Olfactomatics:
Applied Mathematics For Odor Testing

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ABSTRACT

Odor testing seems mysterious and odor data mythical to most practitioners in the waste water industry. For years engineers and treatment plant operators have relied on “odor experts” to interpret odor testing results.

“Olfactomatics” is a specialty field of environmental mathematics that contains several unique concepts and laws for the calculations related to olfactometry (odor testing). Misunderstanding these concepts leads to incorrect representation of odor testing data and, worse yet, sometimes leaves important questions left unanswered.

Some most frequently asked questions of odor testing:

1. What is an “odor unit”?
2. Where does the result come from?
3. How accurate is the result?
4. What is the standard deviation of an odor number?
5. Are these two numbers statistically different?
6. Are there testing standards?
7. Aren’t the odor results subjective?

This paper presents the fundamental math concepts of olfactomatics and several calculation methods used to produce usable odor testing data. The “Laws of Olfactomatics” include the concepts of the “power law”, “best estimate threshold”, geometric progression of ascending concentration series, logarithmic transformations, statistical significance of transformed logarithms, dimensionless dilution ratios, pseudo-dimensions, dose-response function (persistency), and inputs/outputs of dispersion models.

Example calculations (practice problems) of odor testing are presented as well as example graphics used to illustrate odor testing results. This paper provides a thorough review of the necessary mathematical concepts that will be needed by the field practitioner, design engineer, treatment plant operator, and facility manager in order to understand and interpret odor data.

Frequently, odor testing is overlooked as a valuable tool for engineering and operations. This paper presents the tools for all practitioners to understand and use odor testing data successfully.

KEYWORDS

odor, odour, olfactomatics, olfactometry, olfactometer, testing, sensory, olfactory

INTRODUCTION

Community odors remain one of the top three complaints to air quality regulators and government bodies around the U.S. and internationally. The majority of all air pollution complaints to the EPA are odor related.

Odors from a facility, such as a wastewater treatment plant, can affect the community. These odors commonly lead to nuisance complaints. Estimating the effects of odors from a facility often requires laboratory odor testing. In order to accomplish this testing, air samples from the facility 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.

Odor testing in the laboratory is conducted to quantify an odorous air sample in terms of human perception. During normal breathing, chemical molecules in the air pass by the olfactory receptors in the top, back of the nasal cavity. The olfactory nerves signal the brain and create a psychophysical response. For the general population the olfactory response to odors is normally distributed. Therefore, a representative group of the population is called an odor panel (odor assessors).

This paper presents the fundamental math concepts of olfactomatics and several calculation methods used to produce usable odor testing data. The “Laws of Olfactomatics” include the concepts of the “power law”, “best estimate threshold”, geometric progression of ascending concentration series, logarithmic transformations, statistical significance of transformed logarithms, dimensionless dilution ratios, pseudo-dimensions, dose-response function (persistency), and inputs/outputs of dispersion models.

The Laws of Olfactomatics are:

0th Law	Odor is a Psychophysical Phenomenon
1st Law	Odor is Dimensionless
2nd Law	Odor is Suprathreshold
3rd Law	Odorant Dose causes Perceived Response
4th Law	Odor Pleasure is Subjective
5th Law	Odor Character is Objective

MAKING SENSE OF SMELL

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 a chemical odorant.

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 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.

In 1991, researchers Dr. Linda buck and Dr. Richard Axel at Columbia University discovered that over 1000 genes in the human body encode the olfactory receptors. This vast number of genes, almost one percent of all human genes, allows humans to perceive over 10,000 different odors.

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 a 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. The entire trip from the nostril to the signal in the brain takes as little as 500 milliseconds.

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 a tone is played. When multiple chemical odorants are present the result is a cord or specific perception. For example, if keys 1, 3, and 7 are "hit", then the brain perceives "banana." Likewise, if keys 4, 6, and 12 are "hit", then the brain perceives "sewer." The greater the number of odorant molecules present (higher concentration), the louder the cord is played. The loudness of the cord is analogous to the intensity of the odor perception [McGinley, M.A. 1999].

