21. Odor Measurements

Ralf Petrich, Axel Delan

Odor measurements in the atmosphere are carried out using human noses or instruments as sensors. Only human noses are currently able to record an odor impression. To measure odor intensity, distinguish between the presence or absence of odors, or classify odors, instruments can also be used.

From the perspective of typical applications, there are two basic approaches. On one hand, high odor concentrations in the air (several orders of magnitude above the human perception threshold) are measured using olfactometry. This method combines a device for dilution and the evaluation of the diluted odors, usually by human noses. Applications of this method are the determination of odor emitter concentrations in industry or agriculture and, beyond the scope of atmospheric measurements, the characterization of scents. On the other hand, the measurement of low odor concentrations (around or slightly above the human perception threshold) are obtained by means of field inspections. In this case, human assessors breathe the air to be tested and record their odor perception.

Odor concentration, perception frequency, and hedonic impression are typical parameters determined within the scope of odor measurement. Statistical methods play an important role during the evaluation of the raw data obtained from the assessors to finally get representative measurement values.

Measurements of odors in the atmosphere have become more and more important in the last 20 years. In contrast to indoor odor measurements and scent characterization of consumer products, atmospheric odor measurement is usually connected to the assessment of odor nuisances around facilities with odor emissions, such as industrial plants, agricultural operations (livestock), waste and wastewater treatment plants, or composting facilities. There are methods of direct odor measurement, such as field inspections by panel members who visit the locations where odor measurements are required. Moreover, the concept of odor units was developed to measure the amount of an odor within a unit volume. Thus, it is possible to mathematically describe processes like odor emission, dilution, mixture, or dispersion. Also, direct odor concentration measurements can be carried out using olfactometry.

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21.1 Measurement Principles and Parameters

Odor measurements can be carried out for several reasons. For instance, odor annoyances reported by people living near odor emitting facilities are quantified based on odor measurements. Furthermore, if the scents of certain consumer products like perfumes, cars, or food must be characterized, odor measurements (outside the scope of atmospheric measurements) are used.

21.1.1 Measured Parameters

Different kinds of parameters can be obtained from an odor measurement. Odor concentration plays a central role. This concentration describes the amount of odor within a given volume of air. In this context, odor is mathematically treated as an extensive magnitude like, for instance, mass or energy. To accomplish this, the concept of an *odor unit* must first be introduced. An odor unit (OU) is defined as exactly the amount of an odorant (a substance that stimulates the human olfactory sense) within one cubic meter of gas, which constitutes the average human odor perception threshold. Thus, the concentration of one odor unit per cubic meter is the concentration at which the average (regarding her or his odor perception) human starts to perceive the odor. A more detailed representation of the theory behind this concept is given in Sect. 21.3.1.

Once the odor unit and its concentration are defined as quantities, they can be used for calculations and to derive other quantities. For instance, if a gas with an odor concentration of $100\,\mathrm{ou\,m^{-3}}$ is diluted by the factor 20, the resulting concentration is $5\,\mathrm{ou\,m^{-3}}$. Furthermore, if the amount of time is determined during which a concentration in ambient air, for instance $1\,\mathrm{ou\,m^{-3}}$, is exceeded, the perception frequency of a specific odor is obtained as another measured parameter.

Other parameters like the hedonic impression of a specific odor, for instance *pleasant* or *unpleasant*, can usually not be treated within the concept of a numerical quantity, but as verbal descriptions. The most relevant measured parameters are summarized in Table 21.1.

21.1.2 Principles of Measurement

As usual, *to measure* means comparing a quantity to a standard. To measure odors is complicated for two reasons. On one hand, the only standard to compare to is the human olfactory perception, which to be precise means the human olfactory perception threshold. On the other hand, the method to compare a sample of gas to this standard can also be difficult if dilution or a special sample treatment is involved. To accomplish the task of comparison, two basic approaches can be used. The conventional method uses human noses as detectors. Recently, technical instruments have also been used to characterize odors.

