Odor Testing Biosolids for Decision Making

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ABSTRACT

The measurement of odors from wastewater treatment facilities is usually a requirement for compliance monitoring, planning, site expansion, and review of operational practices. These odor measurements are often focused on the "front end" of the facility, i.e. head works, primaries, and aeration processes. Sometimes attention is also placed on digesters and dewatering processes. However, the odor of the biosolids material is often overlooked as a parameter in decision-making at the wastewater treatment facility.

Odor is a serious issue in the acceptance of biosolids at a landfill and, more so, a critical issue in public acceptance for land application of biosolids. The biosolids industry recognizes a wide variability in the odor from different biosolids. In the search for operational parameters that influence biosolids odor, the need to select and trust odor measurement methods is critical.

Research on biosolids odor includes identifying the origin, mechanisms, and parameters for odor production, quantifying odor generation, defining "low odor" processes, and measuring odor in the ambient air surrounding land application operations. All of these research objectives need common, standard, and trustworthy "odor testing" methods (standard practices). Equally important to defining and accepting standard methods, is the over riding need to understand the odor testing results for decision making within the Environmental Management System.

Odors have measurable parameters that are not always understood. The parameters of odor include: "odor concentration" (thresholds), "odor intensity" (intensity referencing), "odor character" (standard descriptors), "odor persistency" (the "hang time" of the odor), and "odor Hedonic Tone" (subjective measure of pleasantness/unpleasantness). Each of these parameters have certain limits of "accuracy" that must be understood for appropriate decision making. Without consideration for parameter variability, two odor test results may appear to be different, but may not be statistically different. Likewise, two odor test results may appear to be "nearly the same", but the differences may be significant when all the odor parameter results are presented in combination for decision-making. Biosolids odors need to be tested with reference to the facility's processes and with reference to the environmental situations at the time of land application.

KEY WORDS

Odor, biosolids, olfactometry, odor measurements, threshold, odor intensity.

INTRODUCTION

Odors from wastewater collection systems, treatment facilities, and biosolids can affect the surrounding communities. Estimating the effects of these odors requires field and laboratory odor testing. Specifically, odors can be quantified in the field and quantified in an odor laboratory. The quantification of odors is typically required for the following purposes:

1. Compliance monitoring for compliance assurance.
2. Determination of compliance for permit renewal.
3. Determination of baseline status for expansion planning.
4. Determination of specific odor sources during complaint investigation.
5. Monitoring operations for management performance evaluation.
6. Comparison of operating practices when evaluating alternatives.
7. Monitoring specific events or episodes for defensible, credible evidence.
8. Comparison of odor mitigation measures during tests and trials.
9. Determination of an odor control system's performance for warranty testing.
10. Verification of estimated odor impacts from dispersion modeling.

These odor measurements are often focused on the "front end" of the facility, i.e. head works, primaries, and aeration processes, as well as on digesters and dewatering processes. However, the odor of the biosolids material is often overlooked as a parameter in decision-making at the wastewater treatment facility and in the field during transport, disposal, and land application.

Odor is a serious issue in the acceptance of biosolids at a landfill and, more so, a critical issue in public acceptance for land application of biosolids. The biosolids industry recognizes a wide variability in the odor from different biosolids. In the search for operational parameters that influence biosolids odor, the need to select and trust odor measurement methods is critical.

Research on biosolids odor includes identifying the origin, mechanisms, and parameters for odor production, quantifying odor generation, defining "low odor" processes, and measuring odor in the ambient air surrounding land application operations. All of these research objectives need common, standard, and trustworthy "odor testing" methods (standard practices). Equally important to defining and accepting standard methods, is the over riding need to understand the odor testing results for decision making within the Environmental Management System.

WHAT IS ODOR ?

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 chemical odorants. The trigeminal nerve (fifth cranial nerve) processes the irritation or pungency of chemicals, which may or may not be odorants.

During normal nose breathing only 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 turbinates. These receptors, in both nasal cavities, are ten to twenty-five million olfactory cells making up the olfactory epithelium. 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 chemical odorants. Chemical odorants 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 the chemical odorant. The response created by the reception of a chemical odorant 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 information is processed with other sensations and is compared with cumulative life experiences for the individual to possibly recognize the odor and make some decision about the experience.

Frequently the terms **odor** and **odorant** are used interchangeably and, often incorrectly. There is a distinct difference between these two terms, which is fundamental to the discussion of odor and odor nuisance related to wastewater treatment facilities. The term **“odor”** refers to the perception experienced when one or more chemicals come in contact with receptors on the olfactory nerves (a human response). The term **“odorant”** refers to any chemical in the air that is part of the perception of odor by a human.