THE ZEROTH LAW : 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:

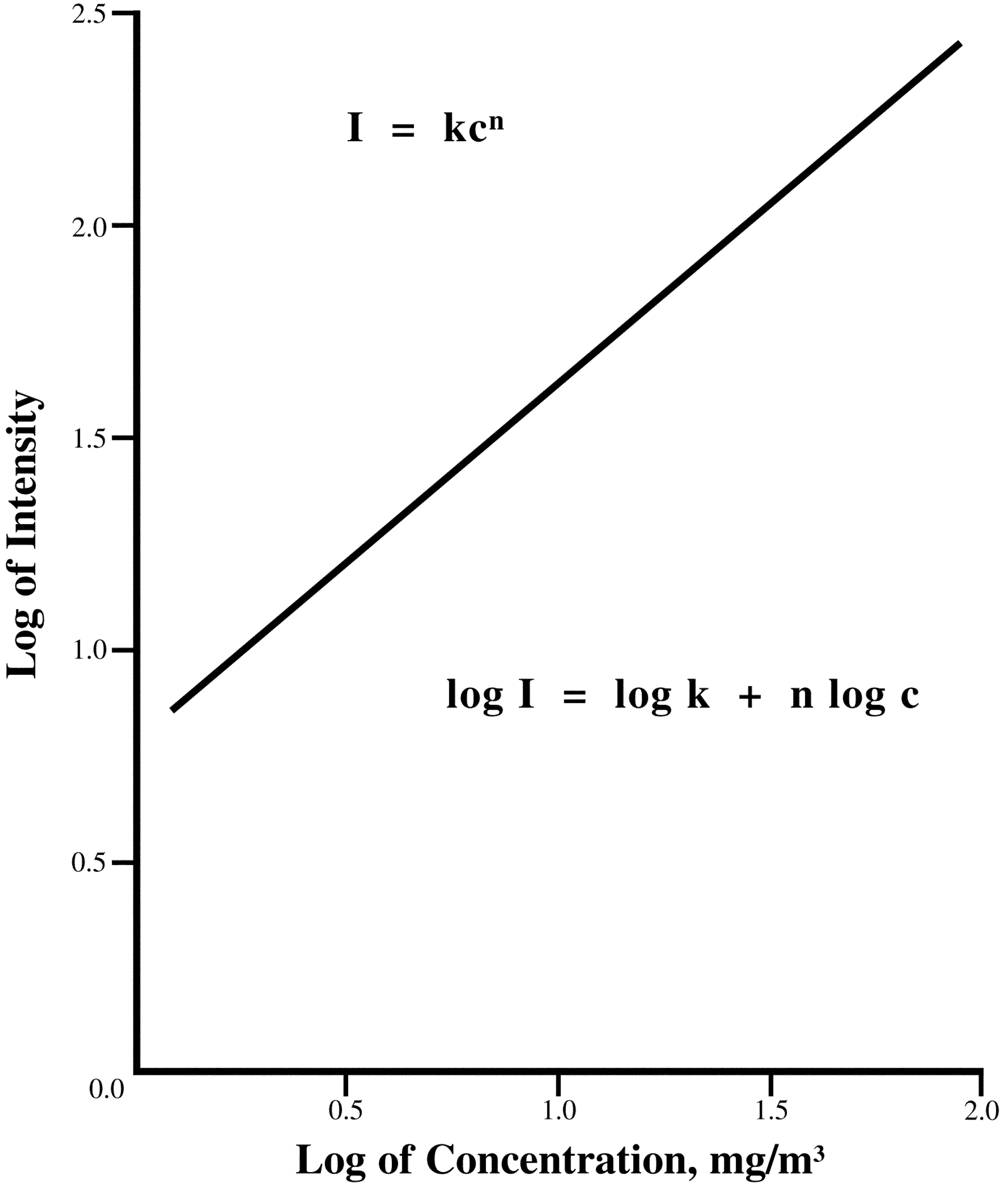
$$I = k\,C^n$$

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.