Another way to structure measurement principles is based on the odor concentration of the gas under study. On one hand, high odor concentrations in the air (several orders of magnitude above the human perception threshold) are measured using olfactometry. This method combines a device for dilution and the evaluation of the diluted odors, usually by human noses. Applications of this method are the determination of odor concentration of odor emitters in industry or agriculture and, beyond the scope of atmospheric measurements, the characterization of scents. On the other hand, the measurement of low odor concentrations (around or slightly above the human perception threshold) is obtained by means of field inspections. In this case, human assessors (panel members) breathe the air under investigation and record their odor perception. Field inspections can be carried out as grid inspections or plume inspections.

For grid inspections, panel members visit a spatial grid of fixed measurement points over a representative time span (typically one year) and record their odor perceptions, usually every ten seconds over a period of ten minutes at each measurement point. Thus, a spatial distribution of the perception frequency is obtained for the assessment area.

Plume inspections are used to determine the shape and size of the area where an odor plume originating from a given point can be perceived and recognized, with respect to the specific meteorological and odor source conditions. For that, the panel members record the presence or absence of the odor under investigation at different points downwind of a source. They can stay at a fixed measurement point in the assessment area over a certain time (stationary method) or they can move around and follow a plume in the assessment area and record their perception as a function of location and time (dynamic method).

More detailed background information on the measurement principles is given in Sect. 21.3. Table 21.2 shows the sensor types and their respective measurement principles and parameters.

Table 21.1 Measured parameters

Parameter	Description	Unit	Symbol
Odor concentration	Mathematical equivalent to mass concentration, describing the amount of odor within a given volume of air	$\mathrm{ou\,m^{-3}}$	c
Perception frequency	Percentage of time during which a specific odor is perceived	%	P
Hedonic impression	Verbal description of the type of odor (pleasant, unpleasant, etc.)	–	–

Table 21.2 Principles of odor measurements and applications

Type of sensor	Measurement principle			Parameter		
	Olfactometry	Grid inspection	Plume inspection	Odor concentration	Perception frequency	Hedonic impression
Human nose	×	×	×	×	×	×
Instrument		×	×		×	

21.2 History

Olfaction is phylogenetically the oldest sense and man's interest in scents or odors can be traced back into ancient history [21.1]. But only in the nineteenth century were efforts to assess olfaction solidified by *Gabriel Valentin* (1810–1883) in 1842 and *J. Passy* in 1892 [21.2]. Around 1888, *Hendrik Zwaardemaker* developed a device for obtaining olfactory perception thresholds. This device can be regarded as the predecessor for the olfactometers since developed and produced.

The last 20 years of the twentieth century saw development in olfactometry, when interest in the quantification of olfactory perception was promoted by applications in pollution management, environmentalism, and scent management for consumer products. Many test procedures were developed for the human olfactory sense from a medical perspective. Also, studies on the olfactory sense and its statistical parameters (for instance odor perception threshold) were carried out in North America and Europe.

At the end of the twentieth century, a lot of knowledge was available regarding the measurement of the parameters mentioned above.

Sophisticated devices (olfactometers) were developed and built to accurately dilute samples. At first, these olfactometers had simple dilution mechanisms controlled manually; later, computer-controlled dilution mechanisms were introduced. The first olfactometers were able to serve only one panel member; recent devices can serve up to ten panel members at once. Elaborate statistical methods were also developed to accomplish quality management.

With this knowledge and the availability of devices, it was finally possible to handle odor measurements at the same scientific level as the measurements of other atmospheric parameters.

Finally, a set of regulations was developed in Europe and North America to regulate the procedures of olfactometry and field inspections as the most common odor measurement principles [21.3–5].

21.3 Theory

In the following section the concept of odor units is described. Based on this concept, several measurement principles are introduced later in the section.

21.3.1 Derivation of the Odor Unit Concept

As mentioned in Sect. 21.1.2, the basic odor measurement concept is the odor unit. An odor unit is defined as the amount of an odorant within one cubic meter of gas, which constitutes the average human odor perception threshold.

Regarding this definition, several important aspects must be considered. The actual amount of an odorant expressed as its mass in a given volume of air is proportional to the number of odor units within this volume with respect to the specific odorant. The mass concentration of an odorant that corresponds to $1\,\mathrm{ou\,m^{-3}}$ is the specific odor threshold of this odorant. For ammonia, for instance, this value lies between $1\,\mathrm{mg\,m^{-3}}$ and $5\,\mathrm{mg\,m^{-3}}$.

