A Detailed Assessment of
The Science and Technology of Odor Measurement

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1.0 INTRODUCTION

Odors remain at the top of air pollution complaints to regulators and government bodies around the U.S. and internationally. Ambient air holds a mixture of chemicals from everyday activities of industrial and commercial enterprises.

A person's olfactory sense, the sense of smell, gives a person the ability to detect the presence of some chemicals in the ambient air. Not all chemicals are odorants, but when they are, a person may be able to detect their presence. Therefore, an odor perceived by a person's olfactory sense can be an early warning or may simply be a marker for the presence of air emissions from a facility. For whatever reason, it is a person's sense of smell that can lead to a complaint.

When facility odors affect air quality and cause citizen complaints, an investigation of those odors may require that specific odorants be measured and that odorous air be measured using standardized scientific methods. Point emission sources, area emission sources, and volume emission sources can be sampled and the samples sent to an odor laboratory for testing of odor parameters, such as odor concentration, odor intensity, odor persistence, and odor characterization. Odor can also be measured and quantified directly in the ambient air, at the property line and in the community, using standard field olfactometry practices, e.g. odor intensity referencing scales and field olfactometers.

Standardized measurement of odors from municipal, industrial and commercial facilities is typically required for the following purposes:

1. Monitoring for compliance assurance as part of permit requirements.
2. Determination of compliance for permit renewal.
3. Determination of baseline status for facility 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 operating 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.

The stakeholders for standardized odor measurement are: regulators, industries, citizens, environmental control equipment manufacturers, consultants, and researchers.

Presently, international standards are in place, which dictate the scientific methods and practices of odor measurement. These international standard methods for quantifying odor are: objective, quantitative, dependable, and reproducible.

From ASTM International:

- ASTM E679-91: *Standard Practice for Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits*

- ASTM E544-99: *Standard Practice for Referencing Suprathreshold Odor intensity*

From the Comité Européen de Normalisation (CEN)

- EN13725:2003: *Air Quality – Determination of Odour Concentration by Dynamic Olfactometry*

The following odor limits may be incorporated into odor regulations or into facility permits as compliance determining criteria when the standard odor testing methods are applied.

Ambient Odor Limits:

- Odor concentration as D/T or
- Odor intensity as part per million butanol.

Source Odor Limits:

- Odor concentration as odor units per cubic meter or
- Odor rates as odor units per second.

The intent of this report is to presents the basics of measuring odorous air. A brief explanation of "nasal anatomy" is presented in Section 2. In Section 3 odor parameters are defined and the basics of laboratory olfactometry are presented, including a description of odor panels. Section 3.7 presents the applicability of laboratory olfactometry including costs. Section 4 describes the history and present day practices of field olfactometry, including applicability. Section 5 presents how specific chemical odorants can be tested and the costs associated with their analysis. Section 6 introduces the subject of community odor studies and outlines several odor study methods. This report has seven appendices that include: odor terminology; methods for sampling odorous air; example odor analysis; statistics of odor data; details of odor intensity and persistency; examples of odor characterization; and a case study involving a community odor survey.

2.0 OLFACTORY ANATOMY

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 a natural aversion response to malodors and irritants. Human olfaction is a protective sense, protecting from tainted food and matter, such as rotting vegetables, putrefying meat, and fecal matter. 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 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. Sites on the olfactory cells, assisted by specialized proteins, receive the chemical odorant. The response created by the reception of a chemical odorant depends on the mass concentration, i.e. the number of odorant molecules. Each reception creates an electrical response of the olfactory nerves. A summation of these electrical signals leads to an action potential. If this action potential has high enough amplitude (i.e. 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. See Figure 2.1, Chemical Odorant vs. Odor Perception, which illustrates how an odorant creates the odor perception. The term **odor** refers to the perception experienced when one or more chemical substances in the air come in contact with the various human sensory systems (odor is a human response). The term **odorant** refers to any chemical in the air that is part of the perception of odor by a human (odorant is a chemical). Odor perception may occur when one odorant (chemical substance) is present or when many odorants (chemical substances) are present.

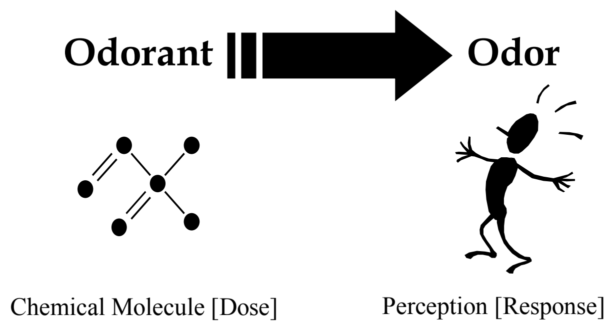

Figure 2.1 Chemical Odorant versus Odor Perception

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

3.0 LABORATORY OLFACTOMETRY

3.1 Overview of Odor Parameters

Odor is measurable using scientific methods. Odor testing has evolved over time with changes in terminology, methods, and instrumentation. Odor terminology is linked to standard methods and the instrumentation used in these standard methods. A clear understanding of odor terminology is needed in order to discuss the uses of odor measurements. See Appendix I for a detailed listing of odor terminology.

Four measurable, objective parameters of perceived odor are:

1. **Odor Concentration** – measured as dilution ratios and reported as detection threshold or recognition thresholds or as dilution-to-threshold (D/T) and sometimes assigned the pseudo-dimension of odor units per cubic meter.
2. **Odor Intensity** – reported as equivalent parts per million butanol, using a referencing scale of discrete butanol concentrations.
3. **Odor Persistence** – reported as the dose-response function, a relationship of odor concentration and odor intensity.
4. **Odor Character Descriptors** - what the odor smells like using categorical scales and real exemplars (e.g. fruity → citrus → lemon: from a real lemon).

These odor parameters are objective because they are measured using techniques or referencing scales dealing with facts without distortion by personal feelings or prejudices.

Additional measurable, but subjective, parameters of perceived odor are:

1. **Hedonic Tone** - pleasantness vs. unpleasantness.
2. **Annoyance** - interference with comfortable enjoyment of life and property.
3. **Objectionable** - causes a person to avoid or causes physiological effects.
4. **Strength** - word scales like "faint to strong".

These odor parameters are subjective because individuals relying on their interpretation of word scales and relying on their personal feelings, beliefs, memories, experiences, and prejudices to report them. Written guidelines for subjective odor parameter scales assist individuals (citizens and air pollution inspectors) in reporting observed odor, however, the nature of these parameters remains subjective.