The best analogy to understand what is happening with odor perception in the olfactory system is that the receptor nerves are like keys on a piano. As a chemical **odorant** "hits" the piano keyboard (the olfactory epithelium) a tone is played. When multiple chemical **odorants** are present the result is a cord or perception. For example, if keys 1, 3, and 7 are "hit" by three odorants, the brain perceives "banana." Likewise, if keys 4, 6, and 12 are "hit" by three odorants, the brain perceives "sewer." The greater the number of **odorant** molecules present (higher concentrations), the louder the cord is played. The loudness of the cord is analogous to the intensity of the **odor** perception.

ODOR PARAMETERS

Odor is a psychophysical phenomenon. Psychophysics involves the response of an organism to changes in the environment perceived by the five senses [Stevens 1960]. 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 grows as a power function of the stimulus odor. S. S. Stevens showed that this power law (Steven's Law) follows the equation:

$$I = k\, C^n$$

Where I is the odor intensity (strength), C is the mass concentration of odorant (i.e. milligrams/cubic meter, mg/m^3), and k and n are constants that are different for every odorant [Stevens 1962]. As shown in Figure 1, this equation is a straight line when plotted on a log-log scale.

ODOR CONCENTRATION

The most common odor parameter determined during odor testing is "odor concentration" (odor strength). This determination is made using an instrument called an "olfactometer." The standards followed for olfactometry are ASTM Standard of Practice E679-91, "Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits" and EN 13725 – "Air Quality – Determination of Odour Concentration by Dynamic Olfactometry" (EN refers to a European Normalization Standard). EN13725 supports and exceeds the standard practices of ASTM E679-91. The following countries are bound by the CEN/CENELEC International Regulations to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Greece, Germany, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. The new European standard is also adopted in Australia, New Zealand, and much of the Pacific Rim. Therefore, "EN 13725" has become the de facto International Standard for odor/odour testing.

During an odor test, the odor panelist (assessor) sniffs a dilute sample of the odor as it is discharged from the olfactometer as one of three sample presentations (one presentation with the dilute odor and two with odor free air). The assessor sniffs all three of the presentations and must select the one of the three that is different from the other two, even if they must guess. This statistical approach is called "triangular forced-choice." The assessor declares to the test administrator if the selection is a "guess", a "detection" (the selection is different from the other two), or a "recognition" (the selection smells like something) as defined by ASTM E679-91.

The assessor is then presented with the next set of three presentation choices, one of which contains the diluted odor sample. However, this next set of three samples presents the odor at a higher concentration (e.g. two times higher). The assessor continues to additional levels of higher concentration (lower dilution) presentations following the "triangular forced-choice" procedure and the required designation of "guess", "detect", or "recognition". This statistical approach of increasing levels of sample presentation is called "ascending concentration series."

Therefore, "odor concentration" or odor strength is a number derived from the laboratory dilution of sample odors. The dilution ratio (total presentation volume divided by odor sample volume) at each sample presentation level is used to calculate the concentration of the evaluated sample. Figure 2 is an example of an odor evaluation data sheet from an odor laboratory. Note the response key at the bottom of this figure [1=incorrect guess, 2=correct guess, 5=incorrect detect, 6=correct detect, 7=incorrect recognition, and 8=correct recognition].

As an example, follow the results of Assessor 101 in Figure 2. This assessor did not indicate "detection" of the odor at dilution level 7 which is a dilution ratio of 1000, but did indicate a detection at the next highest odor concentration (lower dilution ratio) of 500 (two times more odor than 1000). The assessor's individual estimated detection threshold is the geometric mean between 1000 and 500, or 707. The result of this statistical method is called the "best-estimate" threshold.

$$(\text{Log } 1000 + \log 500)/2 = (3.0 + 2.7)/2 = 2.85 \qquad \{10^{2.85} = 707\}$$

The geometric mean is used when calculating the "best estimate" threshold due to the lack of "equal variance" along the dilution ratio scale [Stevens 1962].

The example shown above alludes to a very important concept in analyzing odor testing data. The ascending concentration series followed during testing of odors is a geometric progression (each dilution level twice the previous level). Since each dilution ratio is half of the previous presentation (twice the amount of odor), the scale does not have an equal spread between values. Applying a logarithm base 10 transformation forces the presentation scale to have an equal spread between dilution levels or, in other words, equal variance along the logarithm scale [Dravnieks 1986].

The individual estimated thresholds of six to ten assessors are averaged to determine the detection threshold for which 50% of individuals will observe the presence of an odor. In the example in Figure 2, this average of 8 assessors' transformed detection threshold estimate is 2.62 or 420 Odor Units (antilog of 2.62 = 420 O.U.). The "detection threshold" value that is obtained from odor testing is actually derived from dilution ratios, and is therefore 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."