THE FIRST LAW : Odor is Dimensionless

The most common odor parameter determined during odor testing is "odor concentration" (odor strength). This determination is made using an instrument called an "olfactometer." In the United States the standard followed for olfactometry is ASTM Standard of Practice E679-91, "Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits." In 2000, the European Union will be following 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 when the standard is accepted as expected in 2000). 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 expected to be adopted in Australia, New Zealand, and much of the Pacific Rim. Therefore, "EN 13725" will become the de facto International Standard for odor/odour testing.

Figure 1: Power Law



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 [McGinley, C.M. 1999].

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

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

Figure 2: Odor Testing Data Sheet from Odor Evaluation Laboratory

Olfactometer Evaluation Results
AC'SCENT® International Olfactometer

Page 1 of 1

Test Name : Municipal WWTP
Test No. : 3847
Test Date : 12/17/99
Test Administrator : John Doe
Test Method : Triangular Forced Choice
Flow Rate (lpm) : 20
Sniff Time (sec) : 3

SAMPLE INFORMATION
Sampling Date : 12/16/99
Lab No. : 1
Field No. : 1864-25
Sampling Time : 13:55
Description : Scrubber B - Outlet
Sample Collector : Jane Smith
Sample Source : Scrubber B - Outlet

Dilution Level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	Calibration Date :
Sample Volume	0.3	0.6	1.3	2.5	5.0	10.0	20.0	40	80	160	320	640	1250	2500	12/17/99
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	THRESHOLDS
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	G = Guess
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	D = Detection
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	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

Friday, December 17, 1999

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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.”

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.

THE SECOND LAW : Odor is Supra-Threshold

Perceived odor intensity is the relative strength of the odor above the recognition threshold (suprathreshold). 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. 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].

THE THIRD LAW : Odorant Dose Causes Perceived Response

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):

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

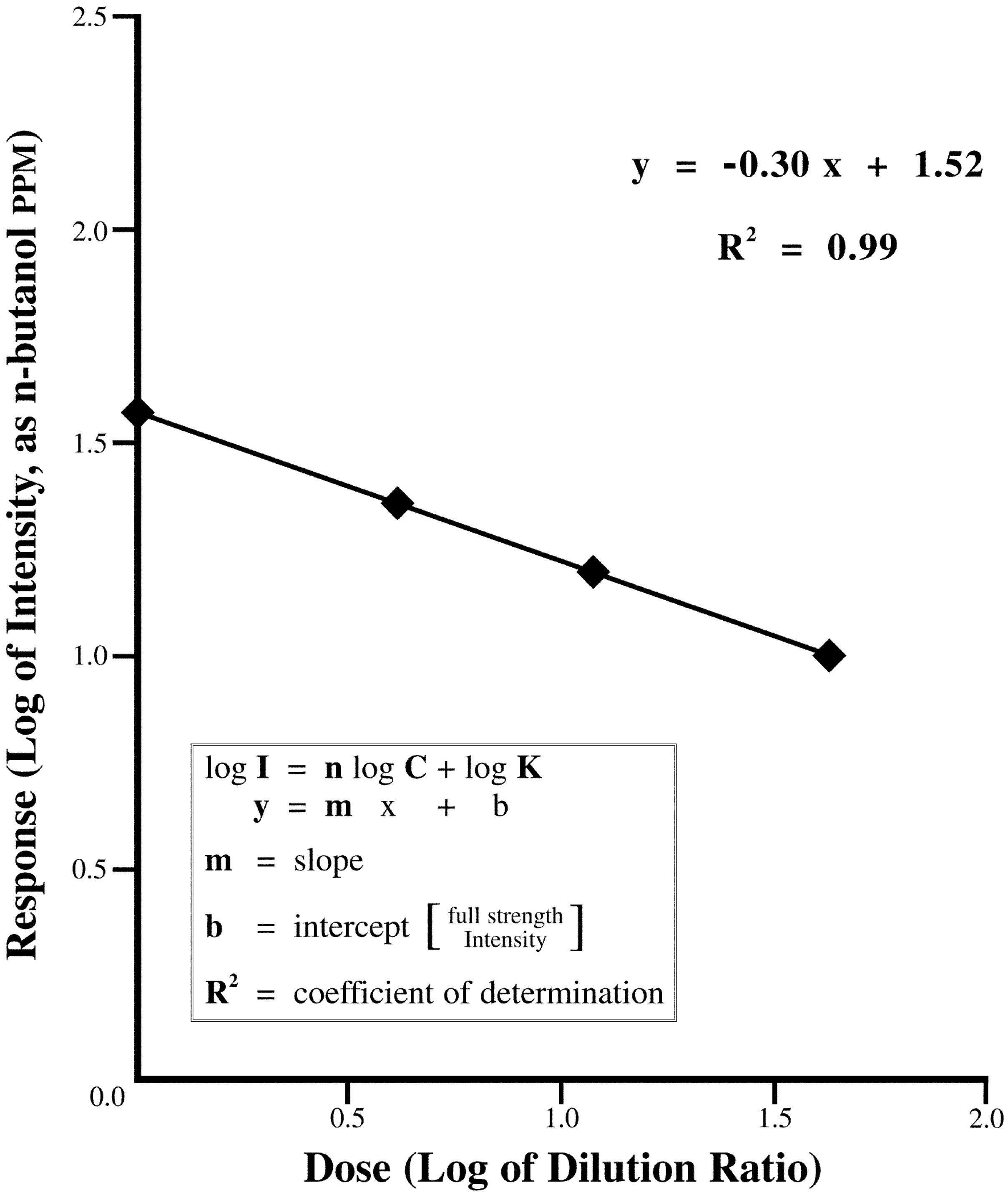
Through logarithmic transformation this function can be plotted as a straight line:

