Odor Intensity Scales for Enforcement, Monitoring, and Testing

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ABSTRACT

Odor intensity relates to the degree of strength and magnitude of the observed ambient air. ASTM E544-99[1], Standard Practice for Referencing Suprathreshold Odor Intensity, presents two methods for referencing the intensity of ambient odor or a sample of odorous air: Procedure A - Dynamic Scale method and Procedure B - Static Scale Method. The Dynamic Scale Method utilizes a laboratory olfactometer device with a continuous flow of a standard odorant for presentation to a panelist (assessor). The panelist compares the intensity of an odor sample (gas sample bag) to a specific concentration level of the standard odorant from the laboratory olfactometer device. The Static Scale method utilizes a set of bottles with fixed dilution's of the standard odorant in a water solution. Enforcement field inspectors and facility or citizen odor monitors commonly use the Static Scale method. The Static Scale Method has also been incorporated as a standard of practice by a number of odor laboratories, because of its low cost of set-up compared to an olfactometer device.

The dilution levels for each procedure are determined by the specific olfactometer device or from interpretation of the ASTM Procedure 'B' scale choices. Several scales are in practice, differing by the starting point of the scale, the geometric progression of the scale, and the standard odorant used (i.e. n-butanol or sec-butanol).

For the enforcement field inspector an odor intensity scale is a valuable tool for verifying compliance or determining whether a specific odor episode has exceeded a pre-set limit in the community. Facility or community monitors equally find odor intensity scales essential in their work to document facility performance or track facility compliance.

Laboratory testing of odor samples utilizes odor intensity for determining the dose-response function (persistency) of a sample, which is useful in ranking sources and conducting odor modeling.

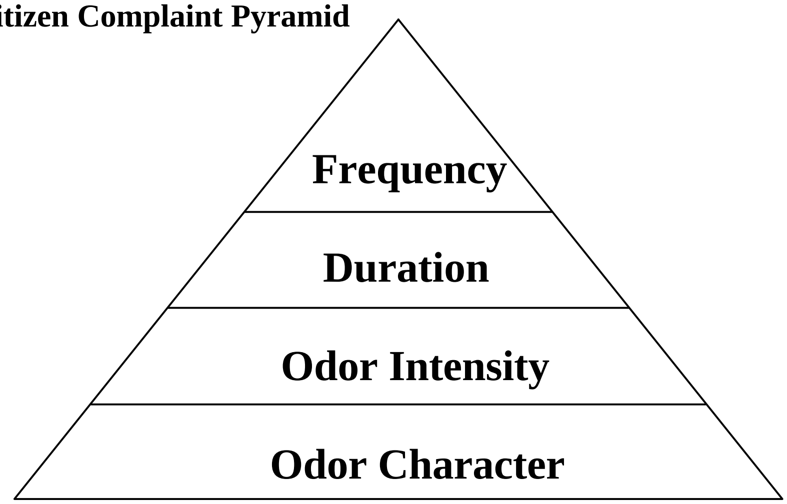
This paper presents the relationship between the intensity scales commonly used and further describes their use and applicability to enforcement of odor regulations and verification of odor compliance plans.

INTRODUCTION

Ambient air in the community holds a mixture of odorous chemical (odorants) from the everyday activities of its citizens and the commercial and industrial enterprises that make up modern day society. The daily exposure to odorants is a part of life and a part of the community. However, from time to time, citizens find some odors objectionable and a nuisance.

A conceptual model for what leads to an odor nuisance is the "Citizen Complaint Pyramid" (See Figure 1) which starts and builds with "Odor Character", Odor Intensity", "Episode Duration", and "Episode Frequency"[2]. The cumulative effect of these four building blocks creates the nuisance experience that may lead to a citizen complaint.

Figure 1. Citizen Complaint Pyramid



An Odor Episode

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 verses unpleasantness of an odor. The assigning of a 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 E544-99[1], "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 inspectors, monitors, plant operators and citizens 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, such as the scale number or the equivalent butanol concentration, are not directly used in odor dispersion modeling, however, some researchers use intensity values along with other data (dose-response) 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.

