Elements of Successful Odor / Odour Laws

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ABSTRACT

The search for the perfect "odor (odour, *the international English spelling*) regulation" most likely began a few thousand years ago in a community that smelled something annoying. That search continues today in societies throughout the world. However, different societies have inherently different levels of acceptance for odors in their communities.

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.

Community odors remain one of the top air pollution complaints to regulators and government bodies. An odor nuisance usually is a result of a series of odor episodes experienced by a citizen or citizens. The frequency of these episodes, the duration of each odor episode, the intensity of the odors, and the character or offensiveness of the odors all contribute to the nuisance experience.

From state to state, in communities across the United States, and in other countries odor issues are addressed by a variety of "odor laws", whether they are called an ordinance, rule, regulation, or policy. An “odor law” is effective if, and only if; the odor law uses a criterion or criteria to define compliance. The “odor laws” address community odor issues in several well defined approaches that utilize “compliance determining criteria”: annoyance criteria (subjective categories and complaint criteria), ambient odor criteria (threshold or intensity), ambient odorant criteria (mass concentration, i.e. milligram per cubic meter, mg/m^3), episode duration-frequency criteria, source emission criteria (threshold or mass concentration), and best available control technology criteria (i.e. industry standard). The various approaches are not mutually exclusive and are sometimes combined in one "odor law".

Underlying the "approaches" to odor laws are the basic elements that have been placed into successful regulations of air pollutants other than odors. However, these elements must be adapted and formulated for an "odor law". Programs to educate and infrastructure to guide and administer the "odor law" are needed to support the community, whether it is state, county, or local jurisdiction.

Keywords: odor, odour, laws, rules, regulations, ordinances, annoyance, nuisance

INTRODUCTION

The search for the perfect "odor/odour regulation" most likely began a few thousand years ago in a community that smelled something annoying. That search continues today in societies throughout the world. However, different societies have inherently different levels of acceptance for odors in their communities.

In the United States odor is not an EPA regulated pollutant and, therefore, states and local jurisdictions have attempted or are attempting to regulate odors. In the absence of "odor laws", citizens and communities often find remedies and relief in basic "common-law" nuisance law suits. However, exclusions and exemptions, such as "right-to-farm" laws, can sometimes make nuisance actions difficult and expensive to win.

From state to state, in communities across the United States, and in other countries odor issues are addressed by a variety of "odor laws", whether they are called an ordinance, rule, regulation, or policy. An “odor law” is effective if, and only if; the "odor law" uses a criterion or criteria to define compliance. Odor laws address community "odor issues" in several well-defined approaches that utilize “compliance determining criteria”:

1) Annoyance criteria (subjective categories),
2) Complaint criteria (numbers of complaints),
3) Ambient odor detection threshold criteria,
4) Ambient odor intensity criteria,
5) Ambient odorant criteria (mass concentration, i.e. milligram per cubic meter, mg/m^3)
6) Episode duration-frequency criteria (“odor-hours”)
7) Source emission criteria (threshold or mass concentration), and
8) Best available control technology criteria (i.e. industry standard).

The various approaches are not mutually exclusive and are sometimes combined in one "odor law".

Underlying the approaches that utilize various compliance determining criteria for "odor laws", are the basic elements that have been placed into successful regulations of air pollutants other than odors. However, these elements must be adapted and formulated for an "odor law". Therefore, a number of successful elements of "odor laws: have been developed. Examples of the necessary elements are:

1. Purpose statement
2. Authority source
3. Definitions
4. Jurisdiction identified
5. Complaint verification
6. Low density population
7. Abnormally sensitive population
8. Compliance criteria (i.e. standards and limits)
9. Notices of violation
10. Penalties

11. Remedies
12. Appeals
13. Permitting
14. Exclusions
15. Modeling
16. Limitations

Programs to educate and infrastructure to guide and administer the "odor law" are needed to support the community, whether it is state, county, or local jurisdiction.

BACKGROUND

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. [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 laws". "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.