3.2 Odor Panels

The origins of sensory evaluation and nasal organoleptic testing are in the trade industry. Products such as perfumes, coffee, tea, wine, liquors, meats and fish were sniffed or tasted to determine the quality of the product. Eventually, individuals became known as expert judges and were used to rate or grade products.

In the 1940's and 1950's great advancements took place in sensory testing by researchers performing sensory evaluation for developers of U.S. government war rations. Since that time, panels of trained sensory assessors have been the preferred method of evaluating sensory characteristics of products in a laboratory setting.

In the field of environmental engineering, odorous air samples can be collected from emission sources. Appendix II presents a case study of odorous air sample collection methods. Odor evaluation of odorous air samples is conducted under controlled laboratory conditions following standard industry practices using trained panelists known as assessors.

An odor laboratory is an odor-free, non-stimulating space. Each odor assessor, when working on odor evaluations, focuses on the task of observing the presented odor sample. Noise and distracting activities in the evaluation area can break the focus of the odor assessor. Odor panel sessions are organized and scheduled in order to maintain panel lengths not to exceed a period of 3-hours. Limiting panel length minimizes panelist fatigue.

Attention to the assessors' comfort and working environment nurtures their commitment and dedication to quality performance. The waiting area of the assessors is separated from the testing area. The assessors are provided water for drinking during the waiting time between sample testing. The assessors are not permitted to eat, chew gum, or drink beverages during a panel session. A comfortable and relaxing waiting area enhances a low stress environment for the assessors. A variety of activities are available to the assessors to help occupy their time, i.e. reading, puzzles, etc.

Odor assessors are recruited from the community at large. From a pool of on call assessors, five to twelve assessors are selected for a scheduled odor panel. Odor panels consist of assessors that are selected and trained following the "Guidelines for Selection and Training of Sensory Panel Members" (ASTM Special Technical Publication 758) and EN13725 (ASTM, 1981; CEN, 2003). A person who smokes, who uses smokeless tobacco, who may be or is pregnant, or who has chronic allergies or asthma is excluded as a candidate for the odor panel.

Standing **odor panel rules** are part of the assessor's agreement to participate in odor testing. Assessors:

1. Must be free of colds or physical conditions that may affect the sense of smell;
2. Must not chew gum or eat at least 30 minutes prior to the odor panel;
3. Must refrain from eating spicy foods prior to the odor panel;
4. Must not wear perfume, cologne, or after shave the day of the odor panel;
5. Must wear unscented deodorant the day of the odor panel;
6. Must avoid other fragrance cosmetics, soaps, etc. the day of the odor panel;
7. Must have their hands clean and free of odors the day of the odor panel;
8. Must have their clothes odor free the day of the odor panel;
9. Must keep the odor panel work confidential; and
10. Must not bias the other panelists with comments about the observed samples.

Each odor assessor is tested to determine their individual olfactory sensitivity using standard odorants, e.g. n-butanol and hydrogen sulfide. The assessor receives training that consists of olfactory awareness, sniffing techniques, standardized descriptors, and olfactometry responses.

With proper training of odor panelists, the communication between the panelists and the panel leader is clear, concise, and efficient. A well-organized efficiently conducted odor panel ensures quality odor evaluation work.

3.3 Determination of Odor Concentration in the Laboratory

The most common odor parameter determined by odor testing is odor concentration. Odor concentration is determined using an instrument called an olfactometer and is expressed as a dilution factor (dilution ratio). Odor concentration is reported as the Detection Threshold (DT) and Recognition Threshold (RT). Several advances in technology and standard practice have changed the science of olfactometry over the last 50 years and the new millennium began with the publication of a new internationally accepted standard for determination of odor concentration.

In the 1950's, sensory evaluation in the laboratory came into practice to quantify the strength of odorous air emissions. Laboratory olfactometry involves diluting the odorous air sample at varying concentrations then presenting the diluted odor to human assessors to determine the threshold of the odorous emission. The laboratory dilution process simulates the dilution of the odor in the ambient air. Figure 3.1, "Dilution of Odor in the Ambient Air", illustrates how the wind dilutes odorous air emissions.

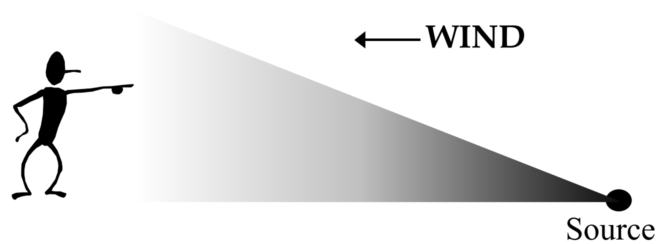

Figure 3.1 Dilution of Odor in the Ambient Air.

3.3.1 ASTM D1391

In 1957, the ASTM International E-18 Sensory Evaluation Committee approved and published a method for measuring environmental odors in a laboratory setting, which was originally developed by the Los Angeles Air Pollution Control District (Mills et. al., 1963). The ASTM standard D1391 was called, "Measurement of Odor in Atmospheres" (ASTM, 1978). The D1391 standard came to be known as the syringe static dilution method because it used 100-mL glass syringes to dilute the odorous air with odor free air. The practice involved presenting assessors syringes of diluted odorous air samples with syringes of odor-free air. The assessors would then report which syringe contained the odor sample (Benforado, 1969).

The cumbersome nature of static dilution methods, like ASTM D1391, led to the development of dynamic olfactometers, which were designed to perform the dilutions of the odorous air automatically and continuously.

3.3.2 ASTM E679

In 1979, ASTM International published E679-79, "Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits." This method was based on the use of dynamic olfactometry to automatically perform the dilutions of the odorous air and then present the dilution mixture to the human assessors. In March 1985, the ASTM E18 Committee officially withdrew the "Syringe Method", D1391, from publication. The dynamic dilution method, E679, was subsequently revised in late 1991 and later re-approved in 1997.

The ASTM E679 procedure is based on a presentation method called 3-alternative forced-choice (3-AFC) or triangular forced-choice (TFC). Each assessor performs the odor evaluation task by sniffing the diluted odor from an olfactometer. The assessor sniffs three sample presentations; one contains the diluted odor while the other two are blanks (odor-free air). Figure 3.2 shows one assessor (left) sniffing from the olfactometer nasal mask while the test administrator (right) operates the olfactometer. The assessor is required, or forced, to choose one of the three presentations. The assessor acknowledges their choice as a guess, a detection or recognition. As defined by E679 a response of detection is determining the selection is different from the other two, and a recognition response is that the sample smells like something.

Figure 3.2 Assessor (left) sniffing at a dynamic dilution olfactometer.