Another aspect in the definition is the term *average human odor perception threshold*. Everyone has their own (personal) threshold (mass concentration of an odorant within ambient air), above which an odorant becomes perceptible. Below this threshold, the odorant is not perceived, though its mass concentration within the ambient air is not zero. To work with a value averaged over a statistically representative set of people (average threshold), the variation in personal thresholds must be investigated. It was found that even for a mixed population (both genders and ages within the adult range), the personal thresholds do not vary by orders of magnitude. The value can therefore be regarded as stable enough to be used in the definition of odor units. Finally, the *average threshold* can be regarded as the amount of an odorant within ambient air at which half of a statistically representative set of people perceives the odor and the other half does not [21.5]. Thus, *averaging* the perception threshold mathematically corresponds to finding the median value.

In practice, the representative set of people mentioned above is constituted by a panel of assessors. To ensure typical odor perception, the panel members are checked on a regular basis to determine whether their odor perception threshold for certain substances (for instance, *n*-butanol) is within a predefined range. Such a panel of assessors is used for all the measurement principles described below.

Finally, one more aspect must be kept in mind. The amount of odor units within a given volume is always coupled to the one odorant under study. Though odor units offer a convenient way to mathematically handle dilutions, it is not possible to describe the processes if odorants are mixed this way. If an air sample with a certain odor concentration (odor units per volume) is mixed with a sample with another odorant, the odor concentration of the resulting mixture cannot be expressed as a weighted average of the original concentrations. This is because different odors can cover, amplify, or attenuate each other on mixing. The only way to obtain the odor concentration of the mixture is to characterize it with an independent measurement.

21.3.2 Conventional Measurement Principles

As summarized in Table 21.1, different measurement principles are available to determine different measurement parameters. The central measurement principle is olfactometry, which can measure the odor concentration and the hedonic impression of a sample. Other measurement principles like field inspections can yield measurement parameters such as the absence or presence of odors, perception frequency, and the hedonic impression. Instrument-aided measurement principles must be calibrated with measurements based on the human nose and can then be used to determine odor concentration, the absence or presence of odors, the classification of odors, and perception frequency. However, while nose-based measurements are usually used to study arbitrary odors, instrument-based measurements can only be used to study exactly the odors they were calibrated for, but no other odors.

Olfactometry

Olfactometry as a measurement principle can be used to investigate odor samples with odor concentrations well above the perception threshold of the odor under study. This is caused by the central principle of olfactometry, the sample dilution. For instance, an air sample is diluted and presented to a panel of human assessors until half of the panel members perceives the odor and the other half does not. At this dilution, the air presented to the panel has an odor unit concentration of $1\,\mathrm{ou\,m^{-3}}$ per definition. The dilution factor is recorded and used to derive the odor concentration of the original, undiluted sample. If, for instance, a dilution of 6000 is necessary to reach the panel's odor threshold, the original sample has an odor concentration of $6000\,\mathrm{ou\,m^{-3}}$.

To implement this procedure, a measurement device called an olfactometer is used. An olfactometer usually has two sections. One section consists of the dilution instrument; the other section presents the diluted sample to a panel of assessors and records their odor perception at different dilution levels.

The dilution instrument is the most sophisticated part of an olfactometer. On one hand, it must allow for calibrated dilution in a typical range from 10 to 5000. Even higher dilutions might be reached using predilution. On the other hand, the instrument components must not emit their own odors or modify the odors under study. Thus, typically only materials like glass, stainless steel, or polytetrafluorethylene (Teflon, PTFE) can be used.

Twentieth-century olfactometers were manually controlled to adjust the dilution factor. Current devices usually use automatic control units to adjust the dilution as part of a computerized measurement procedure. Panel sizes to test the diluted sample range from one to ten for common olfactometers.