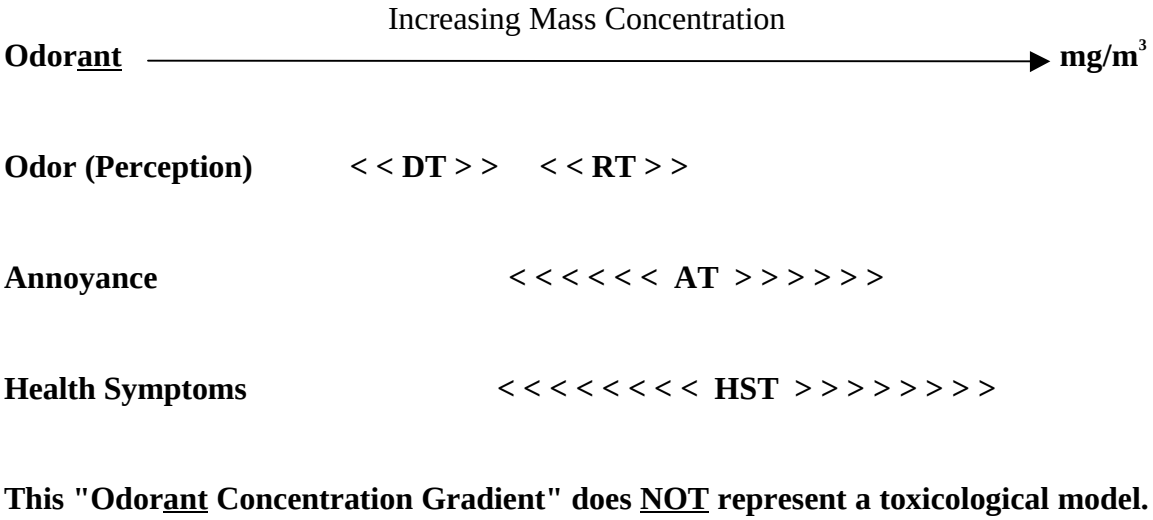
An individual citizen's odor perception may consists of exposure to one or more odorants. Non-odorous chemicals may accompany these odorants. The exposure to one or more of the odorants or one or more of the accompanying non-odorous chemicals may follow a traditional toxicological paradigm, where different 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.

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 [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 [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" [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 [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" is probably time and duration dependent (i.e. similar to the toxicological paradigm) and would 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



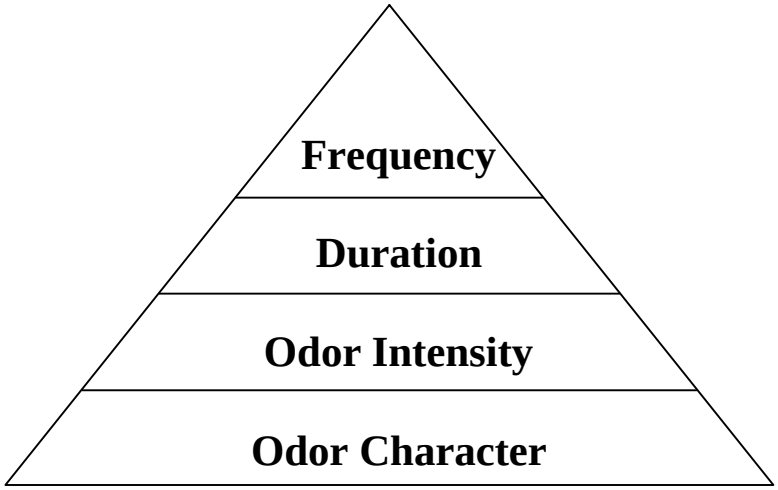
KEY:

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.)

Odor Nuisance

A conceptual model for what leads to an odor nuisance is the "Citizen Complaint Pyramid" (See Figure 2) which starts and builds with "Odor Character", Odor Intensity", "Episode Duration", and "Episode Frequency". The cumulative effect of these four building blocks creates the nuisance experience that may yield a citizen complaint.

Figure 2. Citizen Complaint Pyramid



The first building block of the complaint pyramid is "Odor Character", the actual description of what the odor “smells like.” Odor character is sometimes called the “quality” of the odor or the "offensiveness" of the odor. More offensive odors will be more annoying. Citizens often describe odors with qualifying words, such as bad, stink, awful, dreadful, terrible, gagging, etc., which are not actually descriptive of the odor character. Odors can be characterized using a referencing vocabulary for the "Taste", "Sensation", and "Odor" that is perceived by the individual observer, i.e. citizen, plant operator, trained inspector, or air pollution investigator. Odor character is a nominal (categorical) scale of objective measurement. Odor character differs from the "Hedonic Tone" of the perceived odor. Hedonic Tone is a measure of the pleasantness or unpleasantness of an odor. The assigning of an Hedonic Tone value to a perceived odor by an observer is subjective to the observer, because it relies on personal feelings, beliefs, memories, and life experiences. The assigning of an "Odor Character" to a perceived odor by an observer is objective, if the observer uses a "standard" categorical scale of odor descriptors.