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

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,
i.e. hydrogen sulfide. 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, which may contain hydrogen sulfide and other odorous compounds.]

Figure 3: Odor Persistency
(Dose-Response)



THE FOURTH LAW : Odor Pleasure is Subjective

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.

THE FIFTH LAW : Odor Character is Objective

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.

As stated in the Fourth Law of Olfactomatics (Odor Pleasure is Subjective), through training, all assessors set aside their personal feelings and biases and make objective decisions regarding character identification by referencing standard designated categories.

EXAMPLE APPLICATIONS OF OLFACTOMATICS

A waste treatment plant operator plans to characterize two emission sources at the facility. The treatment plant operator wants to check the outlet performance of a chemical scrubber system and the performance of a biofilter as well as. The outlet performance specification of the chemical scrubber is 500 Odor Units [using the proposed European Standard method of olfactometry, prEN 13725]. The performance specification of the biofilter requires an odor removal efficiency of 90%.

The waste treatment plant operator collects the three samples and ships them overnight to an odor evaluation laboratory for analysis within 24 hours. Three days later the operator receives an odor evaluation report from the odor laboratory. This report is shown in Figure 6.

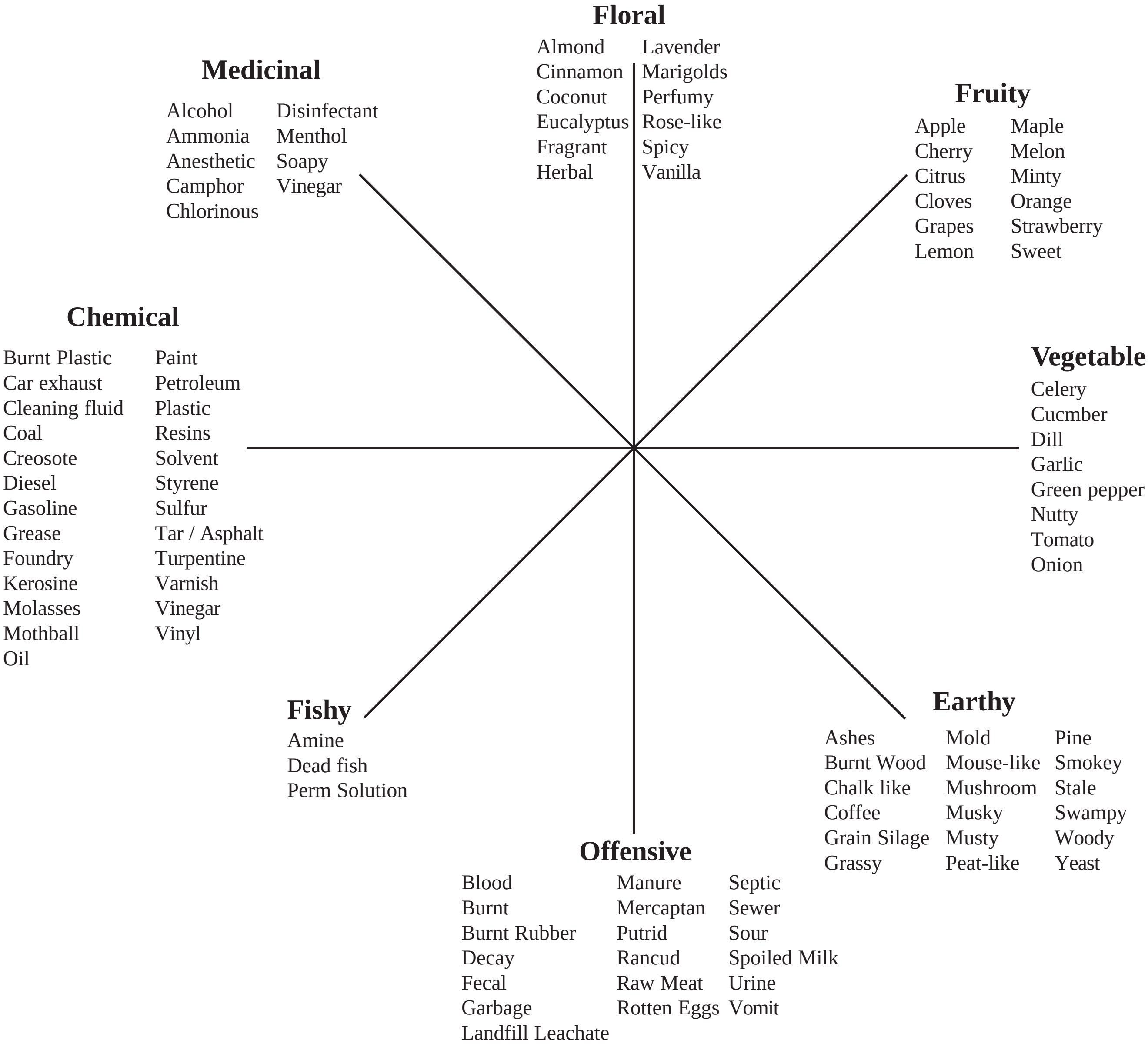