Usually, the measurement procedure starts with a very high dilution so that the diluted sample presented to the panel is well below the perception threshold of all panel members. Then, the dilution is decreased step by step (for instance, a factor of two at each step) and the odor concentration presented to the panel increases. When the perception threshold of all panel members is reached (perceptions from all members have been recorded), the procedure is finished and will be evaluated. To decrease statistical uncertainty, this procedure is repeated with the same sample a number of times, for instance three times.

Two common procedures for presenting the diluted sample to the panel members are known [21.5]. In the *yes/no mode*, the assessor is asked to evaluate the presented gas and to indicate if an odor is perceived (yes/no). The assessor is aware that in some cases blanks (only neutral gas) are presented. An additional outlet that always presents neutral gas may be made available to the assessor to provide a reference. Also, neutral reference gas might be presented between the stimulus cycles.

In the *forced choice mode*, the assessor is presented with two or more outlets, of which one presents the stimulus and the other(s) neutral air. The location of the stimulus in consecutive presentations is randomly changed among the two or more outlets. The assessor is asked to indicate which of the outlets presented the stimulus.

By evaluation of the panel member responses over the decreasing dilution factor, it is possible to find the panel's average odor perception threshold. If this threshold is reached, the respective dilution factor is used to determine the sample's odor concentration. Detailed information on olfactometry can be found in [21.5].

Field Inspection – Grid Mode

Grid mode is one of the field inspection methods mentioned in Sect. 21.1.2. Because olfactometry, with its practical lower detection limit of approximately $10\,\mathrm{ou\,m^{-3}}$, cannot be applied to directly determine odor exposure in the field (faint odors at the concentration where they can just be recognized), grid inspection is not based on the dilution of sample air but brings the panel members to the field for in-place assessment [21.3].

The grid inspection is a statistical survey method carried out over a sufficiently long period of time (typically one year) to provide a representative map of the exposure to recognizable odor, spatially distributed over the assessment area. These measurements are used to determine the distribution of the perception frequency for recognizable odors in ambient air in an assessment area under meteorological conditions that are assumed to be representative for the local meteorology [21.3].

The odor perception frequency can, for instance, be used as an exposure indicator to assess the odor annoyance originating from one or many specific odorant source(s) emitting in a particular area under study.

For grid inspections, the panel members visit a spatial grid of fixed measurement points many times and record their odor perceptions. Usually, the perception is recorded every ten seconds over a total period of ten minutes (60 records) at each measurement point. From these records, a value for the perception frequency can be derived at the respective measurement point.

Typically, the assessment area is inspected with a frequency of approximately twice per week, while the actual time of day for the measurement changes stochastically. Also, the panel member carrying out the measurement is selected stochastically from a pool of at least ten assessors.

Inherently, each inspection represents only a snapshot of the real situation. For that reason, extensive statistical evaluation must be carried out to determine the relevance of the results. The perception frequency usually uses an hour as the time basis (odor hour frequency). By taking two snapshots per week, only 104 samples are available after a typical assessment time of one year. A perception frequency value with respect to the 8760 h of one year derived from only 104 snapshots bears a high statistical uncertainty. This aspect is one of the major disadvantages of grid inspection, besides the immense expense of visiting the assessment area 104 times.

Field Inspection – Plume Mode

Plume inspections are used to determine the shape and size of the area where an odor plume originating from a given point can be perceived and recognized with respect to the specific meteorological and odor source conditions. In contrast to the grid mode, the assessment area is not visited sequentially over a long span of time by the panel members; instead, a snapshot at a specific time is taken by a group of panel members visiting the assessment area simultaneously. The panel members record the presence or absence of the odor under investigation at different points downwind of a source. They can stay at a fixed measurement point in the assessment area over a certain time (stationary method) or they can move around and follow a plume in the assessment area and record their perception as a function of location and time (dynamic method).

The primary parameter measured with this method is the presence or absence of recognizable odors at a specific location downwind of a source, which is recorded by a number of panel members. From these results, the extent of the plume can be assessed as the transition from absence to presence of recognizable odor.

On one hand, the results are typically used to determine a plausible extent of potential exposure to recognizable odors. On the other hand, it is possible to estimate the total emission rate based on the plume extent, using reverse dispersion modelling [21.4].