“Odor Intensity” is the second building block of the complaint pyramid and refers to the overall strength of the perceived odor. The more intense the odor, the more likely an individual citizen will be annoyed. Even pleasant odors such as perfumes can be very annoying at high intensities and, conversely, offensive odors such as "fishy" can be very annoying at low intensities.

Perceived odor intensity is the relative strength of the odor above the recognition threshold (suprathreshold, as defined in ASTM E544). ASTM E544-75 (1988), "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. Both methods use a series of increasing concentrations of a standard odorant, butanol. Field odor investigators, monitors, and plant operators commonly use the Static-Scale Method to reference the ambient odor intensity at a facility's fence line or at various points in the surrounding community. The odor intensity reported by the field observer is expressed in parts per million (PPM) of butanol (n-butanol or sec-butanol). The butanol "Odor Intensity Referencing Scale" (OIRS) is an objective measure of ambient odor intensity. [NOTE: Observed intensity values are not directly used in odor dispersion modeling, however, some researchers use intensity values along with other data in the interpretation of odor dispersion modeling.]

"Duration", the third building block of the complaint pyramid, is the elapsed time of each separate odor episode. An odor episode is a period of time in which odorants are transported down wind to citizens and are perceived as odor. Longer duration odor episodes can cause a citizen to make changes in activities or make changes in plans on their property or in the community. Odor episodes of short duration may be annoying but expire before the citizen adjusts activities or plans. Odor episode duration is an objective time measurement.

The final, "capping", building block of the complaint pyramid is the odor episode's "Frequency", which refers to how often the citizen experiences odor episodes of any type. The more frequent that odor episodes intrude into a citizen's life, the more annoying each odor episode experience becomes.

APPROACHES TO ODOR LAWS

An "odor law" is effective if, and only if; the "odor law" uses a criterion or criteria to define compliance. The criteria need not be purely or scientifically "objective". However, objective measurements of odor are available and standardized, and therefore, may be incorporated into "odor laws".

The basic approaches to utilizing "compliance determining criteria" are:

1) Annoyance criteria (subjective categories),
2) Complaint criteria (numbers of complaints),
3) Ambient odor detection threshold criteria,
4) Ambient odor intensity criteria,
5) Ambient odorant criteria (mass concentration, i.e. milligram per cubic meter)
6) Episode duration-frequency criteria ("odor-hours")
7) Source emission criteria (threshold or mass concentration), and
8) Best available control technology criteria (i.e. industry standard).

The various approaches are not mutually exclusive and are sometimes combined in one "odor law".

Annoyance Criteria

Annoyance determining criteria often uses a single statement that defines "nuisance". These types of "nuisance definitions" have successfully "stood the test of time". An example statement defining a community nuisance is:

"Anything which is injurious to health, or indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property, is a nuisance." [Minnesota Statutes, Section 561.01, 1976]

Nuisance law criteria vary from community to community and from state to state. Additional examples include: [Mahin, et al., 1999]

"…air contaminants (including odor) in quantities and duration to injure human health and welfare." [Alabama]

"…unreasonably interfere with enjoyment of life and property." [Alaska]

"…unreasonable interferes with the comfortable enjoyment of life or property of a substantial part of the community." [Arizona]

"…which causes injury, detriment, nuisance, or annoyance to any considerable number of persons or to the public (agricultural odor exempt)." [California]

"...Odor constitutes a nuisance if it unreasonably interferes with the enjoyment of life or use of property." [Connecticut]

"…odors beyond his property…to create a public nuisance… defined includes affecting a considerable number of persons and injurious to health or interfere with the comfortable enjoyment of life and property." [Montana]

The examples illustrate the variation in wording and "sub-criteria". Sub-criteria might include the requirements that the nuisance must be acting on more than one person, i.e. public nuisance.