Before showing specific example calculations, it is important to again discuss the importance of the logarithm base 10 transformation that is used during odor testing. This transformation is used to make the non-linear dilution ratio scale a linear scale in logarithm base 10. More specifically, the transformation is 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 Intervals

With the odor testing results in hand, the waste treatment plant operator wants to determine if the chemical scrubber is meeting the outlet performance requirement of 500 Odor Units (O.U.) detection threshold. The reported Detection Threshold is 420 O.U. and this is indeed below 500 O.U. However, the operator wishes to investigate this value further by determining the 95% confidence interval of this detection threshold.

The waste water treatment plant operator obtained the standard deviation of the odor testing results from the odor evaluation laboratory. The reported standard deviation for the scrubber outlet was S_D=0.21. This is the standard deviation on the transformed scale of logarithms. The detection threshold of 420 O.U. is the result of the panel average based on the transformation of dilution ratios. This is a logarithm base 10 value of 2.62. The 95% confidence interval

Figure 4: Odor Descriptor Wheel



Floral

- Almond
- Cinnamon
- Coconut
- Eucalyptus
- Fragrant
- Herbal
- Lavender
- Marigolds
- Perfumy
- Rose-like
- Spicy
- Vanilla

Fruity

- Apple
- Cherry
- Citrus
- Cloves
- Grapes
- Lemon
- Maple
- Melon
- Minty
- Orange
- Strawberry
- Sweet

Vegetable

- Celery
- Cucmber
- Dill
- Garlic
- Green pepper
- Nutty
- Tomato
- Onion

Earthy

- Ashes
- Burnt Wood
- Chalk like
- Coffee
- Grain Silage
- Grassy
- Mold
- Mouse-like
- Mushroom
- Musky
- Musty
- Peat-like
- Pine
- Smokey
- Stale
- Swampy
- Woody
- Yeast