The assessor is then presented with the next dilution level. The assessor is again presented with three sample choices, one of which is the diluted odor sample. However, this next dilution level presents the odor at a higher concentration (e.g. two times higher). This is one-half the dilution ratio. The first dilution level presented to the assessors is below the odor thresholds (sub-threshold). The assessor proceeds to higher levels of sample presentation following these methods. The statistical approach of increasing the concentration is called "ascending concentration series."

The convention of calculating dilution factors for olfactometry is based on the ratio of Total Volumetric Flow divided by Odorous Sample Flow (Turk, 1973; Dravnieks et. al., 1979, 1980, 1986; ASTM, 1978; ASTM, 1991; AWMA, 1995, CEN, 2003):

$$Dilution\_Factor = \frac{V_d + V_o}{V_o} = Z$$

Where V_d is the volumetric flow rate of odor-free, dilution air and V_o is the volumetric flow rate of the odorous air sample. The dilution factor, 'Z', is used in modest honor of H. Zwaardemaker, a Dutch scientist and early investigator in olfactometry.

Alternative terminology in use includes: Dilution-to-Threshold Ratio (D/T), Odor Unit (OU), and Effective Dose at 50% of the population (ED50) (ASTM, 1991).

A large dilution ratio (e.g. 65,000) represents a high dilution of the odor sample. A high dilution of odor is similar to a person standing at a great distance from the odorous emissions. A small dilution ratio (e.g. 8) represents a small dilution of the odor sample. A small dilution of the odor is similar to a person standing close to the odorous emissions.

The odor concentration results from olfactometry testing are expressed as a detection or recognition threshold. The detection threshold (DT) is an estimate of the number of dilutions needed to make the actual odor emission non-detectable. The recognition threshold (RT) represents the number of dilutions needed to make the odor sample faintly recognizable.

A detection threshold for an odorous air sample is larger than its recognition threshold value, because more dilutions with odor-free air are needed to make the odor non-detectable compared to making the odor faintly recognizable. A large value of odor concentration (DT or RT) represents a strong odor. A small value for odor concentration represents a weak odor.

The odor panel used for the ASTM E679 test procedure consists of 6-12 trained and experienced human assessors. The assessors are selected from the general population as assessors with no specific hypersensitivity or Anosmia (lack of sensitivity) to odors. The assessors are selected and trained following standard procedures (ASTM, 1981). The odor concentration is a number derived from the panel of assessors' responses to the laboratory dilution of odorous air samples. Appendix III provides a detailed example of the determination of the odor concentration, detection and recognition thresholds, of one odorous air sample.

3.3.3 EN13725

During the 1980's, countries in Europe began developing standards of olfactometry. Some of these standards developed and published include:

France	AFNOR X-43-101 (drafted in 1981 & revised in 1986)
Germany	VDI 3881, Parts 1-4 (drafted in 1980 & revised in 1989)
Netherlands	NVN 2820 (drafted in 1987 & issued in 1995)

Various inter-laboratory studies as well as collaborative projects involving multiple odor testing laboratories in the '80's showed that laboratory results still differed significantly even with these standard practices (Heeres et. al., 1990).

The development of a draft odor testing standard in the Netherlands led to an International Laboratory Comparison study organized in 1989 (Hermans, 1989). N-butanol and hydrogen sulfide were used as standard odorants for the study. Through 1990 to 1992, the results of this Dutch Inter-Laboratory study led to the development of strict assessor performance criteria. During the first year, the inter-laboratory repeatability was in the range of factors from 3 to 20. An analysis of the data from the first year showed the majority of variability was between assessors. Individual assessors were repeatable within a factor of 3 to 5.

Van Harresveld presents a clear conclusion resulting from this study in his 1999 publication in the Journal of the Air & Waste Management Association, "A Review of 20 Years of Standardization of Odor Concentration Measurement by Dynamic Olfactometry in Europe." He states: "The notion that the panel should be representative of the general population was explicitly abandoned…" The researchers found that the only way to meet the agreed upon repeatability criteria was to control the instrument sensor, the human assessors, by selecting assessors who were all similar in sensitivity (van Harresveld, 1999).

Standards were then set for assessor performance to a standard odorant, n-butanol. Only assessors who met predetermined repeatability and accuracy criteria were allowed to continue as assessors (average n-butanol odor threshold of 20-80ppb and log standard deviation of <2.3). Over the next two years, these new criteria were implemented within each of the laboratories involved in the study.

In 1993, a final round of testing yielded an inter-laboratory repeatability of a factor of 2 to 3. The Dutch inter-laboratory study from 1989 to 1993 showed a convergence towards the agreed upon n-butanol reference threshold through the improved repeatability of results. The results in March 1993 showed the benefit of all laboratories implementing assessor selection criteria (Klarenbeek, 1995).

The work of this inter-laboratory study led to the final Dutch standard released in 1995 and set the foundation for the development of a new European odor testing standard.

A working group formed within the Comité Européen de Normalisation (CEN), Technical Committee 264 – "Air Quality", to develop a unified European olfactometry standard. This working group saw a need to help the industry and regulators develop a consistent basis for monitoring and testing odors, and, thus help determine the potential for odor nuisance. This was to be accomplished by developing a method that:

1. Improved consistency within each laboratory (repeatability);
2. Achieved comparable results among laboratories (reproducibility); and
3. Connected the results to a traceable reference material, e.g. n-butanol (accuracy)

In order to achieve these goals, the committee focused on the following issues:

1. Sampling procedures,
2. Sample containers,
3. Olfactometer construction and operation,
4. The olfactometer and assessor interface,
5. The odor testing room,
6. Methods of data processing, and
7. Assessor selection, training, and performance.

The first complete draft of the European olfactometry standard was released in 1995. Then in the spring and summer of 1996, nineteen laboratories from five countries participated in an Inter-Laboratory Comparison of Olfactometry ("ICO") study. The purpose of the study was to validate the requirements, methods, and procedures outlined in the draft standard. The conclusions of this study were:

1. All quality requirements and performance criteria were attainable for all testing methods studied (Forced-Choice and Yes/No); and

2. Those labs following the standard for the longest period of time performed the best with regards to accuracy and repeatability (van Harreveld, 1999).

The CEN olfactometry standard was released to the public at the end of 1999 through the standard organizations of each participating country. The standard was released as Proposed CEN standard #13725 (prEN13725) "Air Quality – Determination of Odour Concentration by Dynamic Olfactometry" (CEN, 1999). A public comment period closed at the end of January 2000. Comments were submitted to each country's standardization body separately. These comments were reviewed in early 2000. The working group met in 2000 to review all comments and issue a final revision of the standard. The final revision was sent to the CEN organization in 2001 for final translation and official voting. The standard was approved and published in 2003 (CEN, 2003).