Word categories, for defining odor annoyance and defining objectionable odor, aid in the interpretation of “odor nuisance”. Air pollution inspectors assigned to “nuisance determination” have used the following “odor referencing word categories”:

Strength Categories:

0. No Odor
1. Very Faint
2. Faint
3. Noticeable
4. Strong
5. Very Strong

Intensity Categories:

0 No Odor
1 Barely Perceivable (Detection Threshold)
2 Faint but Identifiable (Recognition Threshold)
3 Easily Perceivable
4 Strong
5 Repulsive

Annoyance Categories:

1. Not Annoying
2. A Little Annoying
3. Annoying
4. Very Annoying
5. Extremely Annoying

Nuisance Categories:

1. An odor that would ordinarily not be noticed by the average person but could be detected by the experienced inspector or hypersensitive individual.
2. An odor, so weak, that the average person might detect it if attention was called to it but would not otherwise attract attention.
3. An odor of moderate intensity that would be readily detected and would be regarded with disfavor.
4. An odor that would force itself upon the attention of the average person and that would make the air very unpleasant.
5. An odor of such intensity that the air would be absolutely unfit to breath.

Objectionable Categories:

0. Odor not detectable.
1. Odorant present in the air, which activates the sense of smell but the characteristics, may not be distinguishable.
2. Odorant present in the air, which activates the sense of smell and is distinguishable and definite but not necessarily objectionable in short durations but may be objectionable in longer durations.
3. Odorant present in the air, which easily activates the sense of smell, is very distinct and clearly distinguishable and may tend to be objectionable and/or irritating.
4. Odorant present in the air, which would be objectionable and cause a person to attempt to avoid completely, could indicate a tendency to possibly produce physiological effects during prolonged exposure.
5. Odorant present, which is so strong, it is overpowering and intolerable for any length of time and could tend to easily produce some physiological effects.

Complaint Criteria

Citizen complaints form the basis of "odor nuisance". The conceptual model of the "Citizen Complaint Pyramid", presented in Figure 2, illustrates the hierarchy of the nuisance experience. An "odor episode" may cause a citizen to complain to a local or state authority.

In order for the regulating authority to determine that a community annoyance or nuisance exists, the "odor law" for the community would contain specific criteria for complaints. A minimum number of complaints may be required, from a minimum number of different households, within a specific period of time, for the authority to declare that a nuisance exists. Additionally, a minimum number of the complaints may need to be "confirmed" or "verified" by the authority or by an agent of the authority. For example: *"…at least 10 independent complaints …and the total number of complaints include at least 5 different households (or places of business) …all of the independent complaints were made within a 90 day period …at least 5 of the independent complaints were confirmed (verified) through an inspection by a representative or agent…"* [Minnesota DRAFT "Odor Rule", 8/23/94].

The community (authority) must decide if an individual citizen or a small group of citizens have the "right" to be protected from "unreasonable odor". Language in an “odor law” that requires a minimum number of complainant “households” might implicitly exclude one citizen’s complaint. Likewise, a low-density population area may find it difficult to meet a “complaint number” criterion. Persuasive arguments for the protection of low-density populations and abnormally sensitive citizens call for language in "odor laws" that will include protection of these populations. [Prokop, Mitchell, Mulvaney, 1978]. For example: *"…the authority may accept less than the minimum numbers required … provided that a detailed request for the relaxed requirement is included with the complaint…"*

The "odor law" may also require establishment of: [DesMoines, Iowa, Subchapter 8]

1) An "odor hotline" for the receipt of telephone odor complaints.
2) Specific complaint forms for use by the authority.
3) Odor inspector training.
4) Inspection and complaint verification procedures.
5) Procedures to inform the complainants of the inspection results.
6) A "Citizen Odor Board" for the review of complaint records.
7) Procedure to notify owner(s) of alleged odor source(s).

Ambient Odor Criteria - Detection Thresholds

Ambient odor limits, such as detection thresholds, can be used 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 criteria for "odor laws". 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 3, "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 3. 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. [Huey, 1960]

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

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.

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

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

The ambient odor criteria of an "odor law" 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") [Wyoming] or a "nuisance criteria" ("…nuisance if…equal to or greater than 7 D/T") [Kentucky].

A practical example is, if the "odor law" uses D/T = 7 and, if the air pollution inspector observed odor 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 "odor law" 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…" [Connecticut] or "…for 2 separate trials (field olfactometer) not less than 15 minutes apart within a 1-hour period…" [Missouri].

Therefore, a field olfactometer (Scentometer-like device) is a realistic alternative to ambient odor samples collected and sent 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 at the odor source 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].