ODOR INTENSITY

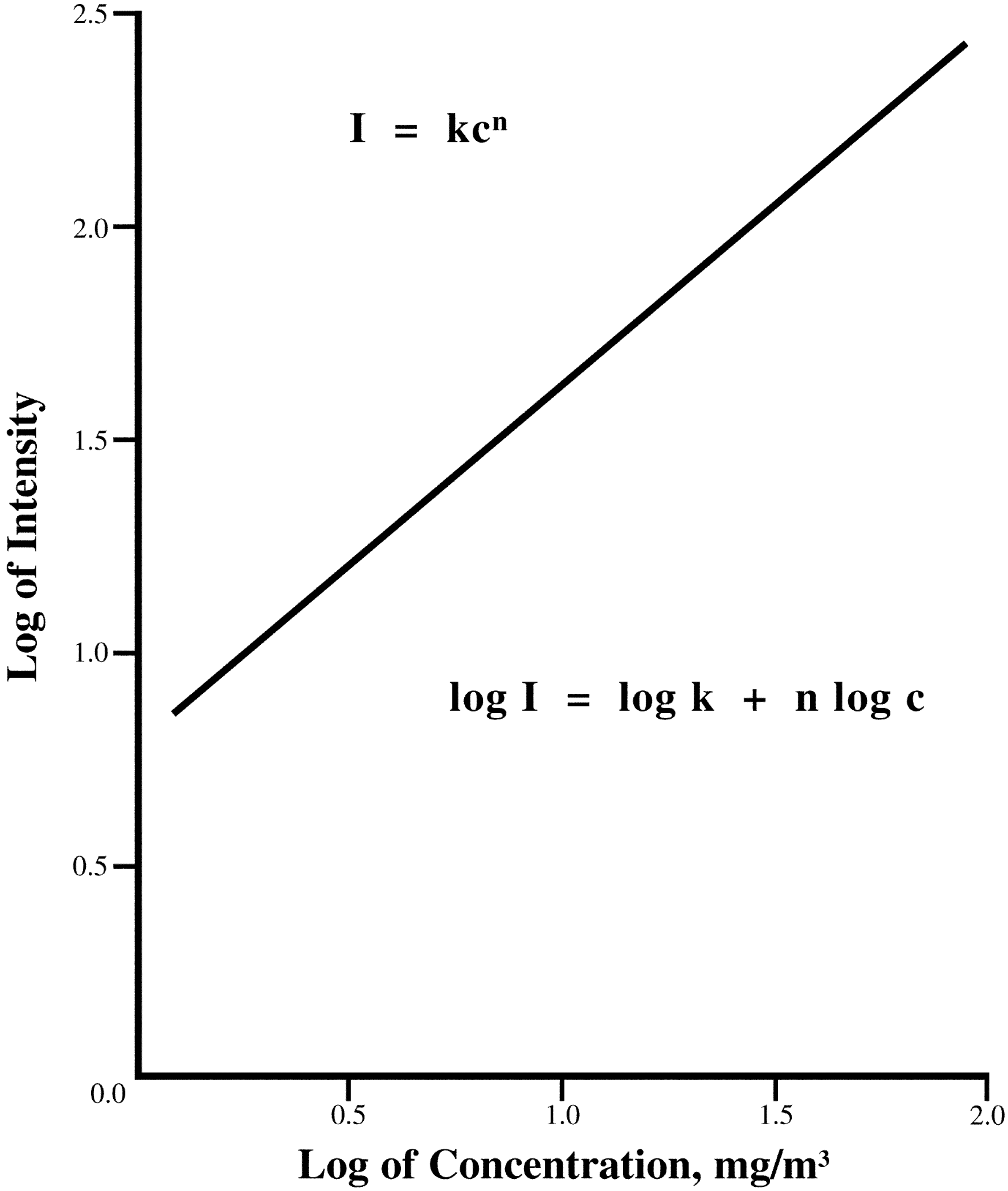
Psychophysics involves the response of an organism to changes in the environment perceived by the five senses [Stevens 1960][3]. Some examples include how the human body perceives sound loudness, lighting brightness, or odor strength.

These psychophysical phenomena lead to sensory responses, which follow a “power law.” Apparent odor strength (odor intensity) grows as a power function of the stimulus odor. S. S. Stevens showed that this power law (Steven’s Law) follows the equation:

$$\mathbf{I = k\,C^n}$$

Where **I** is the odor intensity, **C** is the mass concentration of odorant in milligrams/cubic meter, mg/m^3, and **k** and **n** are constants that are different for every odorant [Stevens 1962][4]. As shown in Figure 2, this equation is a straight line when plotted on a log-log scale.

Figure 2: Odor Intensity Power Law



Odor intensity of the ambient air can be measured objectively using an "Odor Intensity Referencing Scale" (OIRS) [ASTM E544-99][1]. 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][5]. 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][6]. 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".