The approval of this final version of the CEN standard, EN13725, obligates all countries of the European Union to adopt the standard and withdraw any conflicting or redundant national standards. These countries include: Austria, Belgium, Denmark, Finland, France, Greece, Germany, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

The final standard was published in three official languages: English, French, and German. The standards are distributed through the individual country standardization organizations. For example, an English language copy can be obtained from the British Standards Institute (BSI), www.bsi.org.uk, under the designation "BS EN 13725:2003."

3.3.4 International Standardization

The new European standard has been adopted by Standards Australia and Standards New Zealand as AS/NZS 4323.3:2001 (AS, 2001). The standard has also been referenced by national organizations in Singapore, Thailand, and several other S.E. Asian countries. Furthermore, government agencies and universities throughout North America are following or are working towards adoption of the EN13725 standard. Examples of the government agencies include:

1. Agriculture Canada
2. City of Los Angeles, California
3. Los Angeles County, California
4. Metropolitan Council in St. Paul, Minnesota

Examples of the universities include:

1. Duke University
2. Iowa State University
3. Purdue University
4. University of Alberta
5. University of Illinois
6. University of Manitoba
7. University of Minnesota
8. West Texas A&M University

Therefore, EN13725 has become the de facto international standard for odor testing.

In 2000, an inter-laboratory comparison study was conducted involving 28 laboratories from four countries. This study involved each laboratory testing four standard odorants: n-butanol, hydrogen sulfide, tetrahydrothiopen, and a coffee odor mixture. The 28 laboratories were grouped into three categories based on their level of adherence to the draft standard, prEN13725:

Class 1: *Compliant*.	The laboratory fulfills all the quality criteria of prEN13725.
Class 2: *Essential Compliant.*	The lab observes the most important quality criteria of prEN13725.
Class 3: *Non-compliant.*	The lab does not adhere to the requirements of prEN13725.

The results of this study were reported at the 2001 International Water Association (IWA) First International Odour Conference (Mannebeck, 2001). This study confirmed that laboratories working in compliance with the requirements of prEN13725 achieved a significantly better repeatability than the labs that were not compliant. The results produced by these laboratories were also closer to accepted thresholds for the reference compounds.

In 1995, the Air & Waste Management Association (A&WMA) EE-6 Odor Committee formed a subcommittee on the "Standardization of Odor Sampling and Measurement." The EE-6 subcommittee developed "Guidelines for Odor Sampling and Measurement by Dynamic Dilution Olfactometry" and submitted a final draft, dated 23 August 2002, for review by the ASTM International E18 Sensory Committee.

In 2003, the E18 Sensory Committee is conducting a comprehensive review of ASTM E679, the elements of the A&WMA guidelines, and the EN13725 standard. Furthermore, researchers from several university agricultural engineering departments have formed a committee within the American Society of Agricultural Engineers (ASAE) to develop a set of agricultural odor sampling and measurement standards based on EN13725. The basic elements of this new standard are being developed as part of a large study, called "Ariel Pollutant Emissions from Confined Animal Buildings," investigating air quality related to feedlot operations currently involving five university odor laboratories in the U.S. (Iowa State University, Purdue University, University of Illinois, University of Minnesota, and West Texas A&M University).

Ultimately, it is critical to understand that if a laboratory follows the EN13725 test method using a 3-Alternative (triangular) Forced-Choice presentation method, the laboratory will be meeting all requirements of ASTM E679 and the A&WMA EE-6 Odor Committee Guidelines. The additional requirements of EN13725 will improve the repeatability, reproducibility, dependability, and accuracy of all odor analyses performed by the laboratory.

3.4 Odor Intensity

Perceived odor intensity is the relative strength of the odor above the recognition threshold (suprathreshold). Odor intensity is measured using several methods including: descriptive word category scales, magnitude estimation, and referencing scales.

Descriptive word category scales have the assessor rate the odor on a scale. One such scale used is a 5-point scale where zero is “no odor” and the other five points correspond to “barely perceptible,” “slight,” “moderate,” “strong,” and “very strong.” The shortcomings of this approach are that the five points on the scale do not represent a linear increase in perception and that each assessor may interpret the scale differently, regardless of the assessor’s training.

Magnitude estimation is a procedure where the intensity of one odor is compared to another odor. For example, the assessor would be presented odor sample A. The assessor would give the intensity of this odor an arbitrary value such as “50.” The assessor would then be presented with sample B, and they would provide a rating based on sample A. Therefore, if sample B were perceived as half as intense as sample A, the assessor would give sample B an intensity of “25.” This method is very difficult to compare across many odors. It is best suited for comparing similar odors.

ASTM E544-99, “Standard Practice for Referencing Suprathreshold Odor Intensity,” presents two methods for referencing the intensity of ambient odors to a standard scale: 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 (n-butanol) for presentation to an assessor. The assessor compares the observed intensity of an odorous air 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 practice by odor laboratories, because of its low cost of set-up compared to an olfactometer device (Turk, 1980).

The butanol referencing method of quantifying odor intensity is the most commonly used method in evaluating environmental odors. Butanol concentrations are a referencing scale for purposes of documentation and communication in a reproducible format. For this method, the odor intensity result is expressed in parts per million (PPM) of n-butanol. A larger value of butanol means a stronger odor. A small value of butanol means a weaker odor.

Another important aspect of the butanol intensity referencing scale is the variety of available scales. Figure 3.3, Example Odor Intensity Referencing Scales (OIRS), presents four common scales. The specific olfactometer device determines the dilution levels of the Dynamic-Scale Method used by laboratories and field investigators. The 8-point OIRS is the common dynamic scale used by odor laboratories. 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 are 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 (i.e. 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.

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

KEY: < XXX > is Parts Per Million n-Butanol Equivalent Odor Intensity

Figure 3.3 Example Odor Intensity Referencing Scales (OIRS)

3.5 Odor Persistency

Odor is a psychophysical phenomenon. Psychophysics involves the response of an organism to changes in the environment perceived by the five senses (Stevens, 1960). Examples of psychophysical phenomenon include how the human body perceives sound loudness, lighting brightness, or odor intensity.

In the 19th Century, E.H. Weber proposed that the amount of increase in a physical stimulus, to be just perceivably different, was a constant ratio. This relationship can be expressed as:

$$\Delta I/I = \Delta C/C = k$$

Where:

I is the stimulus intensity,
C is the measurable amount or concentration of stimulus, and
k is a constant that is different for every sensory property and specific stimulus.