Offensive

- Blood
- Burnt
- Burnt Rubber
- Decay
- Fecal
- Garbage
- Landfill Leachate
- Manure
- Mercaptan
- Putrid
- Rancud
- Raw Meat
- Rotten Eggs
- Septic
- Sewer
- Sour
- Spoiled Milk
- Urine
- Vomit

Fishy

- Amine
- Dead fish
- Perm Solution

Chemical

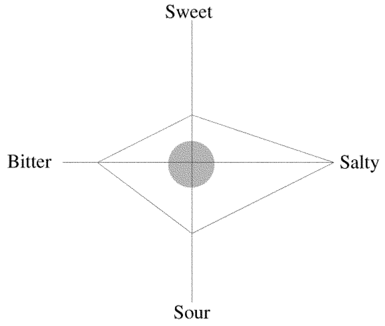
- Burnt Plastic
- Car exhaust
- Cleaning fluid
- Coal
- Creosote
- Diesel
- Gasoline
- Grease
- Foundry
- Kerosine
- Molasses
- Mothball
- Oil
- Paint
- Petroleum
- Plastic
- Resins
- Solvent
- Styrene
- Sulfur
- Tar / Asphalt
- Turpentine
- Varnish
- Vinegar
- Vinyl

Medicinal

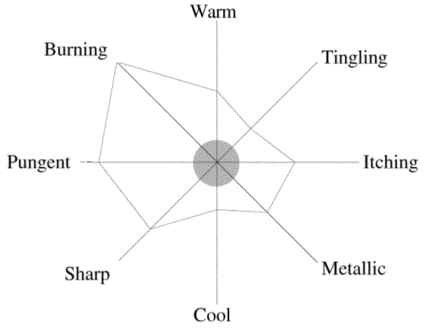
- Alcohol
- Ammonia
- Anesthetic
- Camphor
- Chlorinous
- Disinfectant
- Menthol
- Soapy
- Vinegar

