of odorous gas is diluted with neutral gas in a defined ratio and presented to assessors.

**Olfactometry:** measurement of the response of assessors to olfactory stimuli [ISO 5492].

**Olfactory:** pertaining to the sense of smell [ISO 5492].

**OMP:** Odour Management Plan.
Panel member: an assessor who is qualified to judge samples of odorous gas, using dynamic olfactometry within the scope of this standard.

Panel: a group of panel members.

Perception: awareness of the effects of single or multiple sensory stimuli [ISO 5492].

Point source: a discrete stationary source of emission of waste gases to atmosphere through canalized ducts of defined dimension and air flow rate (e.g. chimneys, vents).

Population annoyance: a measure of the percentage of people in a community who consider themselves to be ‘annoyed’ or even more adversely affected by the impacts of industrial odours in their community (percentage at-least annoyed).

Quality: the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs [ISO 6879].

Recognition threshold (RT): the odour concentration which has a probability of 0.5 of being recognized under the conditions of the test.

Reference odour mass (ROM): the ROM is equivalent to 123 mg of n-butanol evaporated in 1 m³ of neutral gas.

Round: one round is the presentation of one dilution series to all assessors.

Sample: in the context of this standard, the sample is the odorous gas sample. It is an amount of gas which is assumed to be representative of the gas mass or gas flow under investigation, and which is examined for odour concentration [ISO 6879].

Specific or surface odour emission rate (SOER): the SOER per unit area of surface, which has units of odour per unit area per time (e.g. OU/m²s or OU/m²h).

Static dilution: dilution achieved by mixing two known volumes of gas, odorous sample and neutral gas, respectively. The rate of dilution is calculated from the volumes.

Static flux hood: an odour-sampling hood that is placed over an area source and which has a low flow-rate of neutral gas injected to allow a mixed air stream to be expelled from the hood. These devices work on the same principle as wind-tunnel sampling hoods, except that air within the static hood exhibits minimal turbulence.

Static olfactometer: a static olfactometer dilutes by mixing two known volumes of gas, odorous sample and neutral gas, respectively. The rate of dilution is calculated from the volumes.

Volume source: a source of odour emission such as a building structure from which odour diffuses from many different points.

Wind tunnel: odour-sampling wind tunnels are generally elongated hoods that are placed on to an areal odour source and have a flow-rate of neutral gas passed through in a plug-flow manner (i.e. the gas enters one end of the hood and sweeps through to the outlet end, where it is expelled for sampling). These devices generate substantially more turbulence within the hood due to the greater airflows per unit area involved.
Errata Corrige

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(ii) Page xi line 5
“Laura Cappelli” should be read “Laura Capelli”

(iii) Page 50 line 13
“3.6 Estimation of Emission Rate” should be read “3.6 Estimation of Emission Rate∗” where the (*) links to a footnote with the following text “The contents under Sections from 3.6.1 to 3.6.3 are reproduced by permission of Laura Capelli, Selena Sironi and Renato Del Rosso. This material was amended, integrated, updated, completed and published by Capelli et al. as new original work in the paper entitled “Odor Sampling: Techniques and Strategies for the Estimation of Odor Emission Rates from Different Source Types”, 2013, Sensors (ISSN 1424-8220), Issue n. 13 – pages 938–955. Additional information on this issue are reported in the Acknowledgments.”
1.1 Origin and Definition

Odour is the property of a substance, or better; a mixture of substances that depending on their concentration, are capable of stimulating the olfaction sense sufficiently to trigger a sensation of odour (Brennan, 1993; Devos et al., 1990; Bertoni et al., 1993). Even better, odour is a sensory response to the inhalation of air containing chemicals substances. When the sensory receptors in the nose come into contact with odorous chemicals, they send a signal to the brain, which interprets the signal as an odour. The olfactory nerve cells in humans are highly sensitive instruments, capable of detecting extremely low concentrations of a wide range of odorous chemicals. The type and amount (or intensity) of odour are both important in processing the signal sent to the brain. Most odours are a complex mixture of many odorous compounds.

Fresh or clean air is usually perceived as not containing any contaminants that could cause harm and it smells clean. Clean air may contain some chemical substances with an associated odour, but these odours will usually be perceived as pleasant, such as the smell of grass or flowers. However, not everyone likes the smell of wet grass or hay. Due to our sense of odour and our emotional response to it being synthesized by our brain, different life experiences and natural variation in the population can result in people having different sensations and emotional responses to the same odorous compounds (See Section 2.5).

