ENFORCEABLE PERMIT ODOR LIMITS

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ABSTRACT

Ambient air holds a mixture of chemicals from the everyday activities of industrial and commercial enterprises that make up modern day society. Exposure to those chemicals in the ambient air has become a part of modern day life. However, from time to time, citizens find the odors of these chemicals annoying and objectionable and at some point may declare them a nuisance.

Quantifying odors related to a facility is often needed for the following purposes:

1. Compliance monitoring (compliance assurance for permits),
2. Determination of compliance (permit renewal),
3. Determination of status (baseline data for expansion planning),
4. Determination of specific odor sources (investigation of complaints),
5. Verification of complaints (notice of violation),
6. Monitoring daily operations (management performance evaluations),
7. Comparison of operating practices (evaluating alternatives),
8. Monitoring specific events or episodes (defensible, credible evidence),
9. Verification of odor dispersion modeling (model calibration).

Objective measurement of odors is available and standardized for source emission air samples and for ambient air at the property line and in the community. Therefore, three basic odor limits may be incorporated into facility permits as "compliance determining criteria":

1. Ambient odor concentration limits.

2. Ambient odor intensity limits.

3. Source emission odor concentration limits.

The three basic limits are not mutually exclusive and are sometimes combined in one permit. This paper presents the viable options for enforceable permit odor limits.

INTRODUCTION

Community odors remain one of the top air pollution complaints to regulators and government bodies. From state to state and in communities across the United States odor issues are addressed by a variety of odor ordinances, odor rules, odor regulations, or odor policies. One effective odor policy includes placing enforceable odor limits as special conditions of facility permits. Since objective measurement of odors is available and standardized, three basic odor limits have been incorporated into facility permits as "compliance determining criteria".

- Ambient odor concentration limits
- Ambient odor intensity limits
- Source emission odor concentration limits

These basic limits are not mutually exclusive and are sometimes combined in one permit.

Odor is …

Of the five senses, the sense of smell is the most complex and unique in structure and organization. While human olfaction supplies 80% of flavor sensations during eating, the olfactory system plays a major role as a defense mechanism by creating an aversion response to malodors and irritants. This is accomplished with two main nerves. The olfactory nerve (first cranial nerve) processes the perception of chemicals. The trigeminal nerve (fifth cranial nerve) processes the irritation or pungency (sensation) of chemicals.

During normal nose breathing approximately 10% of inhaled air passes up and under the olfactory receptors in the top, back of the nasal cavity. When a sniffing action is produced, either an involuntary sniff reflex or a voluntary sniff, more than 20% of inhaled air is carried to the area near the olfactory receptors due to turbulent action in front of the turbinate bones. These receptors are ten to twenty-five million olfactory cells making up the olfactory epithelium in each nostril. Cilia on the surface of this epithelium have a receptor contact surface area of approximately five square centimeters due to the presence of many microvilli on their surface. Supporting cells surrounding these cilia secrete mucus, which acts as a trap for chemicals.

Chemicals in the air that are sniffed, pass by the olfactory epithelium and are dissolved (transferred) into the mucus at a rate dependent on their water solubility and other mass transfer factors. The more water-soluble the chemical, the more easily it is dissolved into the mucus layer. A “matching” site on the olfactory cells then receives certain chemicals. The response created by the reception of a chemical depends on the mass concentration or the number of molecules present. Each reception creates an electrical response in the olfactory nerves. A summation of these electrical signals leads to an “action potential.” If this action potential has high enough amplitude (a threshold potential), then the signal is propagated along the nerve, through the ethmoidal bone between the nasal cavity and the brain compartment where it synapses with the olfactory bulb.

All olfactory signals meet in the olfactory bulb where the information is distributed to two different parts of the brain. One major pathway of information is to the limbic system which processes emotion and memory response of the body. This area also influences the signals of the hypothalamus and the pituitary gland, the two main hormone control centers of the human body. The second major information pathway is to the frontal cortex. This is where conscious sensations take place, as the information is processed with other sensations and is compared with accumulated life experiences for the individual to possibly recognize the odor and make some decisions about the experience. The entire trip, from nostril to signal in the brain, takes as little as 500 milliseconds[1] [McGinley, M., 1999].

Odorants are …

The term "odor" refers to the perception experience when one or more chemicals come in contact with the receptors on the olfactory nerves and "stimulate" the olfactory nerve. The term "odorant" refers to any chemical in the air that is part of the perception of odor by "stimulating" the olfactory nerves. Odor perception may occur when one odorant (chemical) is present or when many odorants (chemicals) are present.