ODOR DISPERSION

It should be noted that the dilution of the actual odor emission sample is the physical process that occurs in the atmosphere down wind of the odor source. The "receptor" (citizen in the community) sniffs the diluted odor. The dilution ratio is an estimate of the number of dilutions needed to make the actual odor emission "non-detectable" (Detection Threshold). If the receptor detects the odor, then the odor in the atmosphere is above the receptor's detection threshold level.

The pseudo-dimensions of "odor units per cubic meter" are commonly used for odor dispersion modeling, taking the place of "grams per cubic meter." The odor concentration can be multiplied by the air flow rate, cubic meters per second, resulting in a pseudo-dimension of "odor units per second," analogous to grams per second. Because "odor concentrations" from different source types can not be "added" nor can they be "averaged," odor modeling must be conducted with caution. The resulting "odor concentration" value of "1", calculated by a dispersion model, represents the odor detection threshold that was determined using the "best estimate criteria." A value of less than 1 represents "no odor" or "sub-threshold." A value of greater than 1 represents "odor" at a "supra-threshold" level.

ODOR INTENSITY

Perceived odor intensity is the relative strength of the odor above the recognition threshold (suprathreshold). ASTM E544-99, "Standard Practice for Referencing Suprathreshold Odor Intensity," presents two methods for referencing the intensity of ambient odors: Procedure A – Dynamic-Scale Method and Procedure B – Static-Scale Method. 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. Field investigators 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].

The odor intensity result 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]. Butanol concentrations are a referencing scale for purposes of documentation and communication in a reproducible format.

Another 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 and field investigators. Further, the dilution levels of the Static-Scale Method used by laboratories and field investigators 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 investigator. 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 twice concentration of the previous), however, some scales use a geometric progression of 1.5 or 3. All laboratories and investigators presenting the odor intensity data should reference a butanol concentration in air (PPM butanol) to allow comparison of results from different data sources.

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.

Note: Sec-butanol is an alternative to n-butanol for a standard referencing odorant [Anderson 1995].

ODOR PESISTENCY

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):

$$I = k\,C^n$$

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

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

Therefore, the persistency of an odor can be represented as a "Dose-Response" function. The "Dose-Response" function is determined from intensity measurements of an odor 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 3 is an example of an odor persistency graph (Dose-Response Graph) [Dravnieks 1980]. The odorant 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].

[Note: Compare Figure 1 with Figure 3. The Figure 1 log-log plot has a positive slope, because the concentration (x-axis) is the "mass" concentration in mg/m^3 of the odorant. The Figure 3 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.

ODOR HEDONIC TONE

Hedonic Tone is a measure of the pleasantness or unpleasantness of an odor. [Hedonic Tone is derived from the word "hedonistic", the Greek word *hedone* meaning pleasure.] The hedonic tone is independent of the odor's character. An arbitrary scale for ranking odors by hedonic tone is the 21-point scale:

-10 ---------------------	0 -----------------	+10
Unpleasant	Neutral	Pleasant

An assessor uses her/his personal experience and memories of odors as a hedonic tone referencing scale. During training, assessors become aware of their individual odor experience and memory referencing. The reported hedonic tone value by an odor testing laboratory is an average of individual hedonic tone values assigned by each assessor.

Webster's Dictionary provides the following definition for subjective and objective:

Subjective: relying upon ones personal feelings or beliefs; relating to or arising within one's self or mind in contrast to what is outside…

Objective: treating or dealing with facts without distortion by personal feelings or prejudices; dealing with things external to the mind rather than with thoughts or feelings…

The assigning of a hedonic tone value to an odor by an assessor is "subjective" to the assessor. The assessor's experiences and memories force their personal feelings and beliefs into the decision making process. Through training, assessors assign a hedonic tone and then set aside their personal feelings and make objective decisions regarding detection and recognition thresholds, intensity referencing using a butanol scale, and character identification using a category reference.

ODOR CHARACTERIZATION

Odor character is a nominal (categorical) scale of measurement. Odors are characterized using a referencing vocabulary for Taste, Sensation, and Odor Descriptors. The perception of taste is experienced in the evaluation of certain odors. The four (4) recognized taste descriptors are salty, sweet, bitter, and sour. The Trigeminal Nerve (Fifth Cranial Nerve), located throughout the nasal cavity and the upper palate, and other nerves sense the presence of some odors (i.e. "feels like…" vs. "smells like…"). Eight (8) sensation descriptors include: itching, tingling, warm, burning, pungent, sharp, cool, and metallic.