Odour is a parameter that cannot be physically measured, unlike wavelength for sight or pressure oscillation frequency for hearing, nor can it be chemically determined as it is not an intrinsic characteristic of the molecule. It represents, in fact, the sensation that the substance
provokes after it has been interpreted by the human olfactive system. The impossibility of physically and chemically measuring odour, the complexity of the odorants, the vast range of potentially odorous substances, the physical and psychic subjectivity of odour perception and environmental factors, together with the complexity of the olfactory system, represent a series of obstacles that render the characterization of odours and the control of olfactory pollution particularly complex (Zarra et al., 2007a; Dalton, 2002).

Public opinion plays a decisive role in evaluating the extent of annoyance caused by bad odours, often leading to associating unpleasant or malodorous emissions with any industrial or sanitary installation (Bertoni et al., 1993; Stuetz et al., 2001). In fact, even though nuisance odours are not generally associable to harmful effects on human health, they do represent a cause of undoubted and persistent annoyance for the resident population, thus becoming an element of contention both in the case of existing plants as well as in the selection of new sites (Shusterman et al., 1991; Zarra, 2007b). In this light, the impacts caused by the aesthetics of the plants and their inclusion in the landscape, the noise produced, the traffic generated and, above all, the emissions of unpleasant odours are becoming increasingly important (Zarra et al., 2008b).

Over the last few years, there has been more and more technical and scientific interest in these matters thanks to the greater attention being paid to protecting the environment and human health and, above all, due to the growing number of plants located in urbanized zones (Zarra, 2007b). As a result, for some time now, attention has been drawn to the need to monitor air quality in relation to environmental odour levels. However, the particular and complex nature of the substances responsible for odour impact, their variability both over time and with respect to meteoclimatic conditions and the subjective nature of olfactory perception are factors delaying any such regulation (Park and Shin, 2001; Zarra, 2007b).

As described in the following chapters, the components that can be evaluated in order to identify an olfactive type annoyance are concentration, intensity, hedonic tone (i.e. the pleasant or unpleasant sensation obtained from an odour) and quality (association of an odour with a known natural compound). As detailed later, of these components, only the first can be determined in an objective manner, while the others are highly subjective (see Part 3).

1.2 Quantifying Odour

Dynamic olfactometry, electronic noses (e-nose) and specific chemicals can be used (with varying success) to indicate the relative amount of odorous chemicals present in the air. This and other techniques for odour sampling and measurement are described in detail in Part 3.8.

Briefly, we could distinguish between sensorial, analytical and mixed methods. Sensory analysis, carried out prevalently using dynamic olfactometry, provides precise data on odour concentration, but it does not allow to evaluate the magnitude of the disturbance to which a population is exposed, nor can it determine the effective contribution of different sources to the level of environmental odour (Jiang, 1996; Sneath, 2001). The principal causes of the uncertainty of the olfactometric method are the significant biological variability in olfactory sensitivity and its inability to detect low odour concentration. Even though the introduction of criteria for the selection and behaviour coding of the panel has notably increased the repeatability and reproducibility of the measurements, the variability associated with the use of human subjects as detectors constitutes one of the principal limitations (Koster, 1985; Zarra et al., 2008b).
Analytical methods (GC-MS, colorimetric methods) allow the substances present to be screened and their concentrations identified, but they do not provide information on the odorous sensation produced by the mixture as a whole (Davoli, 2004; Zarra et al., 2007b; Zarra et al. 2008c). The analysis methods are also heavily influenced by the sampling techniques (Gostelow et al., 2001) which differ according to the type of source (areal or point, active or passive type) and the actual sampling methods (see Part 5). In order to reduce problems linked to sampling, a number of recent literary works propose the use of portable GC-MS analysers (Zarra et al., 2008b; Zarra et al., 2008c).

1.3 Effects of Odour

Odour exposure could cause annoyance and nuisance. A more serious effect, it may lead to feelings of nausea and headache, and other symptoms that appear to be related to stress. It has been postulated that the mechanism of ‘environmental worry’ helps to explain the occurrence of physiological effects in people exposed to odorous substances at concentrations much lower than might be expected to lead to actual toxic effects (see Section 2.5).

Many odorous compounds are indeed toxic at high concentrations, and in extreme cases of acute exposure toxic effects such as skin, eye or nose irritation can occur. However, such effects are most likely to occur as the result of industrial accidents, such as the rupture of tanks containing toxic compounds or severe upset conditions in chemical or combustion processes.

Repeated exposure to odour can lead to a high level of annoyance, with the receiver becoming particularly sensitive to the odour. Complaints are most likely to come from individuals who are either physiologically or psychologically sensitive to the odour, and certainly a combination of both types of sensitivity will increase the likelihood of complaint. The individual components of an odour necessary to cause an adverse reaction from people are usually present in very low concentrations; far less than will cause adverse effects on physical health or impacts on any other part of the environment.