An analogy to help understand what is happening in the olfactory system is to envision the receptor nerves like keys on a piano keyboard. As a single odorant "hits" the piano keyboard, a tone is played. When multiple odorants are present in the ambient air the result is a "chord" or specific perception. For example, if keys '1', '3', and '7' are "hit" by a set of odorants, then the brain perceives "fishy". Likewise, if keys '4', '6', and '12' are "hit" by a different set of odorants, then the brain perceives "sewer." Also, several "like" odorants may "hit" the same key on the keyboard, say '10', and the brain perceives "sour". The greater the numbers of odorant molecules present (higher concentration), the louder the "chord" is played. The loudness of the "chord" is analogous to the intensity of the odor perception. [McGinley, M., 1999]

Frequently, and incorrectly, the two terms, "odor" and "odorant", are used interchangeably. There is a distinct difference in meaning and inference between the two terms, which is fundamental to the discussion of odor nuisance and odor measurement. "Odor" is perception and "odorant" is chemical.

Odor Effects

Citizens in communities near commercial activities, industrial sites, wastewater treatment plants, landfills, and agricultural operations have experienced non-specific symptoms. Citizens sometimes report that odors are making them sick. The symptoms reported include: headaches, nausea, reflex nausea, gastrointestinal distress, fatigue, eye irritation, throat irritation, shortness of breath, runny nose, sleep disturbance, inability to concentrate, and classical stress response.

An individual citizen's odor perception may consists of exposure to one or more odorants. Non-odorous chemicals may accompany these odorants. The exposure to one or more of the odorants or one or more of the accompanying non-odorous chemicals may follow a traditional toxicological paradigm, where different health outcomes are based on the concentration of the chemicals and the time factors of the exposure (frequency and duration). There may be a known sub-chronic, chronic, or acute health risk value for one or more of the chemicals. However, it is unlikely that health effects are well known for a combination of chemicals, whether they are odorants or non-odorous chemicals.[1]

Odor perception follows a paradigm different from the toxicological model. The concentration gradient of any odorant begins at a sub-threshold concentration. See Figure 1, Odorant Concentration Gradient for One Individual. As the concentration of the odorant increase the individual citizen may detect the presence of the odorant as sensation (trigeminal nerves) or odor perception (olfactory nerves). The citizen declares that the air is no longer the same as it was before (a minute before, five minutes before, an hour before, or yesterday). This is the detection threshold (DT) concentration of the odorant for that individual citizen[2] [ASTM E679-91, Para. 3.1.5 and 7.2]. At some higher concentration the individual citizen will recognize an "odor" character. This is the recognition threshold (RT) concentration of the odorant for that individual citizen[2] [ASTM E679-91, Para. 3.1.6 and 7.2].

Moving up the concentration gradient of the odorant, the individual citizen may reach some point where annoyance begins. This can be called the "annoyance threshold" (AT). This annoyance threshold may be below, but is most likely above, the recognition threshold (RT). The annoyance threshold depends on the individual citizen's memories, socio-economic background, health history, and general "well being" (i.e. physical well being, mental well being, etc.). The degree of annoyance typically increases with increasing concentration of the odorant. Since humans perceive odor according to the "power law"[3] [Stevens, 1960], odor strength (odor intensity) grows as a power function of the stimulus (odorant), not linearly. The power function is expressed in an equation as: $I = k C^n$, where I is perceived intensity, C is odorant mass concentration, k and n are constants, which are different for every odorant[4] [Stevens, 1962]. For example, twice the mass concentration may not cause a doubling of the perceived odor strength (odor intensity).

Another threshold on the odorant concentration gradient is a "health symptoms threshold" (HST). The individual citizen may reach some point on the concentration gradient of the odorant at which non-specific symptoms begin, such as headache, nausea, itchy eyes, etc. The “health symptoms threshold” can be higher on the odorant concentration gradient than the detection and recognition thresholds and may be higher than the annoyance threshold. The “health symptoms threshold" may be time and duration dependent (i.e. similar to the toxicological paradigm) and might be based on the individual's health history, body mass and other conditions of their body, i.e. immune system, general physical and mental "well being".

Figure 1. Odorant Concentration Gradient for One Individual

Increasing Mass Concentration

Odorant ——————————————————▶ **mg/m^3**

Odor (Perception) < < **DT** > > < < **RT** > >

Annoyance < < < < < < **AT** > > > > > >

Health Symptoms < < < < < < < < **HST** > > > > > > > >

This "Odorant Concentration Gradient" does NOT represent a toxicological model.

KEY:

mg/m^3 Mass concentration of odorant, milligrams per cubic meter.