Numerous standard odor descriptor lists are available to use as a referencing vacabulary. Eight recognized odor descriptor categories are illustrated as an "odor wheel": Vegetable, Fruity, Floral, Medicinal, Chemical, Fishy, Offensive, and Earthy. Specific descriptors within each category are listed in the odor descriptor wheel shown in Figure 4. Taste, sensation, and odor descriptors can all be ranked in relative intensity on a 0 to 5 scale (faint to strong). The odor testing data can then be plotted on three separate spider graphs with the distance along each length of the spider graph representing the 0 to 5 scale. Three example spider graphs are shown in Figure 5. Specific odor descriptors are represented on a histogram which presents the percentage of assessors that assigned specific descriptors to the odor sample. An example histogram is also shown in Figure 5.

BIOSOLIDS ODOR

Biosolids odors from a wastewater treatment facility, during transport, disposal, or land application can affect the community. These biosolids odors commonly lead to nuisance complaints. Estimating the effects of biosolids odors often requires laboratory odor testing. In order to accomplish this testing, biosolids samples or air samples are collected and shipped overnight to an odor-testing laboratory. Engineers and managers can use the odor test results to help in their decision-making.

Comparing the odor of biosolids samples is a common management practice during trials of biosolids treatment for odor reduction. Samples of the biosolids odor can be collected in 10-liter Tedlar gas sample bags and shipped to an odor-testing laboratory for evaluation. An alternative method is to collection samples of the biosolids material in jars or sample bags and ship, on ice, the biosolids material to the odor-testing laboratory. The laboratory then prepares the odorous gas samples for evaluation from the biosolids material.

Before showing specific example calculations, it is important to highlight the necessity of the logarithm base 10 transformations that are used during odor testing. These transformations are used to make the non-linear dilution ratio scale a linear scale in logarithm base 10. More specifically, the transformations are performed in order to stabilize (make uniform) the variance. With the uniform variance, the linear transformed data will show symmetry around the group average (panel average result in log base 10). However, this data will be asymmetrical around the reported Odor Unit value of detection threshold and recognition threshold. All statistical calculations, which are based on a normal distribution, must, therefore, be conducted with the transformed values, in this case, the logarithm base 10 values.

CONFIDENCE INTERVAL OF ODOR RESULTS

When odor testing is conducted on a number of biosolids samples, with replicates, the data will produce odor results with a standard deviation. The standard deviation from replicate sampling will represent the odor testing reproducibility. From the reported standard deviation, confidence limits can be calculated for biosolids odor testing.

An example set of biosolids odor data produced a standard deviation of 0.026. This is the standard deviation on the transformed scale of logarithms. A confidence interval can be calculated for a typical biosolids odor concentration value (detection threshold) of 500 using the standard deviation of 0.026. The logarithm base 10 value for 500 is 2.699.

The 95% confidence interval (alpha = 0.05) based on 10 values in the data set (degrees of freedom = 9) for the log transformed scale result is calculated from:

95% C.I. = 2.699 +/- 2.262 x 0.026 / sq root 10

Note: 2.262 is the percentile of the *t* distribution for 9df (area in one tail).

This yields a symmetrical confidence interval for the transformed scale:

2.699 +/- 0.019 or 2.719 to 2.680

Transforming back to the original scale of odor concentration (detection threshold) gives an estimate of the asymmetrical 95% confidence interval:

Antilog_{10} (2.680) = 480 and Antilog_{10} (2.719) = 525

Therefore, the 95% Lower Confidence Limit (LCL) is 480 and the 95% Upper Confidence Limit (UCL) is 525 for the biosolids odor value of 500.

STATISTICAL SIGNIFICANCE

Odor performance standards or odor performance guidelines are often placed on biosolids. If an odor performance standard of 300 is placed on a biosolids material, but the biosolids odor tests at 320, the test result would appear to exceed the performance standard. However, the statistical significance of the 320 value needs to be considered.

In order to compare the statistical significance of the 320 result compared to the 300-performance requirement, the assumption is made that the variance of the 300-performance requirement would be the same as the variance of the 320 biosolids odor test result. The standard deviation of both results for this example could be taken as 0.04.

The logarithm base 10 transformations must be used for these calculations. The null hypothesis that 320 (log 320 = 2.505) **is statistically the same** as 300 (log 300 = 2.477) is tested with a student t test.

The test statistic (t) is computed from:

$$t = (2.505 - 2.477) / (0.05/\text{sq root } 10) = 1.771$$

This value is compared with the t value for a two-tailed test at 95% confidence (alpha=0.05), which is ± 2.262. Since t = 1.771 (p>0.2) is NOT larger than 2.262 (p>0.05), we cannot reject the null hypothesis and in this case 320 is statistically NOT significantly different from 300.