Figure 5: Odor Characterization

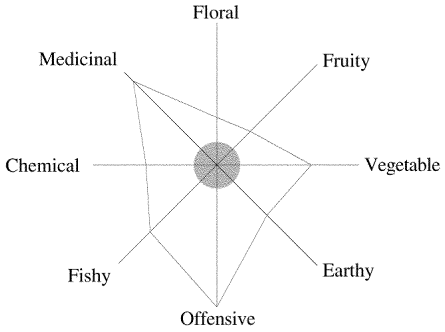
Example Taste Descriptor Graph



Example Sensation Descriptor Graph



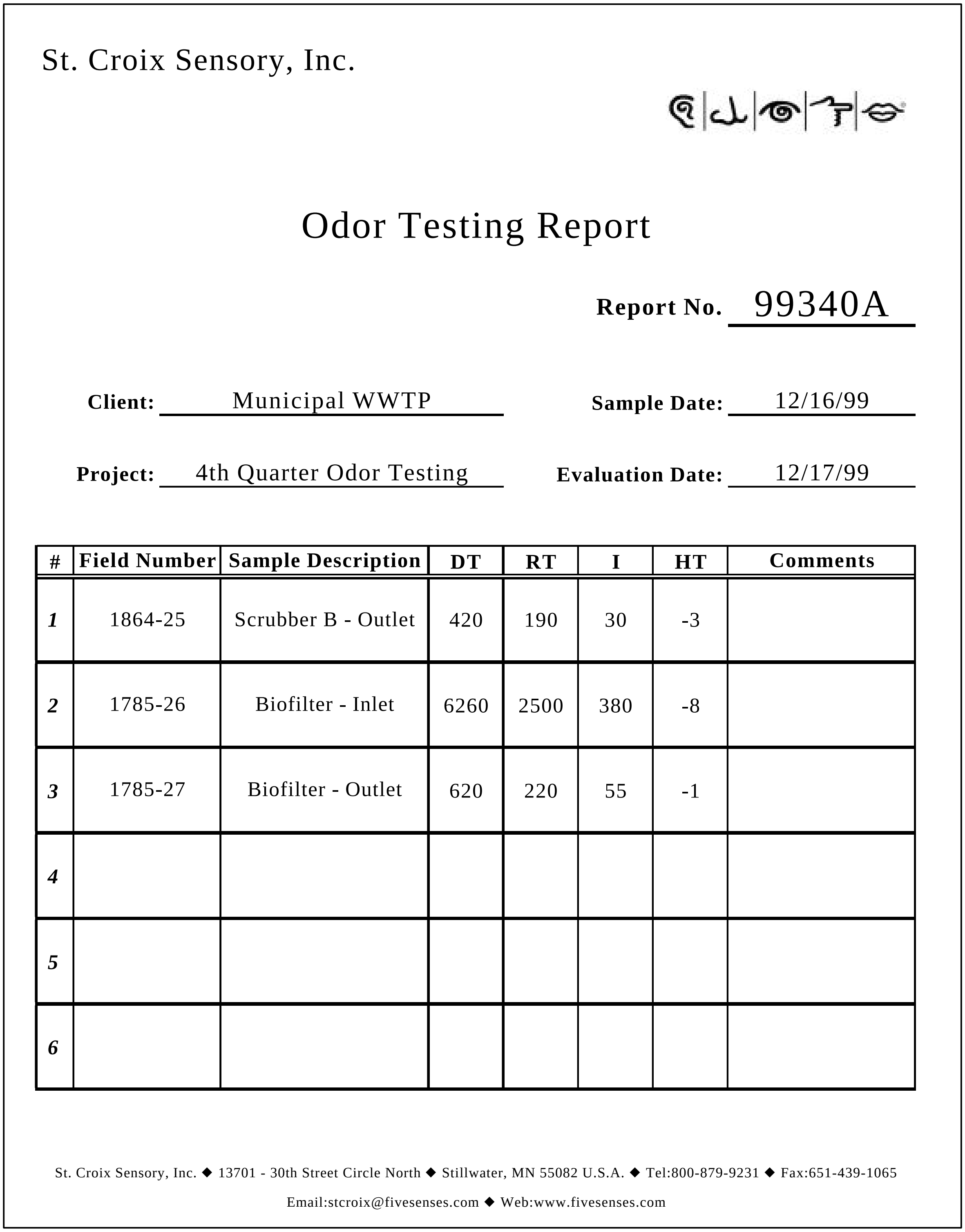
Example Odor Descriptor Graph



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	**************

Figure 6: Odor Testing Report from Odor Evaluation Laboratory



St. Croix Sensory, Inc.

Odor Testing Report

Report No. 99340A

Client: Municipal WWTP

Sample Date: 12/16/99

Project: 4th Quarter Odor Testing

Evaluation Date: 12/17/99

#	Field Number	Sample Description	DT	RT	I	HT	Comments
1	1864-25	Scrubber B - Outlet	420	190	30	-3	
2	1785-26	Biofilter - Inlet	6260	2500	380	-8	
3	1785-27	Biofilter - Outlet	620	220	55	-1	
4							
5							
6							

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(alpha=0.05) based on 8 assessors (degrees of freedom = 7) for the log transformed scale result can be calculated from:

$$95\% C.I. = \bar{x} \pm t \frac{S_D}{\sqrt{n}} = 2.62 \pm 2.365 \times \frac{0.21}{\sqrt{8}}$$

This gives a symmetrical confidence interval for the transformed scale:

$$2.62 \pm 0.176 \quad \text{or} \quad 2.444 \text{ to } 2.796$$

Transforming back to the original scale of dilution ratios gives an estimate of the geometric mean of the individual detection threshold estimates of 420 O.U. with an asymmetrical 95% confidence interval:

$$\text{Antilog}_{10}(2.444) = 280 \quad \text{and} \quad \text{Antilog}_{10}(2.796) = 625$$

Therefore, the 95% Lower Confidence Limit (LCL) is 280 O.U. and the 95% Upper Confidence Limit (UCL) is 625 O.U.

