An Odor Index Scale for Policy and Decision Making Using Ambient and Source Odor Concentrations

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ABSTRACT

The concept of odor strength (odor concentration) is often confusing. There is a need to better understand odor strength terminology and there is a need for odor strength bench marks.

Similar confusion or absence of bench marks once existed in the field of noise and sound measurement. However, now sound measurement values are fairly well understood with the universal use of the logarithm "decibel" sound measurement scale. The decibel, introduced in the early 1900's by researchers at Bell Laboratories, is a dimensionless unit based on the logarithm of the ratio of a measured quantity of sound to a reference quantity of sound.

In 1988, John E. Amore at the APCA 81st Annual Meeting (Amore and O'Neill, 1988) proposed an analogous value and scale to the "decibel" sound scale for expressing odor concentration. Furthermore, in Japan an "Odor Index" scale was introduced in 1995 (Ministry of the Environment, Japan, 1995).

The Odor Index value is dimensionless and universally defined as:

$$\text{Odor Index} = 10 \times \log_{10} (\text{odor concentration})$$

Where odor concentration is determined using laboratory olfactometry or field olfactometry and reported as detection threshold (DT) or dilution-to-threshold (D/T), respectively. Note: odor concentration, a dimensionless dilution ratio, is commonly reported with the pseudo dimension of Odor Units (OU).

With standardization of odor testing methods in ASTM E679-04 (ASTM International, 2004) and EN13725:2003 (Committee for European Normalization, 2003) an Odor Index will provide a standard way to display and to report odor concentration values for policy and decision makers.

This paper will approach the odor index with the historical background and with a rational argument for adopting an odor index for common use.

KEYWORDS

Odor Index, decibel, odor, odor strength, odor concentration, dilution-to-threshold, D/T, detection threshold, EN13725, ASTM E679, olfactometry, odor policy

INTRODUCTION

Ambient odor strength (odor concentration) is commonly reported as odor units or dilution-to-threshold (D/T) values, for example 7 odor units or 7-D/T. Point or area source odor concentrations are commonly reported as detection or recognition thresholds (DT or RT) and often given the pseudo dimension of "odor units". Odor concentration terminology can be confusing. Policy makers and decision makers may easily reject "odor" as a legitimate issue because the terminology "does not make sense".

Engineers and scientists may have the technical training and background to understand odor concentration; however, even technical professionals find it difficult to answer the frequently asked questions:

1) What does 7-D/T mean ?
2) How strong is 7-D/T ?
3) What does 500 odor unit mean ?
4) How strong are 500 odor units ?

Answers to these questions would be easy if odor terminology was less confusing and if there were odor concentration bench marks. Similar confusion or absence of bench marks once existed in the field of noise and sound measurement. However, now sound measurement values are fairly well understood with the universal use of the "decibel" sound measurement scale. The decibel, introduced in the early 1900's by researchers at Bell Laboratories, is a dimensionless unit based on the logarithm of the ratio of a measured quantity of sound to a reference quantity.

$$\text{Decibels} = 10 \times \log_{10} (W / W_o)$$

Where W is the sound power of a source, and W_o is the reference sound power. The reference for sound power is 10^{-12} watt, which is the threshold of hearing at 1,000 Hz.

In 1988, John E. Amore and Robert S. O'Neill at the APCA 81st Annual Meeting (Amore and O'Neill, 1988) proposed an analogous odor value and scale to the "decibel" sound scale for expressing odor concentration. Further, in Japan an "Odor Index" scale was introduced in 1995 (Ministry of the Environment, Japan, 1995). The odor index value is dimensionless and universally defined as:

$$\text{Odor Index} = 10 \times \log_{10} (\text{odor concentration})$$

For example, if an odor concentration is 500 odor units, the odor index value would be calculated:

$$\text{Odor Index} = 10 \times \log_{10} (500 \text{ odor units}) = 10 \times 2.70 = 27.0$$

In 1988, John Amore and Robert O'Neill presented a thorough case for a unifying scale to express olfactory thresholds and odor values. They developed the analogy of a unifying odor scale to the sound decibel scale by pointing out that "the decibel scale has been accepted internationally... it is the common standard on which virtually all measurements of sound levels ... are expressed, and on which regulations, litigation ... are based."

John Amore and Robert O'Neill clearly pointed to the absence, at that time, of standard methods to measure odor and standard methods to reference odor. They proposed the use of 1-butanol as a reference odorant to standardize odor measurement practices. Amore's and O'Neill's unifying odor scale, which they coined the term "Decismel Scale", fell short of universal acceptance, because of the absence of standard odor testing methods and references, as they acknowledged.

The Ministry of the Environment, Government of Japan, revised the 1972 "Offensive Odor Control Law" in 1995, standardizing odor measurement methods in Japan and introducing the Odor Index Regulation No. 71 (Ministry of the Environment, Japan, 1995).