Perceived odor intensity is the relative strength of the odor above the recognition threshold (suprathreshold). ASTM E544-99[1], "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. The Dynamic-Scale Method utilizes an olfactometer device with a continuous flow of a standard odorant (butanol) for presentation to an assessor. The assessor compares the observed intensity of an odor sample to a specific concentration level of the standard odorant from the olfactometer device. The Static-Scale Method utilizes a set of bottles with fixed dilutions of a standard odorant in a water solution. Air pollution inspectors commonly use the Static-Scale Method and it has also been incorporated as a standard of practice by a number of odor laboratories, because of its low cost of set-up compared to an olfactometer device [Turk 1980][7].

The odor intensity value is expressed in parts per million (PPM) of butanol (n-butanol). A larger value of butanol means a stronger odor, but not in a simple numerical proportion. As discussed previously, odor perception is a psychophysical process and thus follows the power law. For example, an increase in butanol concentration by a factor of 2 results in an odor that is less than twice as intense [Stevens 1962][4]. Butanol concentrations are a referencing scale for purposes of documentation and communication in a reproducible format.

An important aspect of understanding the butanol intensity referencing scale is the variety of available scales. The specific olfactometer device determines the dilution levels of the Dynamic-Scale Method used by laboratories. Further, the dilution levels of the Static-Scale Method used by odor laboratories and field observers (inspectors and monitors) is determined from interpretation of the ASTM Procedure B, which accepts numerous scale choices.

The starting point of the scale and the geometric progression of the concentration series is selected by the laboratory or field observer. Common scales used include starting points of butanol concentration in air as low as 10-ppm to as high as 25-ppm.

Many scales use a geometric progression of 2 (each dilution level is twice the concentration of the previous), however, some scales use a geometric progression of 1.5 or 3. All laboratories and field observers presenting the odor intensity data should reference a butanol concentration in air (PPM butanol) to allow comparison of results from different data sources.

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.

Common butanol intensity referencing 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 with a geometric progression of two,
- 8-point dynamic scale starting at 12-ppm with a geometric progression of two, and
- 5-point static scale starting at 25-ppm with a geometric progression of three.

Figure 3, Odor Intensity Referencing Scales (OIRS), compares the four scales listed above with the "Scale Numbers" and the equivalent n-butanol part per million concentration in the air.

ODOR ENFORCEMENT

From state to state, in communities across the United States, and in other countries, odor in the ambient air is addressed by a variety of "odor laws"[2]. Odor laws may be called an ordinance, rule, regulation, or policy. Enforcement of an "odor law" is effective if, and only if, the law, ordinance, rule, regulation, or policy uses a criterion or criteria to define compliance or to define a violation, i.e. existence of a nuisance. The criterion need not be purely or scientifically "objective". However, objective measurements of odor are available and standardized, such as the use of the "Odor Intensity Referencing Scale" (OIRS).

Odor laws, ordinances, rules, regulations, or policies uses several well-defined approaches to utilizing "compliance determining criteria"[8]:

1) Annoyance criteria (subjective categories),
2) Complaint criteria (numbers of complaints),
3) Ambient odor detection threshold criteria ("Scentometer-like devices),
4) Ambient odor intensity criteria (Odor Intensity Referencing Scale, OIRS),
5) Ambient odorant criteria (mass concentration, i.e. milligram per cubic meter)
6) Episode duration-frequency criteria (“odor-hours”)
7) Source emission criteria (laboratory determined odor threshold or mass concentration),
8) Best available control technology criteria (i.e. industry standard).

These various approaches to utilizing "compliance determining criteria" are not mutually exclusive and are sometimes combined in one "odor law".

Figure 3: Odor Intensity Referencing Scales (OIRS)

N-Butanol Odor Intensity < PPM >

12-Point Scale [GPR: 2]	10-Point Scale [GPR: 2]	8-Point Scale [GPR: 2]	5-Point Scale [GPR: 3]
1 < 10 >			
	1 < 12 >	1 < 12 >	
2 < 20 >			
	2 < 24 >	2 < 24 >	1 < 25 >
3 < 40 >			
	3 < 48 >	3 <48 >	
4 < 80 >			2 < 75 >
	4 < 96 >	4 < 96 >	
5 < 160 >			
	5 < 194 >	5 < 194 >	
			3 < 225 >
6 < 320 >			
	6 < 388 >	6 < 388 >	
7 < 640 >			4 < 675 >
	7 < 775 >	7 < 775 >	
8 < 1280 >			
	8 < 1550 >	8 < 1550 >	
			5 < 2025 >
9 < 2560 >			
	9 < 3100 >		
10 < 5120 >			
	10 < 6200 >		
11 < 10240 >			
12 <20480 >			

GPR: Geometric Progression Ratio

The approach using "ambient odor intensity criteria" to determine compliance requires trained observers that have learned one of the "Odor Intensity Referencing Scales" (OIRS). The trained observer, i.e. air pollution inspector, must use a carbon-filtering mask to "refresh" the olfactory sense between observations (sniffing). The number of observations and the time interval between observations is often part of the "odor law" or part of the associated testing procedure.