The scrubber outlet performance requirement of 500 O.U. more than likely did not include a confidence level review, therefore the scrubber would pass its performance test with the result of 420 O.U. However, the waste treatment plant operator now has information about this emission and what may actually be emitted during normal operations. For example, the scrubber outlet odor may be as high as 625 O.U. Furthermore, with this information design engineers may wish to adjust operating parameters in order to improve the outlet performance to meet the 500 O.U. requirement within 95% confidence. Likewise, an engineer may wish to use 625 O.U. in an odor dispersion model as a conservative modeling approach.

Statistical Significance

Another possible scenario is if the scrubber outlet performance requirement was 400 O.U. instead of 500 O.U. At face value the odor testing result of 420 O.U. would appear to show the scrubber failed the performance test. However, the treatment plant operator should look at the statistical significance of this value.

In order to compare the statistical significance of the 420 O.U. result compared to the 400 O.U. requirement, the assumption is made that the variance of the 400 O.U. requirement would be the same as the variance of the 420 O.U. test result. Therefore, the standard deviation of both results would be 0.21. Again, the logarithm base 10 transformation must be used for these calculations. The null hypothesis that 420 O.U. (log 420=2.62) **is statistically the same** as 400 O.U. (log 400=2.60) is tested with a student t test.

The test statistic (t) is computed from:

$$t = \frac{(\bar{x} - \mu)}{(\frac{S_D}{\sqrt{n-1}})} = \frac{2.62 - 2.60}{(\frac{0.21}{\sqrt{7}})} = 0.267$$

This value is compared with the t value for a two tailed test at 95% confidence (alpha=0.05) which is ±2.365. Since t=0.267 (p>0.2) is not larger than 2.365 (p>0.05), we cannot reject the null hypothesis and in this case 420 O.U. is statistically NOT significantly different from 400 O.U. While it appears that the chemical scrubber failed the outlet performance requirement, 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 scrubber failed.

Odor Abatement Efficiency

The waste water treatment plant operator turns attention to the biofilter odor testing results to determine the odor abatement efficiency (η_D). The odor testing results are used to first determine an odor emission rate. The odor emission rate (q_D) in O.U./sec is the product of the odor concentration (c_D) in O.U./m^3 and the volumetric flow of the emission location (V) in m^3/sec. The efficiency is then determined by:

$$\eta_D = \frac{q_{D,Crude} - q_{D,Clean}}{q_{D,Crude}} \times 100\% \quad \text{(prEN13725, 1999)}$$

Since the inlet and outlet volumetric flow rates in the treatment plant biofilter are equivalent, the efficiency can be calculated directly from the odor concentration values from the odor evaluation report. Therefore, in the case of the biofilter the odor abatement efficiency is:

$$\frac{6260 - 620}{6260} \times 100\% = 90.1\%$$

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 are understandable subjects for plant operators, facility managers, engineering practitioners, and citizens.

The nose works like the other four senses. The sense of smell responds to stimuli according to the power law, not according to a linear scale. For example, doubling the stimuli (i.e. chemical odorant) does not double the perceived odor strength.

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. In 2000 the proposed European Normalization Standard, prEN 13725, will be implemented and become the de facto "International Standard" for odor/odour testing.

Odor concentration results, such as detection and recognition thresholds, are dimensionless dilution ratios that follow a geometric progression. Since each dilution ratio is half the previous level (twice the amount of odor), the scale does not have an equal spread (variance) between values. Therefore, statistical calculations must use the logarithm base 10 transformed values, which follow a normal distribution (equal variance).

Understanding the basic "Laws of Olfactomatics" is the cornerstone for understanding odor issues.

The Laws of Olfactomatics are:

0th Law	Odor is a Psychophysical Phenomenon
1st Law	Odor is Dimensionless
2nd Law	Odor is Suprathreshold
3rd Law	Odorant Dose causes Perceived Response
4th Law	Odor Pleasure is Subjective
5th Law	Odor Character is Objective

The “Laws of Olfactomatics” include the concepts of the “power law”, “best estimate threshold”, geometric progression of ascending concentration series, logarithmic transformations, statistical significance of transformed logarithms, dimensionless dilution ratios, pseudo-dimensions, dose-response function (persistency), and inputs/outputs of dispersion models.

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

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