STANDARDIZATION

During the 1990's odor laboratories around the world (i.e. Europe, North America, and Australia) cooperated in research and development for standardizing odor testing. The Committee for European Normalization (CEN) drafted a comprehensive odor testing standard known as prEN13725, "Air Quality-Determination of Odour Concentration by Dynamic Olfactometry". With input and advice from North American and Australian odor laboratories, the CEN odor testing standard was adopted by the European Union in 2003 and is now designated EN13725:2003 (Committee for European Normalization, 2003).

The internationally accepted odor testing standard, EN13725, contains detailed specifications for olfactometer design, olfactometer calibration, odor laboratory operation, and assessor selection. The EN13725 standard requires strict quality assurance and quality control procedures that focus on performance testing of the laboratory as well as continuously monitoring assessors. It is primarily the assessor selection and monitoring requirements of EN13725 that have provided the standardization and references that Amore and O'Neill noted were absent in 1988.

Assessor selection and monitoring elements of EN13725 (Section 6.7.2) involve testing with the standard odorant 1-butanol (n-butanol). The odor laboratory that conforms to EN13725 must determine the butanol threshold for potential assessors through at least ten tests collected on three separate days with at least one day in-between. A prospective assessor must meet two criteria: the geometric mean of the assessor's threshold tests must be in the range of 20 to 80-ppb; and the antilog of the standard deviation calculated from the logarithms of the threshold tests, must be less than 2.3. After meeting the initial acceptance criteria the assessor must be continuously monitored by further butanol testing at least once every twelve odor samples evaluated. All assessors must continue to meet the criteria through a review of their most recent twenty butanol threshold tests. Therefore, EN13725 assessor selection and monitoring requirements have standardized the "sensor" used for odor testing with the standard reference odorant, 1-butanol.

ODOR INDEX

The Odor Index is a standardized way to display and to report odor concentration values for policy and decision makers, similar to how policy and decision makers understand and discuss the Richter earthquake scale and the Decibel sound scale.

The odor index value is dimensionless and universally defined as:

Odor Index $=$ 10 Log_{10} (odor concentration);

Odor concentration is a dimensionless dilution ratio expressed either as dilution-to-threshold (D/T) or detection threshold (odor units).

The odor index for an odor concentration value of 500 odor units would be calculated as:

Odor Index = $10 \log_{10} (500) = 10 \times 2.70 = 27.0$

Where, the logarithm (base 10) of 500 is 2.70.

Note that the odor index value would be reported with three significant figures (27.0), since the log of the odor concentration value is typically reported with three significant figures (2.70). Also, note that the odor index formula would be commonly written without the logarithm subscript "10".

Odor Index = 10 log (odor concentration)

The odor index examples in Table 1 are of point, area, and ambient odor concentrations. These examples are for illustrative purposes only and are not intended to be "certified" emission factors by the authors for the processes or situations presented in the table.

Table 1 - Odor Index Examples

Odor Index Values	**Log Value**	**Odor Units or D/T**	**Example of Odor Source or Odor Situation**
60.0	6.00	1,000,000	Rendering plant uncontrolled exhaust
50.0	5.00	100,000	Venting anaerobic digester gases
40.0	4.00	10,000	Sludge centrifuge vent
30.0	3.00	1,000	Primary clarifier weir cover exhaust
27.0	2.70	500	Dewatering building exhaust
24.8	2.48	300	Biofilter exhaust
20.0	2.00	100	Multistage scrubber exhaust
17.0	1.70	50	Carbon filter exhaust
14.8	1.48	30	Ambient odor adjacent to biosolids land application
11.8	1.18	15	Ambient odor adjacent to aeration basin
10.0	1.00	10	Design value sometimes used in odor modeling
8.5	0.85	7	Ambient odor level sometimes considered a nuisance
7.0	0.70	5	Design value sometimes used in odor modeling
6.0	0.60	4	Ambient odor level common is a city
3.0	0.30	2	Ambient odor level usually considered "just noticeable"
0	0.00	1	Ambient air in a community with "no odor" noticeable

The following are noteworthy Odor Index ranges:

1) Ambient odors - Odor Index range from 0 to 15 (1-D/T to 30-D/T).

2) Outlets of odor control devices - Odor Index range from 15 to 25 (30-D/T to 300-D/T).

3) Uncontrolled process emissions - Odor Index range from 25 to 50 (300-D/T to 100,000-D/T)

The examples and ranges of the odor index values presented above illustrate how the odor index for odor could be incorporated into policy discussions similar to how the Decibel Scale for sound has been incorporated into policy and decision making.

DISCUSSION

The perception of odor is a logarithm sensory phenomenon (Stevens 1960). Odor testing involves presenting to the assessor(s) the odorous air diluted with odor-free air in an ascending series of concentrations in a geometric progression that is typically binary, i.e. each progressive dilution level is twice the concentration (one half the dilution ratio) as the previous level. For example, laboratory olfactometers typically have a binary series dilution range from 64,000 to 8 (64000, 32000, 16000, 8000, 4000, 2000, 1000, 500, 250, 125, 62.5, 31.3, 15.63, and 7.8). Also, field olfactometers typically have a binary series range from 60 to 2 (60, 30, 15, 7, 4, 2).