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" [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].

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 = 1000 but does detect an odor at Z = 500, then the panelist's individual "detection threshold" is calculated as the geometric mean between 1000 and 500, which is 707. The statistical method is called the "best-estimate threshold" [ASTM E679-91].

$$(\log 1000 + \log 500)/2 = (3.0 + 2.7)/2 = 2.85$$

$$\{10^{2.85} = 707\}$$

Then the group threshold of all the panelists is calculated as an average from the logarithm values (i.e. 2.85,…) of each individual panelist.

The detection threshold [ASTM E679-91, Para. 3.1.5 and 7.2] and recognition threshold [ASTM E679-91, Para. 3.1.6 and 7.2] 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 "odor law" that specifies an ambient odor threshold (D/T, 'Z', DT, RT, "Odor Units", etc.) must also specify the method of measurement, i.e. field olfactometer ("Scentometer-like device) or laboratory olfactometer.

Ambient Odor Criteria - Odor Intensity

Odor intensity of the ambient air can be measured objectively using an "Odor Intensity Referencing Scale" (OIRS) [ASTM E54475, 88]. 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. Sec-butanol is an alternative to n-butanol for a standard referencing odorant [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 [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 E544-75, 88, "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" [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 [McGinley, 1995].

The ambient odor intensity criteria of an "odor law" may define a violation of an ambient odor intensity standard if …(the geometric average of) ten (10) observations of the ambient air over a period of 30-minutes… OIRS value of 3.0 (225-PPM n-butanol) or greater if there is a permanent residence upon the property, or 4.0 (675-PPM n-butanol) or greater if the property does not contain a permanent residence [Maplewood, 1994]. The exact wording is important and can be stated as a "compliance criteria" or a "nuisance (violation) criteria".

Ambient Odorant Criteria - Mass Concentrations

Ambient odorant criteria specify mass concentration levels (i.e. milligrams per cubic meter, mg/m^3) for one or more individual compounds. The use of mass concentration criteria presumes that the individual odorants are surrogates for all the odorants in the ambient air.

Odors from sources may or may not correlate with specific chemical compounds in the odorous emission. One or two individual compounds may misrepresent odorous emissions that contain many chemical compounds.

Odorant (individual chemical compounds) that are known to be toxic, hazardous, or have health risk values need to be regulated separately and independently from an "odor law". However, some jurisdictions use ambient odorant criteria not withstanding the limitations described above [California, Connecticut, New York, Washington].

Episode Duration-Frequency Criteria

The conceptual model, "Citizen Complaint Pyramid", acknowledges the importance of the "duration" and "frequency" of odor episodes. "Duration" is the elapsed time of each separate odor episode and "frequency" refers to how often the citizen experiences odor episodes of any type.

An odor episode may include a number of short periods of time the odor is perceived by a citizen at a specific location. The variability in wind direction may cause the odor to be perceived intermittently during an odor episode. Odor dispersion modeling may not accurately predict the length and related severity (intensity) of an odor episode because of the averaging time of the model. Most air dispersion models calculate one-hour average concentrations. However, a person's sense of smell has the ability to detect short periods of odor, such as one-minute or less. A number of short periods (one-minute to three-minute periods) of perceived odor may constitute an odor episode to the person (citizen). Therefore, the duration of an odor episode needs to be based on the record keeping of the observer(s), such as citizen complaint calls, citizen notes or logbooks, or air pollution inspector observations and data collection.

An "odor law" might define the maximum permissible length of an odor episode and the maximum permissible number of odor episodes within a specific time period. When maximum episode lengths and episode numbers are specified, the "odor law" acknowledges that 100% "odor free" ambient air is unrealistic for the community. A community might need to acknowledge that "some" odor is acceptable. The question the community then addresses is the "level of odor acceptance" that is achievable.

The concepts of "Odor-Hour" and "Odor Acceptance Goals" are included in "odor laws" when complaint number criteria (i.e. 10 complaints) within times periods (i.e. 90-days) are specified [Minnesota DRAFT "Odor Rule", 8/23/94]. An "odor law" may, alternatively, use short time periods for complaint criteria (i.e. 10 complaints within a six hour period) [DesMoines, Iowa, Subchapter 8].