DT Detection Threshold (ASTM E679-91, Para. 3.1.5 and 7.2)

RT Recognition Threshold (ASTM E679-91, Para. 3.1.6 and 7.2)

AT Annoyance Threshold (For this example of one individual's annoyance based on memories, socio-economic background, etc.)

HST Health Symptom Threshold (For this example of one individual's on-set of non-specific symptoms.)

PERMIT ODOR LIMITS

Objective measurement of odors is available and standardized for source emission air samples and for ambient air at the property line and in the community. Therefore, three basic odor limits may be incorporated into facility permits as "compliance determining criteria":

- Ambient odor concentration limits.
- Ambient odor intensity limits.
- Source emission odor concentration limits.

The three basic limits are not mutually exclusive and are sometimes combined in one permit.

Ambient Odor Concentration

Ambient odor concentration limits, such as detection thresholds, can be used in permits as criteria for defining compliance or determining non-compliance. Odor is measurable using objective, scientific methods. Odor testing has evolved over the past 40 years with changes in terminology, methods, and instrumentation. A clear understanding of "odor terminology" is needed in order to discuss the use of ambient odor concentration limits for permits. Odor terminology is linked to methods and instrumentation for odor measurement.

In 1958, 1959, and 1960 the U.S. Public Health Service sponsored the development of an instrument and procedure for field (ambient) odor measurement through Project Grants A-58-541; A-59-541; and A-60-541. The instrument, originally manufactured by Barnebey-Cheney Company and subsequently manufactured by Barnebey Sutcliffe Corporation, is known as a "Scentometer".

The original Scentometer produced four (4) dilutions and the modified Scentometer Model 1959-A produced six dilutions of the odorous ambient air by mixing the ambient air with carbon filtered air. The U.S. Public Health Service method defined the dilution factor as "Dilution to Threshold", D/T.

The method of producing "Dilution to Threshold" (D/T) with the Scentometer consists of mixing two "volumes" of carbon filtered air (two 1/2 inch holes, each leading to a carbon beds) with specific "volumes" of odorous ambient air (1/2, 1/4, 3/16, 1/8, 1/16, and 1/32 inch holes). See Figure 2, "Dilution to Threshold (D/T) with the Scentometer".

The method of calculating "Dilution to Threshold" (D/T) for the Scentometer is:

D/T = Volume of Carbon Filtered Air / Volume of Odorous Air

Figure 2. Dilutions to Threshold (D/T) with the Scentometer

Dilution to Threshold D/T	Carbon Filtered Air Volume *	Odorous Air Volume **	Odorous Air Inlet Size (in. dia.)
2	2	1	1/2
7	2	0.285	1/4
15	2	0.1333	3/16
31	2	0.0645	1/8
170	2	0.0118	1/16
350	2	0.0057	1/32

* Two 1/2 inch diameter holes for the "Carbon Filtered Air Flow Path".
** Odorous Air Volume calculated from the D/T column.[5] [Huey, 1960]

The Scentometer or a "Scentometer-like device" is referenced in a number of existing state odor regulations. The "Dilution to Threshold" (D/T) terminology and the method of calculating the D/T is likewise referenced in these odor regulations.

However, olfactometry in the field with a field olfactometer (Scentometer-like device) is inherently different from olfactometry in the odor laboratory. The field olfactometer method for measuring the ambient odor utilizes a portable dilution device (Scentometer-like device) in the hands of a trained air pollution inspector, trained plant operator, or trained professional or para-professional. The laboratory method for measuring ambient or source odor utilizes a laboratory olfactometer with a trained group of assessors (odor panelists).

In the early years of using the Scentometer[5] [Huey, 1960] the following categories were associated with D/T's:

D/T	**Word Category**
2	Noticeable
7	Objectionable
15	Nuisance
31	Nauseating

Permit Limits – Ambient Odor Concentration

The ambient odor concentration limit for a permit may define the compliance as *"… ambient air that is less than D/T (Dilution to Threshold)."* The exact wording is important and can be stated as a "compliance criteria" *("…compliance if…less that 7 D/T")* or a "nuisance criteria" *("…nuisance if…equal to or greater than 7 D/T").*

A practical example is, if the permit language uses D/T = 7 and, if the air pollution inspector <u>observed odor</u> with the field olfactometer set at 7 D/T, then the "nuisance criteria" odor was observed at that time **or** the ambient air was above the "compliance criteria".

The permit language would also define the number of observations that need to be made by the air pollution inspector and the time frame of the observations. For example: *"…three samples or observations in a one hour period separated by 15 minutes each…" or "…for 2 separate trials (field olfactometer) not less than 15 minutes apart within a 1-hour period…".*

An alternative to measuring the ambient odor concentration by a field inspector is to collect samples of the ambient air and send the samples to an odor laboratory for testing.