While it appears that the biosolids odor test (320) failed the performance requirement of 300, a statistical analysis shows that the odor test result is not statistically different from the requirement at the 95% confidence level, therefore it cannot be determined that the biosolids test failed.

ODOR REDUCTION EFFICIENCY

Odor testing of biosolids may be used to determine the odor reduction efficiency (η_D) of a biosolids process or special chemical treatment of the biosolids. If the untreated or "before" biosolids odor was 2000 and the treated or "after" biosolids odor is 450, then the odor reduction efficiency is determined by:

$$E = (2000 - 450) / 2000 \quad x \; 100\,\% = 78\,\% \qquad \text{(prEN13725, 1999)}$$

The efficiency calculations can be conducted using the odor result values and need not use the logarithm transformation. Further analysis can be performed to determine the 95% confidence interval of the abatement efficiency. As shown in the previous example, these calculations must be determined using the logarithm base 10 transformed values, which follow a normal distribution.

CONCLUSIONS

Of the five senses, odor is the most evocative and least understood. In millennium past the "practice of odor" was in the hands of wizards, magicians, and experts. Today odor, odor control, and odor nuisance can be understandable subjects for plant operators, facility managers, engineering practitioners, and citizens.

Odor is measurable and quantifiable using standard practices as published by the American Society of Testing and Materials (ASTM E679 and E544) and by the European Union. The European Normalization Standard, EN 13725, has become the de facto "International Standard" for odor/odour testing.

Managers and engineer use biosolids odor-testing results for decision-making. The measurement of biosolids odors is often a requirement for compliance monitoring, planning, site expansion and review of operational practices. Additional purposes for quantification of biosolids odors includes chemical trials, process tests, and odor reduction performance tests. Each of these purposes dictates a need for dependable and reproducible methods and practices for biosolids odor testing. The trend internationally and in the United States is toward using one unifying odor testing standard, i.e. EN13725.

With the knowledge of fundamental odor testing statistical concepts, field practitioners, design engineers, treatment plant operators, facility managers, and anyone else interested in odors can analyze, interpret, and present biosolids odor testing data in correct and useful ways.

Research on biosolids odors includes identifying the origin, mechanisms, and parameters for odor production, quantifying odor generation, defining "low odor" processes, and measuring odor in the ambient air surrounding land application operations. All of these objectives depend on standard and trustworthy "odor testing" methods (standard practices). Equally important to defining and accepting standard methods, is the over riding need to understand the biosolids odor testing results for decision making within the Environmental Management System.