When ambient odor threshold or odor intensity criteria are used in an "odor law", the duration-frequency criteria become shorter. The "Odor-Hour" then is defined, de facto or specifically, as the length of observation time by the field inspector and the number of observations needed within a time period (i.e. ten observations of the ambient air over 30-minutes) [Maplewood, 1994].

An "Odor-Hour" might be defined as:

- Three 10-minute periods of "Excess Odor" in one hour, or
- One 15-minute periods of "Excess Odor" in one hour, or
- Two 15-minute period of "Excess Odor" in one hour, or
- One 30-minute period of "Excess Odor", etc.

An "odor law" might define "Excess Odor" as the average of, i.e. 10 observations:

- Exceeding 7 D/T using a "Scentometer-like device"
- Exceeding 225 PPM n-butanol equivalent using the OIRS, Odor Intensity Referencing Scale.

The community might set an odor "Acceptance Goal" by using "Odor-Hour" criteria:

	Maximum Acceptable "Odor-Hours"		
% Acceptance	Per Day	Per Week	Per Month
90%	3	16	72
95	2	8	36
98	1	4	15

The concept of "Odor-Hours" and "Acceptance Goals" is consistent with the concepts of "compliance status", "compatibility" of various activities in a community, and the inherent variability of weather that affects source emissions.

Source Emission Criteria - Odor Thresholds

In 2000 the European Union (European Community) may follow a new standard, prEN 13725, "Air Quality - Determination of Odour Concentration by Dynamic Olfactometry" (prEN refers to a proposed European Normalization Standard - the "pr" will be removed if the draft is accepted after review and incorporation of comments). The following countries are bound by the CEN/CENELEC (European Committee for Standardization: “Comite Europeen de Normalisation”) International Regulations to implement European Standards: Austria, Belgium, Denmark, Finland, France, Greece, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

“prEN 13725” may be adopted or adapted in Australia, Canada, New Zealand, and much of the Pacific Rim. Therefore, "prEN 13725" may become the de facto International Standard for odor testing. In the United States the following universities and sanitation districts practice the basic tenets of prEN 13725: Duke University, Iowa State University, University of Minnesota, Purdue University, LA County Sanitation, and Minnesota Metropolitan Council.

The Air & Waste Management Association (AWMA) EE-6 Subcommittee on the Standardization of Odor Measurement developed a set of draft "Guidelines for Odor Sampling and Measurement by Dynamic Dilution Olfactometry" [AWMA EE-6, Second Revision, November 1995]. The basic tenets of the draft EE-6 Guidelines agree with the prEN 13725 draft, except for the recommended air (odor) presentation flow rate to the panelist (assessor). The EE-6 Guidelines recommends a maximum flow rate of 10-liters per minute and the prEN 13725 recommends a flow rate of 20-liters per minute.

Standard sampling and testing methods can determine the odor thresholds (detection, DT, and recognition, RT) of a facility's point, volume and area sources. [ASTM E679-91, AWMA EE-6, and prEN13725]. An "odor law" might require a facility to conduct source sampling and odor testing. The result of sampling and testing would be an "odor emission inventory".

The "odor law" might further require air dispersion modeling (odor modeling) to estimate the ambient odor concentrations at the facility's fence line and in the community.

The "odor law" might further require a method of "back-calculating" from ambient odor criteria, i.e. 5 "odor units" detection threshold. The "back-calculating" method would yield a maximum odor concentration (detection threshold, DT) at the emission source. The "odor law" might then require a facility to develop a compliance plan to reduce odor emissions at the source, based on the odor dispersion modeling [Massachusetts].

Best Available Control Technology (BACT) Criteria

"Odor laws" may require specific types of odor control technology for specific types of facilities. The "new source performance" criteria utilized by regulatory agencies provide a guide for writing and implementing BACT criteria. Alternative terminology may be incorporated in the performance criteria, such as "maximum achievable control".

BACT and performance criteria for "odor laws" may be industry specific or may be process specific. Industry standards for process management, operation, and control may be incorporated in BACT or performance criteria. Specific industries and specific facilities may disagree with the BACT or performance criteria requirements of an "odor law". Persuasive arguments for the exemption of certain industries or the exemption of a facility for "economic" or other exceptional reasons call for language in "odor laws" that will provide an administrative procedure for issuing a "variance" [Massachusetts].