The ambient odor intensity criteria of an "odor law" may define a violation of the ambient odor intensity standard in the following words:

…"The ambient air exceeds the compliance criterion if, over a period of 30-minutes using a 5-point OIRS, the average of ten (10) equally spaced intensity observations (OIRS) of the ambient air is equal to or greater than the OIRS value of 3.0 (225- PPM n-butanol) when there is a permanent residence upon the property or equal to or greater than the OIRS value of 4.0 (675-PPM n-butanol) when the property does not contain a permanent residence." …

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

ODOR PERSISTENCY

Odor Persistency is a term used to describe the rate at which an odor's perceived intensity decreases as the odor is diluted (i.e. in the atmosphere downwind from the odor source). Odor intensities decrease with concentration at different rates for different odors. Odor intensity is related to the odorant concentrations by the "power law" (Steven's Law):

$$\mathbf{I = k\ C^n}$$

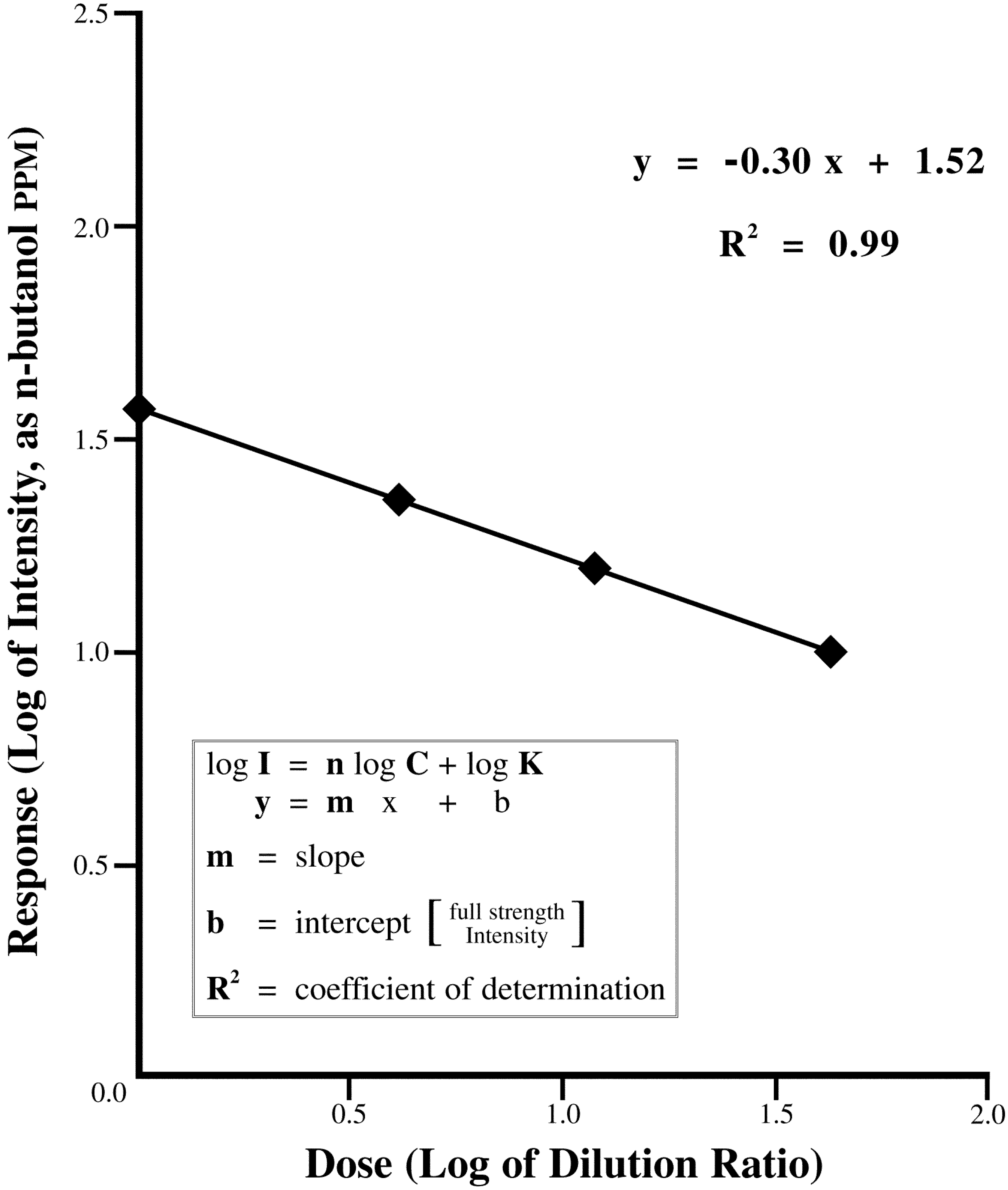
Through logarithmic transformation this function can be plotted as a straight line:

$$\mathbf{Log\ I = n\ log\ C + log\ k}$$

Therefore, the persistency of an odor can be represented as a "Dose-Response" function.

The "Dose-Response" function of a collected odor sample is determined in the odor laboratory from intensity measurements of the odor sample at various dilutions and at full strength. Plotted as a straight line on a log-log scale, the result is a linear equation specific for each odor sample. Figure 4 is an example of an odor persistency graph (Dose-Response Graph) [Dravnieks 1980][8]. The odor concentration (Dose), expressed as the log of the dilution ratio, and the odor intensity (Response), expressed as the log of n-butanol PPM, produces the log-log plot with negative slope. The slope of the line represents the relative persistency. The constant **k** is related to the intensity of the odor sample at full strength [Dravnieks 1986][9].

Figure 4: Dose-Response Graph (Odor Persistency)



[Note: Compare Figure 2 with Figure 4. The Figure 2 log-log plot has a positive slope, because the concentration (x-axis) is the "mass" concentration in mg/m^3 of the odorant, i.e. hydrogen sulfide. The Figure 4 log-log plot has a negative slope, because the concentration (x-axis) is the dilution ratio of an odor sample that was collected from an odor source or from the ambient air, which contains one or more odorous compounds (odorants).]

Odor investigators use dose-response graphs (Figure 4) to compare or rank several odor sources and use dose-response equations in the interpretation of odor dispersion modeling results.

CONCLUSIONS

Odor intensity quantification can be accomplished using an "Odor Intensity Referencing Scale" (OIRS). Odor intensity referencing compares the odor in the ambient air (or the odor of an air sample from a bag) to the odor intensity of a series of concentrations of a reference odorant. A common reference odorant is n-butanol as described in ASTM E544-99, Standard Practice for Referencing Suprathreshold Odor Intensity[1].

Field observation of ambient odors by enforcement air pollution inspectors, facility operators, or citizen monitors is a cost effective means to quantify odors. The observer compares the odor in the ambient air to an OIRS. The person making the observations must use a carbon filter mask to "refresh" their olfactory sense between observations (sniffing). Without the use of a carbon filter mask the observer's olfactory sense would become fatigues or would adapt to the odors in the surrounding ambient air.

Quantifying odors in the ambient air is often prescribed for the following purposes:

1. Compliance monitoring (compliance assurance),
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. Determination of an odor counteractant's efficacy (scientific testing),
10. Determination of an odor counteractant's cost effectiveness (cost minimization),
11. Comparison of odor counteractants and other methods (cost accountability), and
12. Verification of odor dispersion modeling (model calibration).

These activities need a dependable and reproducible method for odor quantification. Referencing the odor intensity of the ambient air using an "Odor Intensity Referencing Scale" (OIRS) fulfills that need. The OIRS is an objective measurement method for ambient odor.

An important aspect of understanding and using OIRS's is the variety of available scales. The starting point of the scales and the geometric progression ratio (GPR) of the concentration series causes each scale to be different. To allow comparison of data from different scales the equivalent n-butanol concentration needs to be reported in PPM n-butanol or the number on the OIRS needs to be reported with the scale's starting point and GPR. [Note: Sec-butanol is an alternative to n-butanol for a standard referencing odorant[5].]

Common "Odor Intensity Referencing Scales" (OIRS) include:

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- 8-point dynamic scale starting at 12-ppm with a geometric progression of two, and
- 5-point static scale starting at 25-ppm with a geometric progression of three.

Figure 3 compares the four OIRS's with the "Scale Numbers" and the equivalent n-butanol part per million concentrations in air.

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Odor, intensity, scales, butanol, enforcement, persistency, modeling, odorants, monitoring, ambient air, ASTM.