21.3.3 Instrument Odor Measurement Systems

For instrument odor measurement systems (IOMSs), the human nose as a sensor is replaced by a technical system that can detect odorants in the air. For a while, these devices were also called *electronic noses*, however all known IOMSs are far from being able to perform similar measurement tasks as the human nose. In particular, the physiological hedonic impression of an odor cannot be measured by an IOMS, but only by the human nose.

Thus, IOMSs are presently restricted to the following measurement tasks:

- Distinguish between the absence and presence of a single specific odor under study
- Classify multiple specific odors under study
- Estimate the odor concentration for a single specific odor under study

Nearly all presently known IOMS rely on a multidimensional sensor system that is sensitive to as many odorants as possible. During measurement, a multidimensional pattern is recorded, where each dimension can be regarded as an indicator for a single odorant concentration. Apparently, most of these sensor systems are not only stimulated by odorants, but also by odorless substances in the air, which leads to adverse cross-sensitivity effects. Conversely, not all odorants that stimulate the human olfactory perception also stimulate the various sensor systems, which leads to the effect that not all the odors perceptible by humans can be detected by the different kinds of IOMSs.

In practice, several kinds of IOMSs are used. For instance, gas chromatography (GC), ion-mobility spectroscopy (IMS), or electrochemical sensor arrays. While the electrochemical sensor arrays are relatively cheap, they usually suffer from cross-sensitivity, drift effects after some time of exposure to the atmosphere, and the lack of enough independent dimensions to reliably characterize an odor. GC and IMS are well-established measurement principles for gas analysis and thus can also be used as IOMSs. For GC, the resulting chromatogram holds the multidimensional information on as many as possible odorants; for IMS it is the drift-time spectrum. Both GC and IMS are much more expensive than arrays of electrochemical sensors, but also much more effective in odor characterization.

Usually, methods of multivariate data analysis or pattern recognition techniques are applied to evaluate the multidimensional information obtained from the measurement systems.

In general, each IOMS must be calibrated using data obtained from measurements with the human nose, usually with measurement principles involving panel members as explained above. At present, there is no known system that is able to measure odors without a calibration based on human olfactory perception.

IOMS are able or will be able to measure specific odors depending on their training. However, the human nose is much more sensitive than any sensor technique currently available. With human noses, not only can odor concentration or the absence/presence of odors be measured, but the hedonic impression or nuisance level can also be determined. Especially for the determination of hedonic impression and nuisance level, an IOMS will not be usable in the near future.

21.4 Devices and Systems

As explained in the previous sections, the most important sensor system for measuring odors is the human nose. It is either used for direct measurement parameter recording or for calibration of IOMSs.

As technical devices used for odor measurement, the olfactometer plays a central role. IOMSs have recently been used for restricted measurement tasks as stated above. The basic operation principles of the devices were explained in Sect. 21.3.

Table 21.3 summarizes the devices introduced so far. Since IOMSs can only be regarded as supplemental sources of measurement data besides the conventional measurement principles described in Sect. 21.3.2, they are regarded here in general as IOMSs, without respect to the possible measurement principles realized within them. Also, the different kinds of olfactometers are regarded as a device class, without distinguishing between the models of different manufacturers.

Table 21.3 Advantages and disadvantages of the different device classes

Devices	Advantages	Disadvantages
Olfactometer	Direct measurement of any odor concentration using the human nose as sensor	Only batch investigations with relatively high expenditures due to necessary laboratory, device, and human resources
IOMSs	Fast measurement even under field conditions with the possibility of real-time applications	Indirect measurement of a specific odor concentration after calibration with olfactometer measurements

Fig. 21.1 Example for an olfactometer with panel members during a measurement (photo courtesy Olfasense)

Fig. 21.2 Example for an IOMS based on ion mobility spectroscopy

Last but not least, it must be kept in mind that the device classes of olfactometers and IOMSs cannot be compared with each aspect of their application scope. IOMSs, for instance, are often used to distinguish between the absence and presence of a specific odor under study or to classify odors at reception level near the human perception threshold. Olfactometers, however, are used to investigate samples with much higher odor concentration by dilution to determine the odor concentration in odor units per volume.