The human nose is able to perceive a slight difference when an odor concentration is doubled or halved. The binary scale of olfactometry utilizes this sensory phenomenon in laboratory and field olfactometers. In the logarithm transformation, a doubling or halving of an odor concentration is a difference of 0.30. Therefore, in the odor index scale, a doubling or halving is a difference in +/- 3.

The olfactometry binary scale logarithm step of 0.30 does not represent olfactometry precision. Olfactometry laboratory precision, in terms of logarithm values, has been reported as precise as 0.05 (standard deviation). Therefore, in the odor index scale, laboratory olfactometry precision could be defined with a 95% interval of +/- 1, for example 20 +/- 1.

Odor reduction efficiency is also a common issue with policy and decision makers. The odor index scale, because it is derived from the logarithm transformations of odor concentrations, yield a consistent set of values for odor reduction efficiencies. For example, 90% reduction efficiency will always be a decrease of 10 in the odor index. Likewise, 95% reduction and 98% reduction will always be a decrease of 13 and 17 in the odor index, respectively. Furthermore, 99% reduction will always be a decrease of 20 in the odor index.

Engineers and scientists need to be aware of how the odor index value differs from a laboratory derived odor concentration and a field derived odor concentration. Based on laboratory olfactometry standards of ASTM E679-04 (ASTM International, 2004) and EN13725:2003, the detection threshold (DT) is calculated as:

$DT_{Laboratory}$ = (Volume of Dilution Air + Volume of Odor Air) divided by (Volume of Odor Air)

In comparison, based on field olfactometer convention, the D/T value is calculated as:

D/T_{Field} = (Volume of Dilution Air) divided by (Volume of Odor Air)

The difference between the two resulting odor index values is only noticed below the D/T of 100 when one decimal (thee significant figures) is reported in the odor index. Table 2 illustrates the differences.

Table 2 - Differences in odor index values from laboratory and field olfactometry calculations

$(DT)^1_{Laboratory}$	Log $(DT)^1_{Laboratory}$	Odor Index Laboratory	$(D/T)^2_{Field}$	Log $(D/T)^2_{Field}$	Odor Index Field
100,001	5.000	**50.0**	100,000	5.000	**50.0**
1,001	3.000	**30.0**	1,000	3.000	**30.0**
101	2.004	**20.0**	100	2.000	**20.0**
99	2.000	**20.0**	98	1.991	**19.9**
61	1.785	**17.9**	60	1.778	**17.8**
31	1.491	**14.9**	30	1.477	**14.8**
16	1.204	**12.0**	15	1.176	**11.8**
8	0.903	**9.0**	7	0.845	**8.5**

[1] DT is detection threshold as commonly reported by laboratory olfactometry.
[2] D/T is dilution-to-threshold as commonly reported by field olfactometry.

The authors recommend that the field olfactometry D/T be used for the odor index calculation because the practical limit of laboratory olfactometry is approximately 30 and the differences above 30 for the odor index derived values is no more than 0.1 (odor index scale).

CONCLUSIONS

Because ambient odor concentrations (D/T's) and point or area source odor concentrations (detection and recognition thresholds) are difficult to understand, there is a need for a common "odor concentration scale", the Odor Index scale.

Similar confusion once existed in the field of noise and sound measurement. However, sound measurement values are now well understood with the universal use of the logarithm "decibel" sound measurement scale. The decibel, introduced in the early 1900's by researchers at Bell Laboratories, is a dimensionless unit based on the logarithm of the ratio of a measured quantity of sound to a reference quantity of sound.

John E. Amore at the 1988 APCA 81st Annual Meeting proposed an analogous value and scale to the "decibel" sound scale for expressing odor concentration. Furthermore, in Japan an "Odor Index" scale was introduced in 1995 and has been subsequently adopted by over 200 local units of governments in Japan, including the Tokyo Metropolitan Government.

The odor index value is dimensionless and is universally defined as:

Odor Index = 10 Log (odor concentration)

Ambient odor concentrations are commonly reported as dilution-to-threshold (D/T) values, for example 7-D/T. Point or area source odor concentrations are commonly reported as detection or recognition thresholds (DT or RT) and often given the dimension of "odor units". These differences alone can cause confusion.

Policy makers and decision makers often reject "odor" as a legitimate issue because the terminology seems complex and "does not make sense". Engineers and scientists may have the technical training and background to understand odor concentrations or odor strength, however, even these professionals sometimes struggle with the meanings of: D/T; detection thresholds; or odor units.

Odor concentration terminology need not be confusing if a common Odor Index was adopted. The Odor Index would provide a standard way to display and to report odor concentration values for policy and decision makers, similar to how policy and decision makers understand and discuss the Richter earthquake scale and the Decibel sound scale.

An odor index value is easy to calculate and the Odor Index scale is easy to comprehend and utilize for comparing, ranking, and prioritizing odors.

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