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Figure 1: Power Law

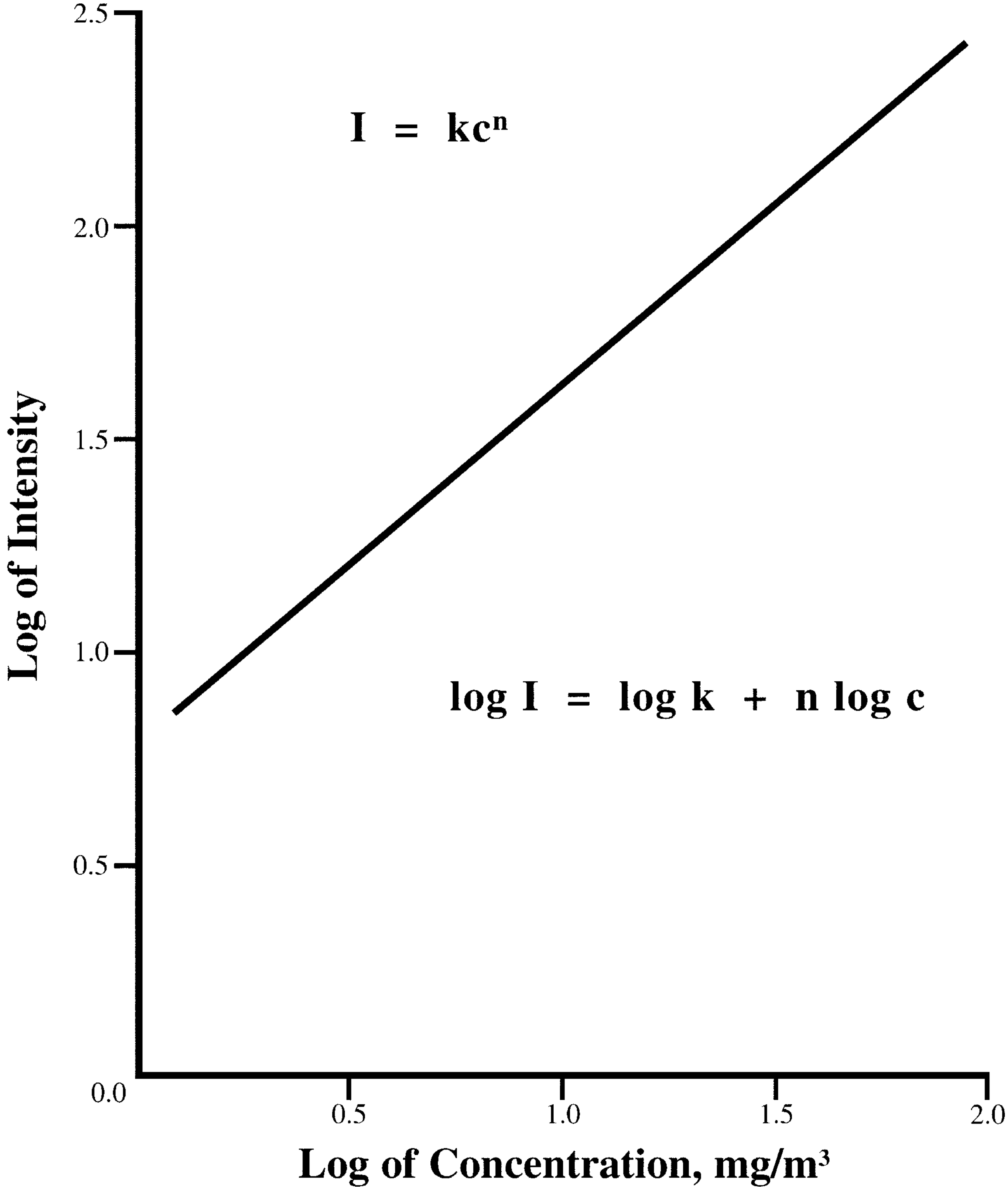


Figure 2: Odor Testing Data Sheet from Odor Evaluation Laboratory

Olfactometer Evaluation Results
AC'SCENT® International Olfactometer

Test Name : Municipal WWTP **Test No. :** 9741 **Test Date :** 7/17/01

Test Administrator : John Doe **Test Method :** Triangular Forced Choice

Flow Rate (lpm) : 20 **Sniff Time (sec) :** 3

SAMPLE INFORMATION

Sampling Date : 7/16/01

Lab No. : 1 **Field No. :** 1947-2 **Sampling Time :** 13:55

Description : Biosolids **Sample Collector :** Jane Smith

Sample Source : Storage Tank No. 2

Dilution Level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Sample Volume	0.3	0.6	1.3	2.5	5.0	10.0	20.0	40	80	160	320	640	1250	2500
Total Volume	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Dilution Ratio	66,667	33,333	16,000	8,000	4,000	2,000	1,000	500	250	125	63	31	16.0	8.0
Geometric Mean	94,281	47,140	23,094	11,314	5,657	2,828	1,414	707	354	177	88	44	22.4	11.3
Log (Geo. Mean)	4.97	4.67	4.36	4.05	3.75	3.45	3.15	2.85	2.55	2.25	1.95	1.65	1.35	1.05

Calibration Date : 7/16/01
THRESHOLDS
G = Guess
D = Detection
R = Recognition

Assessor/Round																**Log G**	**Log D**	**Log R**
101	1						2	1	6	8						2.85	2.85	2.55
102	1						2	1	1	6	8					2.55	2.55	2.25
103	1						2	1	2	6	6	8				2.85	2.55	1.95
104	1						1	2	6	6	8					3.15	2.85	2.25
105	1						1	2	8							3.15	2.85	2.85
106	1						2	1	1	1	6	8				2.25	2.25	1.95
107	1						1	2	2	6	8					3.15	2.55	2.25
108	1						2	1	2	6	8					2.85	2.55	2.25

Sample Comments : ____________

Specific Chemical Concentration Data

Chemical : ____________

Concentration (ppm) : ____________

Response Key:

1 = Incorrect Guess
2 = Correct Guess
5 = Incorrect Detection
6 = Correct Detection
7 = Incorrect Recognition
8 = Correct Recognition

Final Results

	G	**D**	**R**
Avg. Log Value	2.85	2.62	2.29
Std. Dev.	0.32	0.21	0.30
Threshold	707	420	193

Figure 3: Odor Persistency
(Dose-Response)