Figure 21.1 shows an olfactometer along with the panel members during a measurement and Fig. 21.2 shows an ion-mobility spectrometer as an example of an IOMS.

21.5 Specifications

The measurement principles explained above have different application domains and are used to determine different measurement parameters. Therefore, a comparison of the specifications cannot be easily accomplished, as is possible for other measurement devices described in this book that use tables containing concrete numerical parameters. Here, it is rather useful to discuss the specifications of each measurement principle separately.

For IOMSs, no specifications can be given since the application of these devices is not yet investigated within the usual scope of a measurement principle.

21.5.1 Olfactometry Specifications

Olfactometry is primarily used to determine the odor concentration, though it is also possible to determine the hedonic impression. When describing specifications, it only makes sense for the odor concentration measurement, since the hedonic impression cannot be quantified.

For insight on specifications, especially measurement accuracy, it is important to review the measurement procedure. Starting at a very high dilution well below the perception threshold of the panel members, the concentration of the diluted sample is increased step-wise by a factor of two at each step until the average perception threshold of the panel is reached. Thus, the inherent resolution of the measurement principle is coupled to this increase step. If only one measurement is carried out, the uncertainty of the measurement result lies between half the result value and double the result value (a factor of two up and down). To reduce this quite large uncertainty, repeated measurements of the same sample are carried out (usually a total of three measurements). From a statistical view, each repetition reduces the statistical uncertainty by the factor 1.41 (square root of 2). In practice, the determination of the total uncertainty must consider the statistical uncertainty of the finite number of panel members (infinity would mean to have the average threshold value without uncertainty) and the systematic errors, for instance due to the precision of the dilution apparatus. A detailed description on handling the different uncertainties during olfactometry is given in [21.5].

The initial inherent uncertainty is of a factor two up and down and seems to be very high compared to the measurement of other atmospheric parameters. However, since according to Weber–Fechner's law the physiological stimulus perceived by humans is proportional to the logarithm of the physical quantity (odor concentration, in this case), the measurement uncertainty can be expressed as approximately three decibels (correlates to a factor of two) on the logarithmic stimulus scale. While the odor concentration can cover a range of several orders of magnitude between the perceptions *none* and *extremely strong* on the stimulus scale, the uncertainty of a factor of two up and down can be accepted, especially if it is further reduced by repeated measurements.

21.5.2 Field Inspection Specifications

Field inspection measurements are principally based on observations of the absence and presence of an odor under study by the panel members. Though, in special cases, the intensity of the stimulus is also recorded, the numerically useful information remains the panel member's decision between absence and presence. Thus, the resolution of a measurement consisting of these yes/no decisions basically depends on the number of independent single measurements. If just a single perception is recorded, the statistical uncertainty of this measurement is 50% if the panel member is presented with a stimulus near the perception threshold. It is to be expected that the panel member might err on the perception, so the single observation is either right or wrong with a probability of 50% each. To overcome this, repeated measurements are carried out over a certain period of time, typically for ten minutes with one observation every ten seconds (60 in total). If all the observations were independent of each other, the statistical uncertainty would be reduced by a factor of 1.41 (square root of 2) for each observation. So, a total number of 60 observations would significantly reduce the statistical uncertainty if all the observations were independent of each other, which of course they are not, since the conditions causing the absence or presence of an odor are not independent within a time span of ten minutes. So, since the dependency of the single observations from each other is very difficult to express and is different for each measurement, a specific uncertainty value cannot be given.

To estimate the measurement uncertainty, an extended approach can be followed. It makes use of the odor hour concept, which by convention declares that an odor hour (time span of one hour, during which a human being has perceived the odor at least once) happens if during the ten-minute measurement period at least six of the 60 single observations stated an odor presence. This concept was introduced to quantify odor nuisance, which was found to be determined primarily by the percentage of odor hours with respect to the number hours in a whole year (perception frequency). If this perception frequency exceeds a certain value, for instance 10%, the overall odor nuisance can be regarded as substantial.