In the early years of odor testing in laboratories, the ASTM D-1391 syringe dilution technique measured odors in the laboratory from samples collected from the ambient air and used the "Scentometer" convention of calculating "dilution factors". However, since 1969 the method of calculating "dilution factors" changed to "Total Flow" divided by "Sample Flow". The change took place when ASTM D-1391 was improved by Benforado [1969] and the ASTM D-2 Task Force D [1977]. ASTM D1391 was subsequently "replaced" with ASTM E679-79, Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits. [Current edition approved on August 15, 1991, and published in October 1991, as ASTM E679-91][2].

The present convention of calculating "dilution factors" for laboratory olfactometers is different from the field olfactometer, "Scentometer Method". The present convention of calculating "dilution factors" for olfactometers is based on the ratio of "Total Flow" divided by "Sample Flow" [7 8 2 9 10] [Dravnieks, 1980 and 1986], [ASTM E679-91], [AWMA EE-6 DRAFT Guidelines, 1995], and [prEN 13725, 1999].

$$\text{Dilution Factor} = \frac{\text{Dilution Volume} + \text{Odorous Sample Volume}}{\text{Odorous Sample Volume}} = \textbf{'Z'}$$

"The dilution factor, 'Z', is used in modest honor of H. Zwaardemaker, a Dutch scientist and early investigator in olfactometry. Alternative terminology in use (1991): Dilution-to-Threshold Ratio (D/T or D-T); Odor Unit (OU); Effective Dose (ED)" [ASTM E679-91, Appendix][2].

However, in laboratory olfactometry the "dilution factor" ('Z') is not the value directly reported for the odor sample concentration. Laboratory olfactometry uses a group of assessors called "panelists"[ASTM E679-91]. Each panelist observes an odor sample in an ascending concentration series (increasing concentration). If a panelist does not detect an odor at Z = 16 but does detect an odor at Z = 8, then the panelist's individual "detection threshold" is calculated as the geometric mean between 16 and 8, which is 11. The statistical method is called the "best-estimate threshold" [ASTM E679-91].

$$(\log 16 + \log 8)/2 = (1.204 + 0.903)/2 = 1.054 \qquad \{10^{1.054} = 11\}$$

Then the group threshold of all the panelists is calculated as an average from the logarithm values (i.e. 1.054,…) of each individual panelist.

The detection threshold [ASTM E679-91, Para. 3.1.5 and 7.2][2] and recognition threshold [ASTM E679-91, Para. 3.1.6 and 7.2][2] of an odor sample are derived using "dilution ratios" and the "best-estimate criteria" and, therefore, are dimensionless. However, the pseudo-dimensions of "Odor Units" (O.U.) or "Odor Units per Unit Volume" are commonly applied. For example: "Odor Units per Cubic Meter". The abbreviations for "detection threshold" (DT) and "recognition threshold" (RT) are sometimes used in order to clarify which 'Z' value is being reported by the odor laboratory.

Samples of ambient air can be collected in Tedlar gas sample bags and sent to an odor laboratory for testing using a laboratory olfactometer. Any permit that specifies an ambient odor concentration limit, i.e. threshold (D/T, DT, RT, "Odor Units") must also specify the method of measurement, i.e. field olfactometer ("Scentometer-like device) or laboratory olfactometer and the testing standard(s), i.e. ASTM E679-91 and prEN13725.

Ambient Odor Intensity

Odor intensity of the ambient air can be measured objectively using an "Odor Intensity Referencing Scale" (OIRS) [ASTM E544-99][11]. Odor intensity referencing compares the odor in the ambient air to the odor intensity of a series of concentrations of a reference odorant. A common reference odorant is n-butanol. Secondary butanol is an alternative to n-butanol for a standard referencing odorant[12] [Anderson, 1995]. The air pollution inspector, plant operator, or odor monitor observes the odor in the ambient air and compares it to the OIRS. The person making the observation must use a carbon-filtering mask to "refresh" the olfactory sense between observations (sniffing). Without the use of a carbon-filtering mask, the observer's olfactory sense would become adapted to the surrounding ambient air or become fatigued from any odor in the surrounding air[13] [McGinley, et al, 1995]. The adaptation of an observer's olfactory sense is a common phenomenon when attempting to evaluate ambient odors, i.e. a wastewater treatment plant operator monitoring treatment plant odors "off-site".