The odour threshold values for many chemicals are several orders of magnitude less than the relative threshold limit values (TLV). This means that the chemicals can be smelled at much lower concentrations than those causing adverse effects on health. Therefore, if present in sufficient quantities, these compounds would create an odour problem at much lower concentrations than would be needed to create a public health problem.

Despite these examples, it should not be assumed that odour thresholds will always be much lower than toxicological thresholds. The potential for significant adverse effects on public health from chemicals in odorous discharges should be considered on a case-by-case basis.

There is very little information available about the physiological effects of odour nuisance on humans. However, it is known that prolonged exposure to environmental odours can generate undesirable reactions in people such as unease, irritation, discomfort, anger, depression, nausea, headaches or vomiting. In our experience, other effects reported by people subjected to environmental odours can include:

- difficulty breathing;
- frustration, stress and tearfulness;
- being woken during the night by the odour;
- odour invading the house and washing;
- reduced appetite and pleasure in eating, and difficulty preparing food;
- reduced comfort at night (the need to close bedroom windows on hot nights);
- reduced amenity due to the need;
- embarrassment when visitors experience the odours;
- reduced business due to prospective customers being affected by the odour.

All these aspects are related to odour attribute and the relative response of people, discussed in Part 2.

1.4 Odour Impact Assessment Approaches

Odour impact is defined as the alteration of air quality in terms of odours that cause nuisances. An assessment of odour impacts in the environment may need to be carried out for a variety of reasons, including:

- preparing or evaluating resource consent applications, or impact assessments, for three separate categories:
  1. renewing an existing activity,
  2. proposed modifications to an existing activity (mitigation or process change),
  3. proposed new activity.
- monitoring compliance with resource consent conditions;
- investigating odour complaints to determine if an offensive or objectionable odour is present.

The methods used to assess the odours will depend on the type of situation. A number of different techniques for odour assessment are available and discussed in Part 7. The choices of the best tools to use for an odour assessment partly depend on whether the assessment is an evaluation or a compliance issue.

Evaluation involves assessing the actual and potential effects of an activity to determine whether significant adverse environmental effects will occur. If the consent is granted, the consent holder is then required to comply with (and be able to demonstrate compliance with) any conditions imposed as part of that consent.

These two processes for evaluation and compliance are quite separate, and often the evaluation criteria are different to the criteria imposed as conditions of consent.

Assessment tools can also be classified in two categories, methods with direct measurement of odour exposures or their assessment by dispersion modelling, and respectively:

1. Odour impact assessment from exposures measurement
2. Odour impact assessment from sources

All these tools with their strengths and weaknesses are discussed in Part 7, where the criteria for choosing the best one according to the specific situation are also presented.

References


2.1 Attribute Descriptors

The correlation between odorous sensations and the chemical structure of the molecules that cause them is still the subject of scientific research, and in which scientists all over the world are investing considerable resources. Nowadays, the characterization of odours is based on an accurate description of the following characteristics, known also as the characterization parameters of an odour:

- concentration;
- perceptibility or threshold;
- intensity;
- diffusibility or volatility;
- quality;
- hedonic tone.

2.1.1 Concentration

The concentration of an odour generally refers to the methods with which it is quantified. When using an analytical technique, the concentration is expressed in μg m$^{-3}$ and, as it cannot be determined with reference to the entire compound, it relates to the numerical...
quantification of the individual substances. The sensorial technique of dynamic olfactometry, instead, expresses concentration as OU/m³. Particularly, a gaseous sample has a concentration of 1 OU/m³ when it is at the perception threshold, that is when at least 50% of the population perceive an odour when sniffing the sample (see Section 3.4).

2.1.2 Perceptibility or Olfactive Threshold

The concentration at which an odour is just detectable to a ‘typical’ human nose is referred to as the ‘threshold’ concentration. This concept of a threshold concentration is the basis of olfactometry in which a quantitative sensory measurement is used to define the concentration of an odour. Standardized methods for measuring and reporting the detectability or concentration of an odour sample have been defined by a European standard (EN 13725:2003). The concentration at which an odour is just detectable by a panel of selected human ‘sniffers’ is defined as the detection threshold and as an odour concentration of 1 European odour unit per cubic metre (1 OUE/m³ or 1 OU/m³), (see Section 3.4).

At the detectability threshold, the concentration of an odour is so low that it is not recognizable as any specific odour at all, but the presence of some, very faint, odour can be sensed when the ‘sample’ odour is compared to a clean, odour-free air sample.