To measure the perception frequency, grid inspections are typically carried out with a total of 104 measurements over one year (two measurements each week). Once again, it can be accepted that the uncertainty of one single measurement is due to the yes/no decision if an odor hour was found or not, especially if the odor concentration in the field is close to the perception threshold. If the panel member doing the measurement is allowed to err in one measurement of the total 104, the overall error due to that single wrong measurement will be almost 1%. If errors happen more often, the yearly error percentage will increase accordingly.

One way to reduce statistical uncertainties is to make sure that the 104 single measurements are equally distributed over as many boundary conditions as possible: over the time of day, days of week, and the four seasons. Also, there should be no correlation between the mentioned boundary conditions and the panel members, meaning that each panel member should cover as much of the other boundary variances as possible. Then, even with the unfamiliar high statistical uncertainties, the results of a field inspection can be used to assess the perception frequency.

A detailed description of uncertainty handling for field inspections can be found in [21.3, 4].

21.6 Quality Control

For odor measurements, quality control must be implemented in terms of the technical devices, laboratory operations, and panel members involved in the measurements. Detailed information on quality control is given in [21.3–5].

The olfactometer as primary device to measure odor concentration must be continuously checked, with a focus especially on the dilution apparatus. At least once every year the dilution apparatus must be checked or calibrated. This is a special challenge, since the range of the dilution factor covers several orders of magnitude and must be precise over the whole range.

Also, panel members must be checked in certain intervals, for instance every six months, to determine if their odor perception threshold is still within a certain range around the expected average. Since the minimum number of panel members usually is ten, it must be guaranteed that this comparatively (within the statistical context) low number of individuals does not contain members with extraordinary low or high odor perception threshold. The check is usually done by letting the members take part in ordinary olfactometry measurement with samples of known odor concentrations. To eliminate the need for calibrating this procedure, samples are prepared from neutral air mixed with a suitable amount of a substance with known odor threshold, for instance *n*-butanol.

Quality control on the level of overall laboratory operation includes full documentation of the regular check and maintenance activities and, if possible, the implementation of a recognized quality management system. Another way to ensure quality is to implement collaborative studies, where a uniform set of samples is investigated by different laboratories with the goal of obtaining comparable results.

Quality control for field inspections (grid and plume mode) are implemented on a general level through the procedures for the panel members described above. Furthermore, quality control on a situation-based level is carried out through plausibility considerations. Thus, for a field inspection, wind direction, for instance, is recorded to be able to decide if an odor source might contribute to an odor stimulus measured during a field inspection. Through these plausibility considerations, erroneous measurements can be sorted out.

Quality control for IOMSs is not currently an issue, however there are activities within the European Committee for Standardization (CEN) to develop standards for quality management for these devices as well.

21.7 Maintenance

Maintenance, like quality control, includes activities pertaining to the devices, especially the olfactometer. Besides the activities to calibrate and check the dilution apparatus, cleaning procedures are especially necessary to prevent unwanted odors being emitted from parts of the measurement system itself. This applies not only to the olfactometer, but to all the components for sampling, diluting, and storing samples.

The panel members should not be regarded as being *maintained*, however regularly checking each member's odor threshold can be regarded as a maintenance activity pertaining to the panel as a whole.

21.8 Application

As discussed in the first sections of this chapter, applications of odor measurements are different for the individual measurement parameters.

One of the most common applications of atmospheric odor measurements is the assessment of odor nuisances around facilities with odor emissions, such as industrial plants, agricultural operations (livestock), waste and wastewater treatment plants, or composting facilities. For this purpose, the measurement of perception frequency delivers a parameter to assess the degree of odor nuisance. Even if the expenditures for carrying out a full grid inspection over one year are quite high, this is the only way to obtain an assessment if modelling the odor perception frequency with dispersion models does not lead to reliable results.

Odor concentration measurement is the standard measurement to characterize the odor emission of the facilities mentioned above. If the amount of odor units emitted per unit time is known, this value can be used to assess the processes within the facilities or to act as input parameters for dispersion modeling. Figure 21.3 shows an example of simulated odor hour frequencies in the vicinity of several buildings.

Finally, though not actually within the context of atmospheric measurements, the odor characterization of consumer products (e.g., perfume scents and car smells) can be accomplished by determination of the hedonic impression.