As an example, this expression means that there would be the same perceived increase in intensity when changing a concentration of sugar in water from 10% to 11% as when changing the concentration from 20% to 22%.

In 1860, G.T. Fechner expressed the Weber law somewhat differently by plotting the perceived intensity versus the stimulus magnitude on a semi-log scale (Fechner, 1860). Fechner's Law was expressed as:

$$I = k \log C + b$$

In the 1950's and 1960's, through his work at Harvard University, S.S. Stevens proposed that apparent odor intensity grows as a power function of the stimulus odorant. Stevens showed that this Power Law (Steven's Law) follows the equation (Stevens, 1957, 1962):

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

Where:

I is the odor intensity,
C is the mass concentration of odorant (e.g. milligrams/cubic meter, mg/m^3), and
k and **n** are constants that are different for every specific odorant or mixture of specific odorants.

As shown in Figure 3.4, "Power Law for a Single Odorant", this equation is a straight line when plotted on a log-log scale. The x-axis is the mass concentration (mg/m3) of the single odorant. The upward slope of the graph illustrates that the odor intensity of the single odorant increases as the mass concentration increases. The slope of the power law is less than one for odors since it takes a larger and larger increase in concentration to maintain a constant increase in perceived intensity. Steven's Law has been used most often in modern odor science (Dravnieks, 1979; O'Brien, 1991; Prokop, 1992).

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 dilution at different rates for different odors. Figure 3.5, "Dose-Response of an Odor Sample", illustrates how odor intensity decreases as the odor is diluted. Odor intensity is related to the odor concentration (dilution ratio) by the Power Law (Steven's Law):

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

Where:

I is the odor intensity,
C is the dilution ratio and
k and **n** are constants for each odor sample.

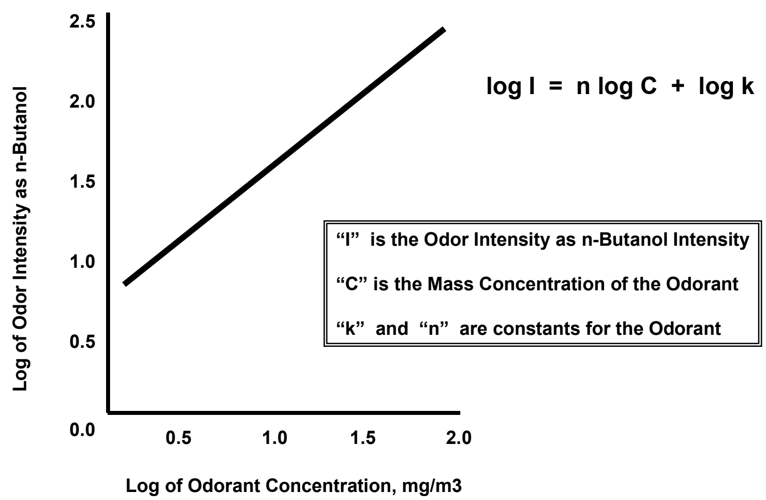

Figure 3.4 Power Law of a Single Odorant

Through logarithmic transformation this function can be plotted as a straight line as illustrated in Figure 3.5:

$$\log I = n \log C + \log k$$

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 (Dravnieks, 1980). Plotted as a straight line on a log-log scale, the result is a linear equation specific for each odor sample. 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 logarithm of the constant k is related to the intensity of the odor sample at full strength (Dravnieks, 1986), i.e. the y-axis intercept.

Note that comparing Figure 3.4 to Figure 3.5, Figure 3.4 has a positive slope, because the concentration (x-axis) is the mass concentration in mg/m^3 of the odorant, e.g. hydrogen sulfide. The log-log plot in Figure 3.5 has a negative slope because the concentration (x-axis) is the dilution ratio of an odor sample. See Appendix V for example odor intensity and persistency data and related dose-response graphs.

Other researchers have investigated other relationships between odor intensity and dilution ratios (Cain et. al., 1974). For example, in 1999 Chen et.al. found that while the Power Law and the less common Beidler model described the data effectively, the Beidler model showed the best fit of the relationship between odor intensity and the threshold dilution ratio for the hog manure in the study (Chen et. al., 1999).

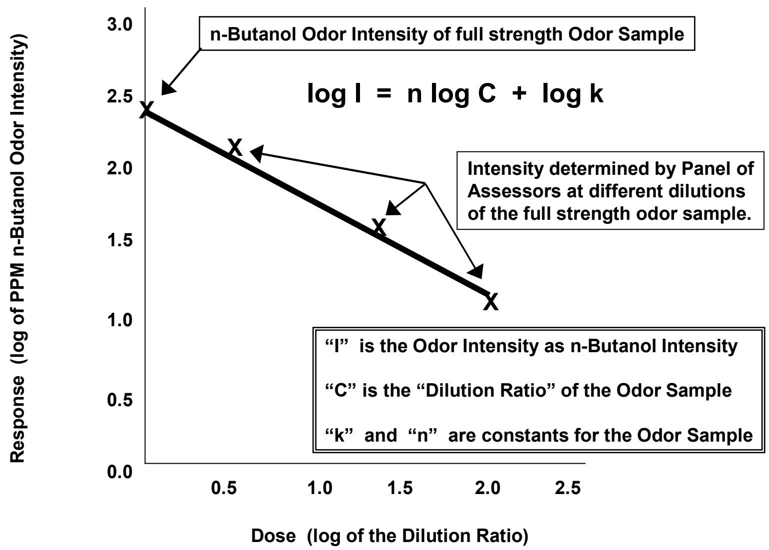

Figure 3.5 "Dose-Response" plot of an Odor Sample

3.6 Odor Characterization

Descriptive analysis is a sensory science term used to describe the action of a panel of assessors describing attributes about a product or sample (qualitative) and scaling the intensity of these attributes (quantitative). The food, beverage, and consumer product industries have formally used descriptive analysis to obtain detailed information about the appearance, aroma, flavor, and texture of products for well over 50 years.

The earliest perfumers and chemists used their senses to characterize chemicals in their industry. Experts in wine, tea, coffee, and other industries have long used their senses to characterize their products for trade and commerce. The first formal, systematic descriptive procedure was the Flavor Profile Method developed at A.D. Little Corp. in the late 1940's.

Odor character, often called odor quality, is a nominal scale of measurement. Odors can be characterized using reference vocabulary. Standard practice has been to provide assessors with a standard list of descriptor terms, which are organized with like terms in groups. Similarly, terms with negative connotation (unpleasant) would be grouped with other negative terms and positive (pleasant) terms with other positive terms (Harper, 1968).