ODOR LAW INFRASTRUCTURE

The development and implementation of an "odor law" requires a scientific and an administrative infrastructure. Adequate regulatory resources are critical if the "odor law" is detailed and relies on on-going involvement of the regulatory agency staff (i.e. active enforcement and facility permitting). The planning and implementation of odorous emission sampling, odor testing, ambient odor monitoring, and related chemical testing are as essential as the administration of the "odor law". The foundations of the "odor law" infrastructure include:

1) Odor Complaint "Hot Line"
2) Air Pollution Inspectors with Supplemental Odor Inspection Training
3) Administrative Procedure for Odor Complaint Review
4) Odor Testing Laboratory
5) Chemical Testing Laboratory
6) Odor Modeling Capabilities
7) Procedure for Odor Prevention and Odor Control Technology Review

The enforcement of an "odor law" follows one of two basic paths:

1. Review of a proposed facility's construction or expansion.

A regulating agency needs to apply appropriate engineering review of a proposed facility's construction or expansion, including the review of odor prevention, management and operation plans. The engineering review also requires appropriate odor dispersion modeling and interpretation of the forecasted odor in the surrounding community.

2. Determination of a facility's compliance status or implementation of compliance plans.

A regulatory agency will effectively and accurately determine a facility's compliance status or identify a facility as the probable cause for a community odor nuisance with a program that includes:

1. Reviewing historical information available from the community.
2. Compiling odor complaint records.
3. Conducting surveillance or field monitoring by the agency.
4. Reviewing odor-monitoring data collected by the facility.
5. Inviting or requiring the facility to conduct an odor emission inventory of sources with odor testing.
6. Requesting or requiring an odor reduction/compliance plan.
7. Continuing odor monitoring by the agency and/or facility.
8. Requiring performance verification of the compliance plan and/or odor control equipment with testing and monitoring.

THE ODOR LAW

Composing the "odor law" requires careful review of all local, state, and national laws that may limit or restrict components of the entire "odor law". The following example elements of "odor laws" and comments about specific sections of "odor laws" provide guidance without guarantee of suitability to a specific jurisdiction or community.

Purpose Statement

An example "Purpose Statement" is: "*…for the purpose of promoting the health, safety, and welfare of the community and in order to maintain compatibility of land uses and values of property…"*

Authority Source

An example "Authority Source" statement is: *"...is authorized to establish air quality standards…adopt land use controls…pursuant to…statutes…"*

Definitions

The following are typical words and terms defined in "odor laws":

- Ambient Air
- Best Available Control Technology (BACT)
- Community
- Community Annoyance
- Compliance Plan
- Emission
- Emission Point
- Field Inspector
- Independent Complaint
- Notice of Violation
- Odor
- Odor Detection Threshold
- Odor Dilution Factor
- Odor Pollution
- Odorous Emission
- Nuisance Odor
- Significant Odor Generator/Source
- Validated Odor Complaint

Jurisdiction Identified

Clearly defining the jurisdiction of the authority and the "odor law" will minimize conflicts with adjoining jurisdictions and excluded land. Frequently "joint powers authority" between two or more jurisdictions address situations with facilities near boundaries.

Complaint Verification

An example "Complaint Verification" statement is: *"…confirmed by or through an inspection/investigation of a representative or agent of the local unit of government…"* Sometimes the "odor law" requires a minimum number of the complaints to be verified.

Low Density Population

Special consideration, "odor law" language, and administrative procedures are required for less populous areas within the jurisdiction.

Abnormally Sensitive Population

The authority may need to consider administrative procedures that will include or exclude special cases where "abnormally sensitive" citizens reside or are present during portions of the day. Examples of "abnormally sensitive" populations include: infants, young children, senior citizens, hospital patients, hospice residents, and hypersensitive individuals.

Standards and Limits (Compliance Criteria)

An "odor law" is effective if, and only if; the "odor law" uses a criterion or criteria to define compliance. The criteria need not be purely or scientifically "objective" (i.e. annoyance criteria). However, objective measurements of odor are available and standardized, and therefore, may be incorporated into "odor laws".

The basic approaches to utilizing "compliance determining criteria" are:

1) Annoyance criteria (subjective categories),
2) Complaint criteria (numbers of complaints),
3) Ambient odor detection threshold criteria,
4) Ambient odor intensity criteria,
5) Ambient odorant criteria (mass concentration, i.e. milligram per cubic meter)
6) Episode duration-frequency criteria ("odor-hours")
7) Source emission criteria (threshold or mass concentration), and
8) Best available control technology criteria (i.e. industry standard).