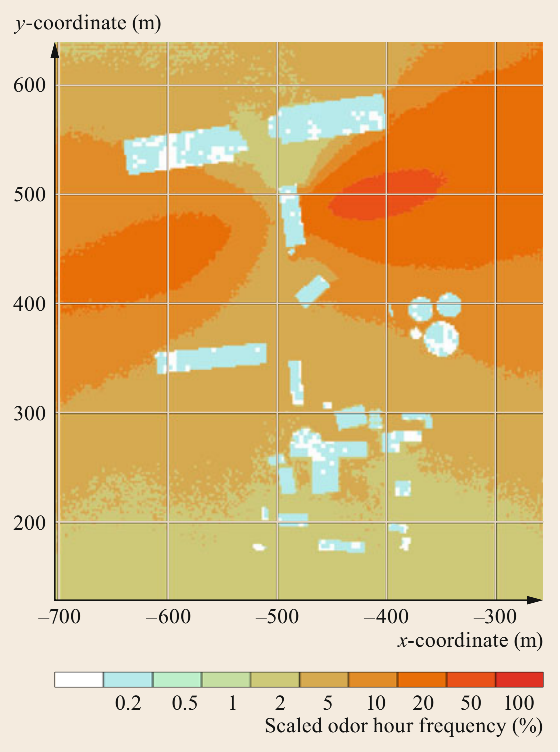

Fig. 21.3 Example of simulated odor hour frequencies obtained from dispersion modeling

21.9 Future Developments

Olfactometry and field inspections are well-established measurement procedures. They deliver reliable results for odor concentration or perception frequency.

Current and future developments should pursue the goals of reducing the expenditures of measurements (field inspections), eliminating the human nose and instead using other sensors to objectify measurements, and obtaining online source monitoring (with odor concentration well above the perception threshold) to obtain an indicator for odor nuisance. For these goals, the development of IOMSs plays an important role. As mentioned before, IOMSs will become available for special measurement tasks, such as detecting the absence or presence of an odor or to classify odors, for instance to do source apportionment.

Odor concentration measurement with IOMSs is still not broadly available and probably will not be in the near future, since changes in odor composition influence the device output the same way or even more than changes to the odor concentration itself.

IMS is currently one of the most promising techniques used for IOMSs, since it combines a very sensitive sensor system with long-term stability and very short measurement cycles within the range of seconds.

Especially for IMS, the data handling is very complicated, since complex and nonlinear relationships between raw data (drift time spectra) and measurement parameters (odor concentration) must be evaluated. However, a lot of progress is expected within this field.

21.10 Further Readings

For further information on odors and olfactometric measurements see:

- Hangartner, M., et al.: Improved recommendations on olfactometric measurements, COST 681 working group *Odour Measurement*. In: Env. Techn. Letters **10**, 231–236 (1998)
- Buettner, A. (Ed.): Springer Handbook of Odor, Springer Handbooks, Springer International Publishing (2017)

Introductory publications on IOMSs include:

- Boeker, P.: Elektronische Nasen: Das methodische Konzept und seine Problematik. In: Gefahrstoffe; Reinhaltung der Luft **70**(7/8), 314–320 (2010)
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Ralf Petrich

IFU GmbH Privates Institut für Analytik
Frankenberg, Germany
ralf.petrich@ifu-analytik.de

Physicist Ralf Petrich received his PhD in the numerical evaluation of optical spectra. He has worked for NASA, Daimler-Benz, and the environmental office of the state of Saxony in Germany. Currently, he heads the development department at IFU GmbH, a private institute for analytics in Frankenberg, Germany. His primary fields of work are numerical modelling of pollution dispersion in ambient air and the development of technical approaches for odor measurement.

Axel Delan

IFU GmbH Privates Institut für Analytik
Frankenberg, Germany
axel.delan@ifu-analytik.de

Axel Delan is a physicist and managing director of IFU GmbH, a private institute for analytics in Frankenberg, Germany, that performs research and development on technical solutions for olfactometry. He has 25 years of experience managing an accredited and notified monitoring company for emissions and immissions of odors. Due to his wide experience, he works on international olfactometry standardization and is a publicly appointed and sworn authorized expert.