In the 1970's American and British brewing and sensory scientists developed a "Beer Flavor Wheel" as a tiered system for describing the flavor (taste and odor) of beers (Meilgaard, et.al., 1982). In the 1980's, the California wine industry developed a wine aroma wheel for the characterization of wines (Noble, 1984).

A descriptor wheel is organized with general descriptors at the center of the wheel and more specific characters are listed towards the wheel rim. For example, an assessor may identify a flavor as **fruity** (general first tier description) and move out on the wheel through **berry** and **raspberry**.

A similar descriptive analysis approach has been used in the environmental odor evaluation industry. Numerous standard odor descriptor lists are available to use as a reference vocabulary by assessors. In 1986, the International Association on Water Pollution Research and Control (IAWPRC) proposed eight major odor descriptor categories for describing odors from natural waters and illustrated the eight categories in an odor wheel: vegetable, fruity, floral, medicinal, chemical, fishy, offensive, and earthy (AWWA, 1987; Bartels, et. al., 1989). At around the same time, ASTM published a document titled, "DS-61: Atlas of Odor Character Profiles," which published a standard odor descriptor list of 146 terms (Dravnieks, 1985).

This list of 146 terms was condensed down from a master list of 800 terms. The ASTM International E18 Sensory Evaluation Committee originally compiled this master list of 800 terms from published literature and industrial organizations (Dravnieks, 1985). The Committee organized a group of 100 professionals from several different industries to rate the usefulness of the terms and create a more manageable standard list (Dravnieks, 1978).

The standard lists are used as a basis for description of environmental odorous air samples. Figure 3.6, is an odor descriptor wheel developed by St. Croix Sensory for use with environmental odor samples. The eight main odor categories are based on the original IAWPRC odor wheel for water samples.

Each of the eight major categories has specific descriptors, which can be presented in training using exemplars. For example, the major category **vegetable** consists of a vocabulary of words that are illustrated with real life items known as exemplars: e.g. celery, cucumber, garlic, onion, tomato, etc.

Assessors observe the odorous air sample and report which general and specific odor descriptors they notice.

When an odor descriptor is assigned to an odor, the main odor descriptor categories can be rated in relative intensity on a 1 to 5, faint to strong, scale (0=not present). The odor testing descriptor data can then be plotted on a spider plot (radar plot) format with the distance along each axis representing the 0-5 scale for each of the categories. The plot creates a pattern that can be readily compared to spider plots for other samples. See Appendix VI for example character descriptor spider plots. Specific odor descriptors can be presented also in a histogram where each reported descriptor is listed along with the percent of reporting assessors.

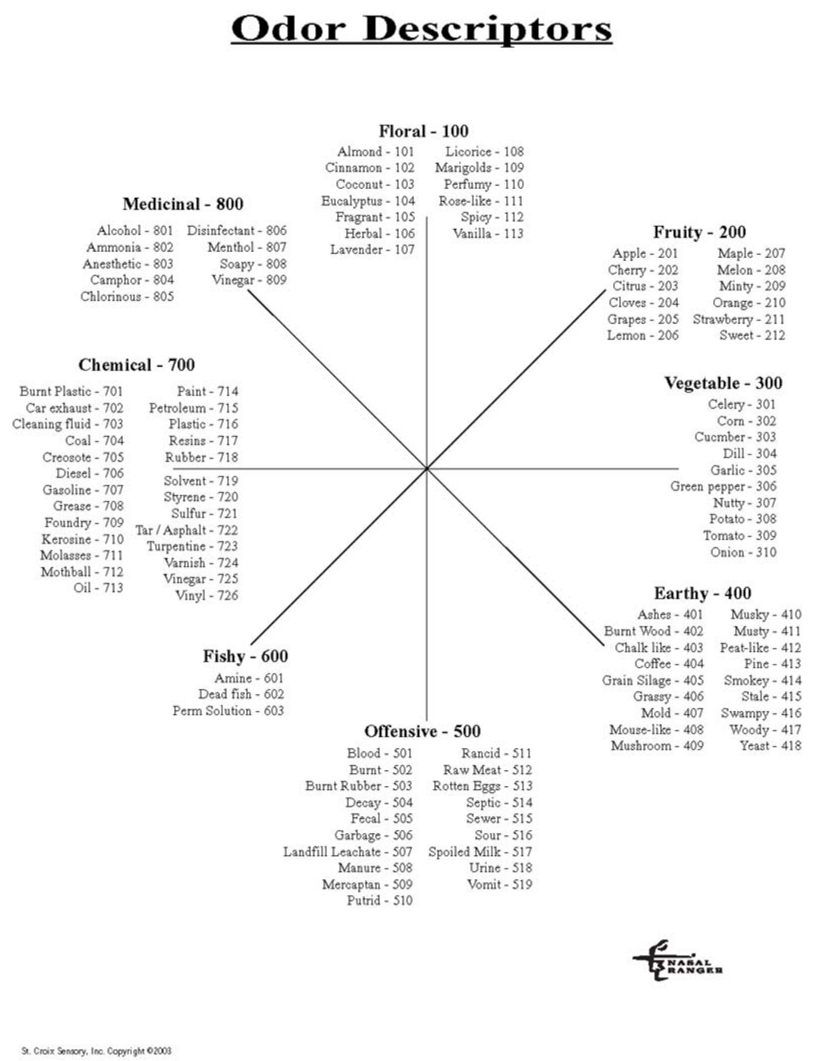

Figure 3.6 Odor Character Wheel Developed by St. Croix Sensory from other Standard Odor Character Lists.

Beyond character descriptors, other attributes of the odor can be characterized using similar profiling methods. For example, the perception of taste is sometimes experienced in evaluation (sniffing) of certain odors. The four (4) recognized taste descriptors are salty, sweet, bitter, and sour. Assessors may rate the strength of these taste descriptors noticed while observing the odor. 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…" rather than "smells like…"). Eight (8) common sensation descriptors that can be used include: itching, tingling, warm, burning, pungent, sharp, cool, and metallic. Again, assessors can rate the strength of the presence of these attributes.

3.7 Applicability of Laboratory Olfactometry

3.7.1 Odor Investigations and Studies

When odor is present in the ambient air and causes citizens to complain, investigation by trained personnel is prescribed. Investigators verify citizen complaints through actions of complaint response and surveillance of the probable sources of odor. Laboratory olfactometry often is a part of or follows field odor investigations and studies. Investigators use field olfactometry (See Section 4.0) to measure and quantify the odor in the ambient air and to identify the probable odor source(s).