The various approaches are not mutually exclusive and are sometimes combined in one "odor law".

The associated objective measurements of odor testing methods include:

- ASTM E679-91 Odor Threshold Determination
- prEN 13725 Odor Threshold Determination (DRAFT)
- ASTM E544-75,88 Odor Intensity Measurement
- AWMA EE-6 Odor Sampling & Measurement (DRAFT)

Notices of Violation

The "odor law" could describes the type and format of the "Notice of Violation" (NOV) with the requirements for compiling the supporting data, procedures for delivering the NOV, and the timing for the required acknowledgement from the facility owner, manager, or operator. Some jurisdictions or regulatory agencies have a separate "law" or "rule" that defines the "Notice of Violation" (NOV) procedure.

Penalties

Specific penalties may be included in the "odor law" for administrative or judicial purposes.

Remedies

The "odor law" typically provides a clear path for the facility to prepare, present, and implement an odor reduction or compliance plan. The authority often recognizes the dual importance of a "nuisance free" community and economic factors within the community.

Appeals

Administrative and judicial appeals are often part of odor nuisance actions. With the "odor law" providing an appeal process with administrative hearings, the facility, authority, and community have the opportunity to explore the data available and discuss common and opposing interpretations.

The City of DesMoines, Iowa, uses a "Citizen Odor Appeals Board" to hear a facility's first appeal. The "Appeals" section of the DesMoines odor law [Subchapter 8, Odor Pollution Prohibited] defines the appeals board and the process for filing and presenting the appeal.

Permitting

The "odor law" may or may not include an administrative process for permitting facilities. The permitting process of an "odor law" may be "activated" when a facility is identified as a "probable" nuisance or when a facility's features or processes cause it to be placed in a category defined by the "odor law", i.e. "non-conforming" or "significant odor generator" [DesMoines, Iowa, Subchapter 8].

Exclusions

The "odor law" might exclude certain facilities, processes, or activities based on the authority and community's interpretation of need and compatibility. Excluded facilities may include: restaurants, amusement parks, certain agricultural activities, etc.

Modeling

"Odor laws" need to identify specific air dispersion models for predicting odor dispersion, predicting detection thresholds in the community, and back-calculating source emission limits. Odor dispersion modeling choices include ISCST3, SCREEN3, INPUFF, CAL PUFF, and AERMOD. Additional models are available, including proprietary models.

A number of important issues need to be considered in selecting and using air dispersion modeling for odor applications. These issues include: averaging time(s), peak-to-mean ratio(s), stability classes, terrain, area source emission rates, etc.

Limitations

The "odor law" needs to acknowledge the limits of the jurisdiction and the applicability of the odor criteria. Additional statements that may provide for confidentiality of certain facility records and exclude compliance as a defense to a civil action can be added to the completeness of the "odor law".

CONCLUSIONS

The search for the perfect "odor/odour law" most likely will continue well into the new millennium. Communities that wish to establish odor nuisance criteria have a number of viable choices and alternatives. Each community has inherently different levels of acceptance for odors. The acceptance of odors from a variety of sources is a dynamic social, economic, and political process within communities. Elected officials recognize that the community welfare includes the preservation of health, well being, property values, economics, and compatibility of various activities.

From state to state, in communities across the United States, and in other countries, odor issues are addressed by a variety of "odor laws", whether they are called an ordinance, rule, regulation, or policy. These "odor laws" attempt to address community "odor issues" in several well-defined approaches that utilize "compliance determining criteria":

- Annoyance criteria (subjective categories),
- Complaint criteria (numbers of complaints),
- Ambient odor detection threshold criteria (odor concentration),
- Ambient odor intensity criteria (butanol scale),
- Ambient odorant criteria (mass concentration),
- Episode duration-frequency criteria ("odor-hours"),
- Source emission limits (odor threshold or mass concentration), and
- Best available control requirements (i.e. industry standard).

The various standard approaches are not mutually exclusive and are sometimes combined in one "odor law".

Underlying the "standard approaches" to odor laws are the basic elements that have been placed into successful regulations of air pollutants and adapted and formulated for "odor laws".

Programs to educate and infrastructure to guide and administer the "odor law" are needed to support the community, whether it is state, county, or local jurisdiction.

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