For a simple, single odorous compound (e.g. hydrogen sulfide), the ‘amount’ of odour present in an air sample can be expressed in terms of ppm, ppb or in mg m⁻³ of air. More usually, odours are very complex mixtures of compounds and the concentration of the mixture can be expressed in European odour units per cubic metre (1 OUE/m³ or 1 OU/m³).

Relating to single odorous compound, the perceptibility or olfactive threshold represents the concentration at which a substance is capable of provoking a stimulus in human beings. It varies with differences in concentration and generally three types can be defined (Centola et al., 2004):

- **perceptibility or detection threshold**: represents the concentration at which the odour is detected with certainty. The threshold of detection is also defined as the concentration at which an odour just becomes strong enough to produce a sensation of odour within the controlled conditions of an odour laboratory. This value is normally indicated with OT (odour threshold). Being dependent on the subject, this value is obviously not uniquely defined. For this reason, use is made of the terms low perceptibility threshold (the smallest value of the concentration at which the odour is detected) and high perceptibility threshold (the highest value of the concentration at which the same odour is detected – OT₁₀₀%), in other words the perceptibility threshold interval. When not indicated, as there is a variation in sensitivity between different individuals, the OT value defined in olfactometry is a statistically derived value that represents an ‘average’ response from 50% of selected odour panellists (OT₅₀%).

- **recognition threshold**: represents the concentration relating to an odour perceived and identified (RT). Even better, the concentration at which an odour becomes recognisable, as a specific odour, is not the same as the concentration at which it is detectable. Whilst the detection threshold is the concentration at which some odour can be sensed, a higher concentration is usually required before the odour can be recognized. The RT is generally about three times the detection threshold, although this factor may be considerably higher outside the controlled environment of a laboratory. The ability to ‘discriminate’ one odour from another is an important attribute when describing an odour. We rely on being able
to discriminate between odours for a whole range of reasons such as fresh and stale food, the addition of flavourings and when determining the source of an odour. This is a human ability to distinguish between odours and is important when needing to identify an odour source;

- **annoyance threshold**: represents the concentration necessary to provoke a sensation of annoyance (see Section 2.5).

The olfactive threshold is also strongly influenced by the duration of the exposure as a consequence of the adaptation conditions that may be generated. In literature, it is possible to find experimentally determined concentrations corresponding to the olfactive thresholds of many pure substances. The work published by J.H. Ruth (1986) is of particular interest in this direction, with it reporting the olfactive threshold intervals from the lowest to the highest and, where available, a description of the type of odour and its annoyance concentration. These values become difficult to evaluate when considering a mixture of different substances, in that odour intensification or masking phenomena may take place. The correlations that can derive from a combination of odorous substances are essentially those of (Centola et al., 2004):

- independence: \( R_{AB} \leq R_A \) or \( R_B \);
- additivity: \( R_{AB} = R_A + R_B \);
- synergism: \( R_{AB} > R_A + R_B \);
- antagonism: \( R_{AB} < R_A + R_B \).

where \( R_A \) and \( R_B \) represent the perceptibility threshold of two pure substances, and \( R_{AB} \) is the perception threshold of the mixture obtained when the two pure substances are combined.

### 2.1.3 Intensity

Odour intensity is defined as the strength of the olfactive stimulus for odorant concentration values exceeding the perceptibility threshold (McGinley et al., 2002). Low concentrations of some compounds in a sample are capable of being perceived as having a high intensity even when close to threshold concentrations. These compounds are common in naturally unpleasant odours such as hydrogen sulfide (rotten eggs). The interdependence of the intensity of the olfactive sensation ‘I’ and the odorant concentration ‘C’ can be described using mathematical functions (Castano et al., 1992).

According to Stevens, this relation is well represented by an exponential function (see Figure 2.1) (Stuetz et al., 2001):

\[
I = K_s (C - C_0)^n \quad \text{with} \quad C > C_0
\]  

(2.1)

where:

- \( K_s \) is the Stevens constant (dependent on the substance considered);
- \( C_0 \) is the odour threshold concentration (OT);
- \( n \) is a coefficient that normally varies between 0.2 and 0.8 depending on the substance considered. Its value constitutes an important indication of the effect of an eventual dilution for odour reduction, which obviously increases as \( n \) increases. For example, for \( n = 0.2 \), a dilution of times 10 reduces the olfactive intensity by a factor of 1.6, while for \( n = 0.8 \) the same dilution causes a reduction of 6.8 (Cernuschi and Torretta, 1996).