The collection of whole-air odor samples (See Appendix II) and the testing of the samples in an odor (olfactometry) laboratory may be:

(1) Part of a developing investigation (i.e. enforcement actions),
(2) Part of an odor study (i.e. comparing or ranking odorous processes),
(3) Part of an odor control system performance test (i.e. manufacturer's guaranty), or
(4) Part of a routine performance test at a facility (i.e. compliance test required by permitting authorities).

Odorous air samples are collected from point emission sources (i.e. stack or vent) and from surface emission sources (i.e. liquid surface or solid surface). Whole-air odor samples are typically collected in 10-liter Tedlar gas sample bags ($20.00 sample bag cost) and express-transported (i.e. priority overnight via FedEx or UPS) to an odor-testing laboratory.

Odor laboratory analysis of whole-air odor samples is cost effective for determination of:

- Odor concentration,
- Odor intensity,
- Odor character (descriptors), and
- Odor persistency (dose-response function).

Per sample analysis cost for odor testing is approximately $200 for one sample analysis to determine odor concentration. The approximate cost to determine odor intensity, odor character and odor persistency, in addition to odor concentration, is approximately $100. Therefore, the approximate total cost for a full odor analysis is approximately $300 per whole-air odor sample.

Engineers, managers, and regulators who are planning odor mitigation can use the results of laboratory olfactometry odor testing to assist in their decision-making.

3.7.2 Odor – Air Dispersion Modeling

Odor concentration is an estimate of the number of dilutions needed to make the actual odor emission non-detectable. The dilution of the actual odor emission is the physical process that occurs in the atmosphere down wind of the odor source(s). See Figure 3.1, Dilution of Odor in the Ambient Air. The receptor (citizen in the community) sniffs the ambient air that has the diluted odor. If the receptor detects the odor, then the odor in the ambient air is said to be at or above the receptor's detection threshold level for that odor.

Odor concentration values are dilution factors (dilution ratios) and are, therefore, dimensionless values. However, the pseudo-dimension of **odor units per cubic meter** is commonly used for odor dispersion modeling, taking the place of grams per cubic meter in the air dispersion model. The odor concentration value (odor units per cubic meter) can then be multiplied by the airflow rate of the emission source, i.e. cubic meters per second, resulting in the pseudo-dimension of odor units per second for the odor emission rate, analogous to grams per second in the air dispersion model.

Because odor concentration values are actually dimensionless, odor concentration from different sources cannot be added nor can they be averaged. Therefore, odor modeling must be conducted with caution. Air dispersion models typically have outputs of concentration (e.g. micrograms per cubic meter) at specific receptors or plotted as isopleths. These standard modeling outputs need to be converted to the pseudo-dimension odor units per cubic meter with proper treatment of the decimal place. The resulting odor concentration value of 1–odor unit per cubic meter, calculated by the dispersion model, represents the odor detection threshold (i.e. 0.5 probability of detecting a difference in the air). A value less than "1" represents no odor or sub-threshold and a value greater than "1" represents odor at supra-threshold.

Practitioners in the technology of odor study and abatement often use regulatory models, e.g. SCREEN3, ISCST3, CAL PUFF, and AERMOD and sometimes use non-regulatory models, e.g. puff or spill models, or proprietary models. Some practitioners use the recognition threshold values determined in olfactometry in lieu of detection threshold odor concentration values. A number of other important issues need to be considered when selecting and using air dispersion models for odor applications: averaging time(s); peak-to-mean ratio(s); stability classes; terrain features; unique building features; variations in area source emission rates; and special/sensitive receptors.

These model approaches assist is decision making to identify and mitigate odors. Further, an odor regulation or permitting process might use odor (air) dispersion modeling to back-calculate an emission source maximum (i.e. odor concentration) from ambient odor criteria, i.e. '4' or '7' D/T ("dilution-to-threshold" or "odor units per cubic volume").

3.7.3 Olfactometry Data used as Compliance Criteria

Odors from a facility's emission sources (i.e. point, area, and volume sources) can be sampled and tested to determine odor concentration and other odor parameters using laboratory olfactometry following standard practices (ASTM E679-91 and EN13725). The results of the odor testing would be an odor emission inventory or an odor control system performance/compliance test that might be required by an odor regulation or a permit.

A facility's permit might place odor concentration limits on the emission sources of the facility. An example of an odor concentration limit for an odor control system is 250 (detection threshold as odor units per cubic meter) determined using laboratory olfactometry in accordance with ASTM E679-91 and EN13725.

A permit might also require a facility to conduct periodic source sampling and odor testing to verify compliance or conformance to best management practices (i.e. industry standards). The permit might also require odor (air) dispersion modeling to estimate the ambient odor concentration at the facility's fence line and in the ambient air in the community. The method of back-calculating from an ambient odor limit or guideline, i.e. '4' or '7' D/T (dilution-to-threshold), can be used to set source emission odor concentration limits in a permit.

4.0 FIELD OLFACTOMETRY

4.1 Overview of Field Olfactometry Methods

Odor can also be measured and quantified directly in the ambient air by trained inspectors using one of two standard practices. The first method uses a standard odor intensity referencing scale (OIRS) made up of the standard odorant, n-butanol, to quantify odor intensity. The second method utilizes a field olfactometer, which dynamically dilutes the ambient air with carbon-filtered air in distinct dilution ratios known as Dilution-to-Threshold dilution factors (D/T's).

4.2 Olfactory Performance of Odor Inspectors

An odor inspector's olfactory sensitivity is a factor when using field olfactometry methods to measure odor in the ambient air. A standardized nasal chemosensory test method would determine the olfactory threshold of an individual (e.g. odor inspector) and allows comparison of the individual's olfactory sensitivity to normative values (normal olfactory thresholds).

In the routine clinical evaluation of patients with olfactory disorders, one commercially available psychophysical testing method is known as Sniffin' Sticks. Sniffin' Sticks, manufactured by Burghart of Germany, are odor-dispensing felt tip marker pens. One nasal chemosensory testing mode can determine a person's odor threshold based on the standard odorant n-butanol.

The results of a published multi-clinic investigation of 1,000 subjects provides normative values for the general population and was used to develop performance criteria for field inspectors (Kobal, et. al., 2000).

It is assumed that olfactory sensitivity varies as a result of random fluctuations in factors such as alertness, attention, fatigue, health status, and the possibility of variable presentation techniques of the testing stimulus source. Therefore, even though the determination of an individual's olfactory threshold is a definable task, the precision of the result is based on the number of times the individual takes the test. Further, an individual's general condition of health, i.e. common cold and seasonal allergies, needs to be considered in the timing and applicability of the testing.