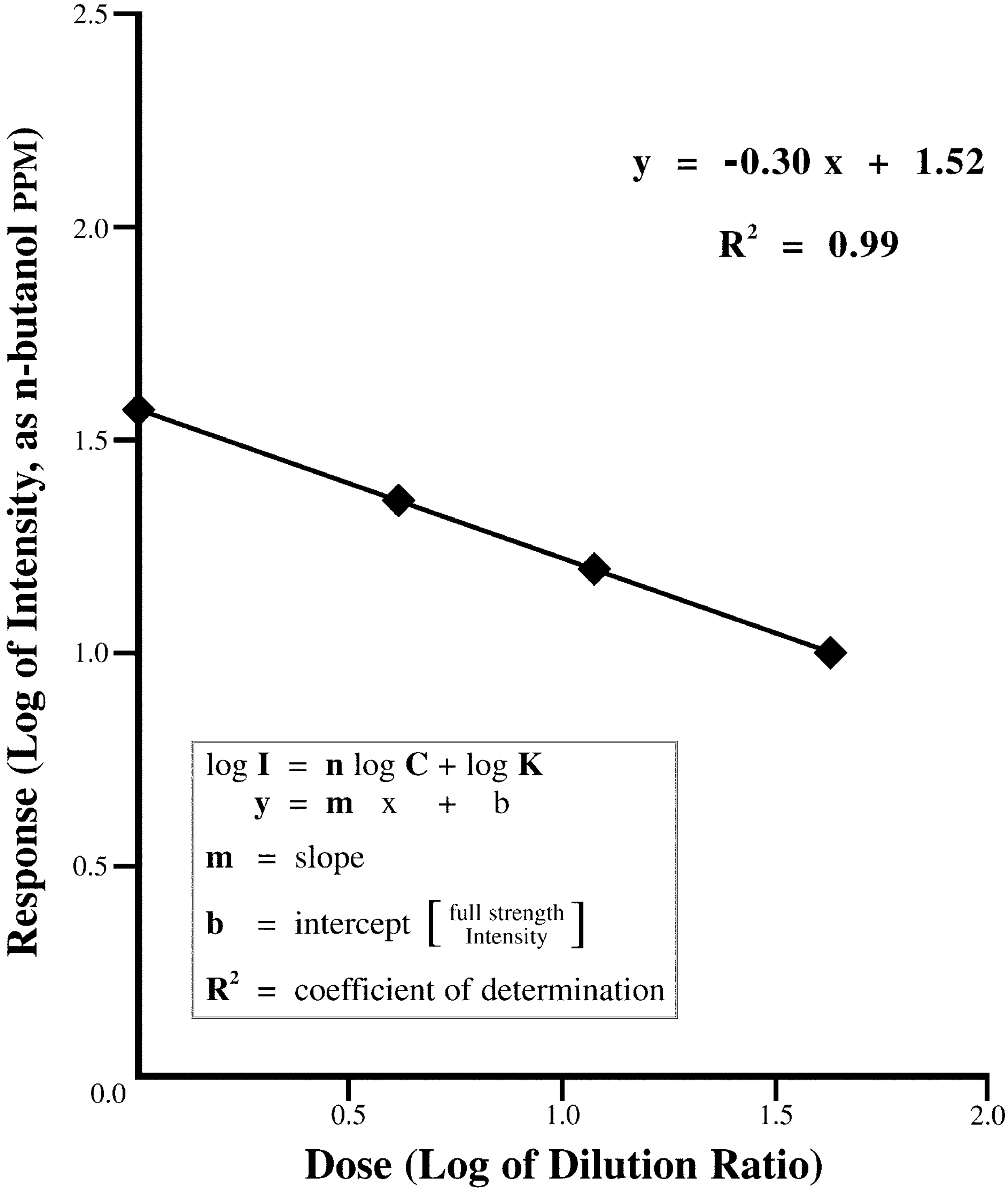


Figure 4: Odor Descriptors Wheel

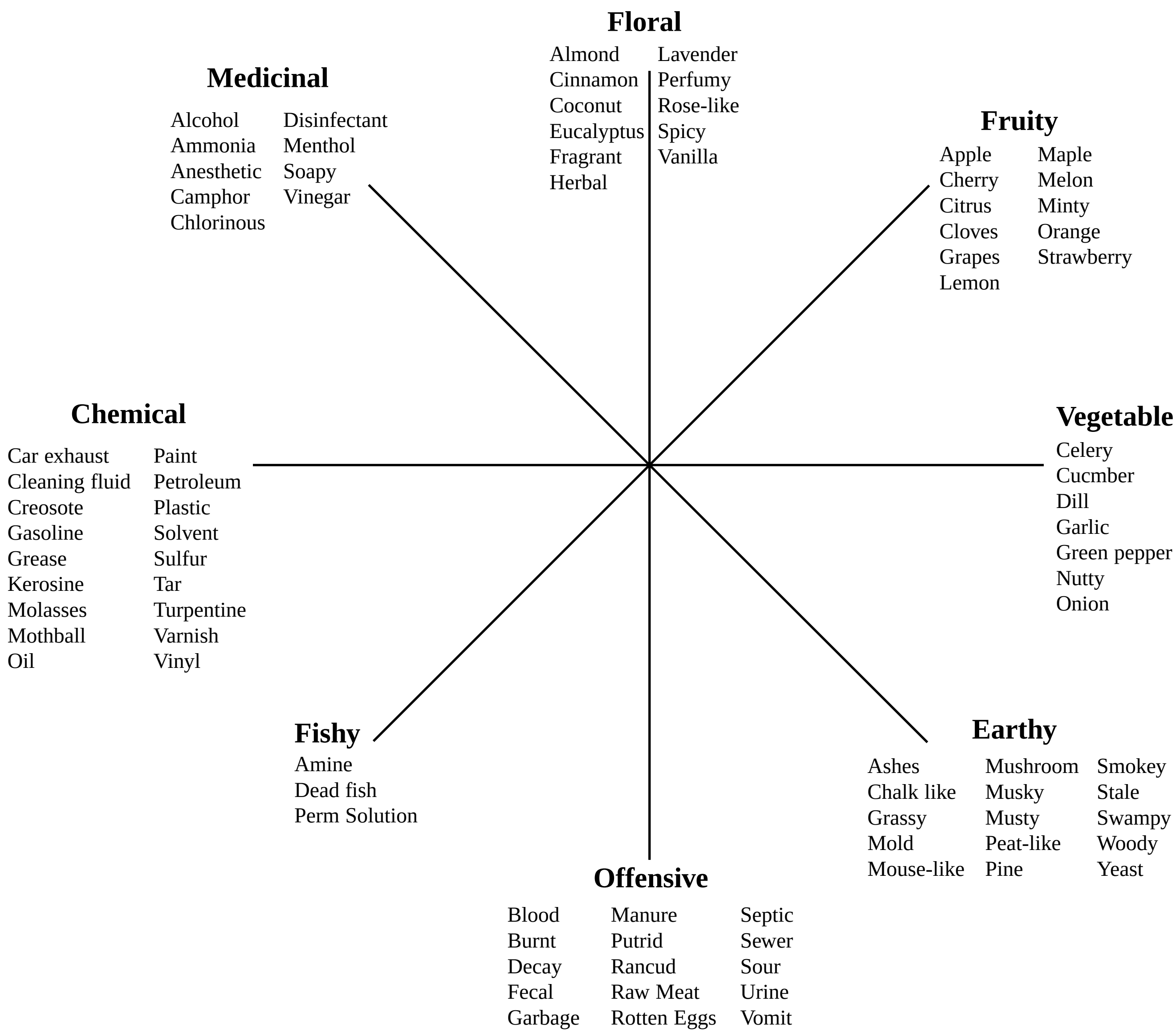
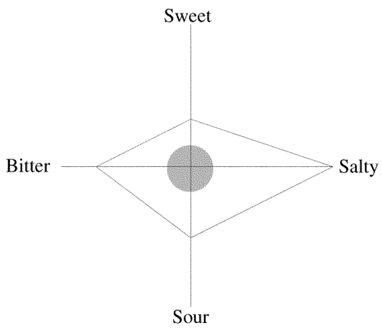
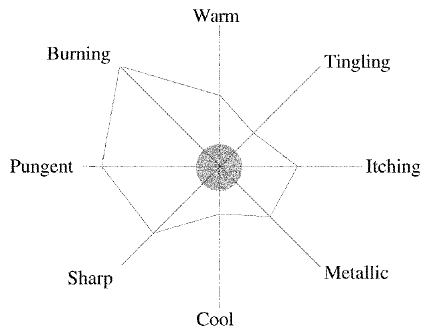


Figure 5: Odor Characterization

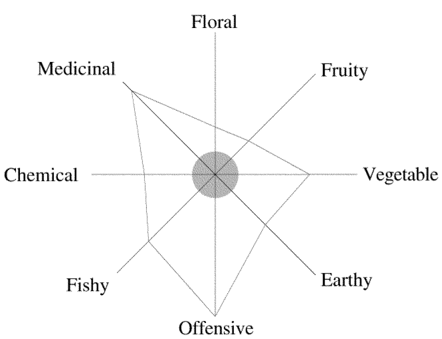
Example Taste Descriptor Graph



Example Sensation Descriptor Graph



Example Odor Descriptor Graph



Example Odor Descriptor Histogram

```
Garlic       *******
Onion        *********************
Apple        *******
Herbal       **************
Almond       *******
Disinfectant *********************
Ammonia      ******************************************
Chlorinous    *******
Oil          **************
Sulfur       *******
Amine        ****************************
Sewer        *************************************************
Burnt        *********************
Manure       **************
Rotten eggs  **************
Putrid       *******
Stale        ****************************
Chalk-like   *******
Smoky        **************
```