ASTM E544-99, "Standard Practice for Referencing Suprathreshold Odor Intensity", presents two methods for referencing the intensity of ambient odors: Procedure A - Dynamic-Scale Method and Procedure B - Static-Scale Method. Field inspectors commonly use the Static-Scale Method and it has become incorporated as a standard of practice by a number of odor laboratories, because of its low cost of set-up compared to a dynamic-scale olfactometer device (Procedure A).

Using the OIRS, the intensity of the observed ambient air is expressed in "parts per million" (PPM) of n-butanol (or sec-butanol). A larger value of butanol means a stronger odor, but not in a simple linear proportion. Odor perception is a psychophysical process and follows the "power law" [3] [Stevens, 1960]. For example, an increase in butanol concentration by a factor of two (2) results in an odor that is less than twice as intense.

An important aspect of using a butanol intensity referencing scale is knowing that a variety of scales are available. Common butanol static-scales include:

- ✓ 12-point static-scale starting at 10-ppm butanol with a geometric progression of two;
- ✓ 10-point static-scale starting at 12-ppm butanol with a geometric progression of two;
- ✓ 5-point static-scale starting at 25-ppm butanol with a geometric progression of three;

The OIRS serves as a standard practice to quantify the odor intensity of the ambient air objectively. To allow comparison of results from different data sources and to maintain a reproducible method, the equivalent butanol concentration is reported or the number on the OIRS is reported with the scale range and starting point.

An example 5-point OIRS with a geometric progression of three is:

Reference Level	n-Butanol PPM in Air
0	0
1	25
2	75
3	225
4	675
5	2025

Field air pollution inspectors (field odor inspectors), using a standard odor intensity referencing scale (OIRS), can provide measured, dependable, and repeatable observations of ambient odor intensity[13] [McGinley, 1995].

Permit Limits – Ambient Odor Intensity

The ambient odor intensity limit of a permit may define a violation of an ambient odor intensity limit if: *"…the geometric average of ten (10) observations of the ambient air over a period of 30-minutes yields an OIRS value of 2.0 (75-PPM n-butanol) or greater if there is a permanent residence upon the property, or 3.0 (225-PPM n-butanol) or greater if the property does not contain a permanent residence."*

The exact wording is important and can be stated as a "compliance criteria" or a "violation criteria".

Source Emission Odor Concentration

Odors from a facility's emission sources may be sampled and tested to determine the odor concentrations. Point, area, and volume emission sources can all be sampled and tested to determine the odor concentration as odor thresholds (detection, DT, and recognition, RT).[2 9 10] [ASTM E679-91, AWMA EE-6, and prEN13725] The result of sampling and testing would be an "odor emission inventory" or an "odor control system performance test".[14]

Permit Limits – Source Odor Concentration

The facility's permit may place odor concentration limits on the emission sources. An example odor concentration limit for an odor control scrubber is 250 (odor units, detection threshold) using olfactometry in accordance with ASTM E679-91 and prEN13725.[2 10]

A permit might also require a facility to conduct periodic source sampling and odor testing to verify compliance. The permit might further require air dispersion modeling (odor modeling) to estimate the ambient odor concentrations at the facility's fence line and in the community. A method of "back-calculating" from ambient odor limits, i.e. 5 "odor units" detection threshold, can be used to set source emission odor concentration limits. The "back-calculating" method would yield a maximum odor concentration (detection threshold, DT) at the emission source. If ambient odor limits are exceeded, the permit might require a facility to develop an odor reduction plan to reduce odor emissions at the source, based on the odor dispersion modeling.

CONCLUSIONS

Quantifying odors related to a facility is often needed for the following purposes:

1. Compliance monitoring (compliance assurance for permits),
2. Determination of compliance (permit renewal),
3. Determination of status (baseline data for expansion planning),
4. Determination of specific odor sources (investigation of complaints),
5. Verification of complaints (notice of violation),
6. Monitoring daily operations (management performance evaluations),
7. Comparison of operating practices (evaluating alternatives),
8. Monitoring specific events or episodes (defensible, credible evidence),
9. Verification of odor dispersion modeling (model calibration).

Community odors remain one of the top air pollution complaints to regulators and government bodies. From state to state and in communities across the United States odor issues are addressed by a variety of odor ordinances, odor rules, odor regulations, or odor policies. One effective odor policy includes placing enforceable odor limits as special conditions of facility permits. Since o<u>bjective</u> measurement of odors is available and standardized, three basic odor limits have been incorporated into facility permits as "compliance determining criteria”.

- Ambient odor concentration limits
- Ambient odor intensity limits
- Source emission odor concentration limits

These basic limits are <u>not</u> mutually exclusive and are sometimes combined in one permit. The limits are measurable using scientific methods, and, therefore, are verifiable and enforceable.

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