4.3 Ambient Odor Intensity

Field air pollution inspectors (field odor inspectors), using a standard odor intensity referencing scale, can provide measured, dependable, and repeatable observations of ambient odor intensity.

Odor intensity of the ambient air can be measured objectively using an Odor Intensity Referencing Scale [OIRS] (ASTM, 1999). Odor intensity referencing compares the odor in the ambient air to the odor intensity of a series of concentrations of a reference odorant. As with laboratory intensity determination, the standard reference odorant for ambient measurement is n-butanol. The air pollution inspector, plant operator, or community odor monitor observes the odor in the ambient air and compares it to the OIRS. The person making the observation should use a carbon-filtering mask to refresh the olfactory sense between observations (sniffing). Without the use of a carbon-filter mask, the observer's olfactory sense may become adapted to the surrounding ambient air or become fatigued from any odor in the surrounding air. The adaptation of an observer's olfactory sense is a common phenomenon when attempting to evaluate ambient odors, i.e. wastewater treatment plant operator monitoring treatment plant odors off-site.

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. Field inspectors commonly use the Static-Scale Method because of its ease of handling and low cost of set-up compared to a dynamic-scale olfactometer device (Procedure A).

Practicing the procedures of ASTM E544 is nearly identical to the standard method of quantifying the opacity of smoke plumes. In April 1975 the U.S. Environmental Protection Agency (EPA) published "Guidelines for the Evaluation of Visible Emissions" (EPA-340/1-75-007), as part of the Stationary Source Enforcement Series. The training course, Visible Emissions Evaluation Field Certification and Classroom Lecture Program, provides a field investigator with an understanding of visible emissions and confidence in quantifying the opacity of a visible emission using the calibrated, unaided eye.

The ability to calibrate one's senses is a learned technique, not unlike the calibration of the sense of hearing in the field of music. Air pollution investigators who are familiar with opacity reading can readily learn to calibrate their sense of smell to the ASTM E544 Odor Intensity Referencing Scale (OIRS). Persons who have not received training in opacity reading can learn the ASTM E544 OIRS procedure with training and field practice (McGinley, et. al., 1995).

Using the OIRS, the intensity of the observed ambient air is expressed in "parts per million" (PPM) of n-butanol. A larger value of butanol means a stronger odor. It is important to know that a variety of OIRS are available. Common butanol static-scales include:

- 12-point scale starting at 10-ppm butanol with a geometric progression of two;
- 10-point scale starting at 12-ppm butanol with a geometric progression of two;
- 8-point scale starting at 12-ppm butanol with a geometric progression of two;
- 5-point scale starting at 25-ppm butanol with a geometric progression of three;

The OIRS serves as a standard practice to quantify the odor intensity of the ambient air objectively. To allow comparison of results from different data sources and to maintain a reproducible method, the equivalent butanol concentration is reported or the number on the OIRS is reported with the scale range and starting point. See also, Figure 3.3, "Example Odor Intensity Referencing Scales," presents four OIRS options.

4.4 Ambient Odor Concentration (D/T)

4.4.1 History of Field Odor Concentration Measurement

In 1958, 1959, and 1960 the U.S. Public Health Service sponsored the development of an instrument and procedure for field olfactometry (ambient odor strength measurement) through Project Grants A-58-541; A-59-541; and A-60-541 (Huey, et. al., 1960). The first field olfactometer, called a Scentometer, was manufactured by the Barnebey-Cheney Company and subsequently manufactured by the Barnebey Sutcliffe Coporation.

A field olfactometer creates a series of dilutions by mixing the odorous ambient air with odor-free (carbon-filtered) air. The U.S. Public Health Service method defined the dilution factor as Dilution to Threshold, D/T. The Dilution-to-Threshold ratio is a measure of the number of dilutions needed to make the odorous ambient air non-detectable.

The method of producing Dilution to Threshold (D/T) ratios with a field olfactometer consists of mixing two volumes of carbon-filtered air (two carbon filters) with specific volumes of odorous ambient air. Figure 4.1 is a block diagram which illustrates the mixing of carbon-filtered air with odorous air in a field olfactometer.

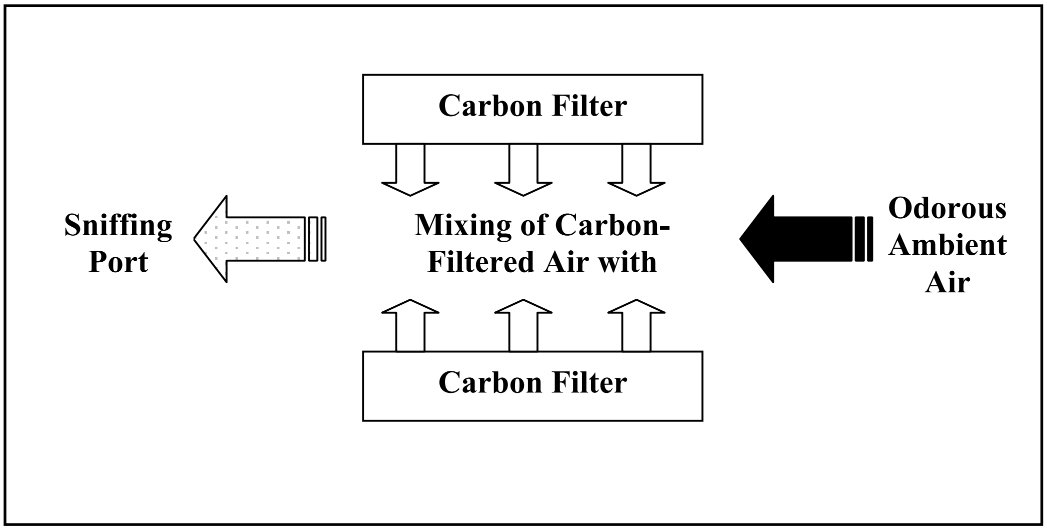

Figure 4.1. Block diagram of field olfactometer air flow.

The method of calculating Dilution to Threshold (D/T) for a field olfactometer is:

$$\text{Dilution Factor} = \frac{\text{Volume of Carbon Filtered Air}}{\text{Volume of Odorous Air}} = \mathbf{D/T}$$

Note that the calculation method for field olfactometry is different from the calculation of the dilution factor in laboratory olfactometry (see Section 3.3).

The calculation difference is illustrated in the following example:

A field olfactometer uses 7 volumes of carbon-filtered air to one volume of odorous air:

$$\frac{7}{1} = 7 \quad \text{(D/T Value)}$$

A laboratory olfactometer uses 7 volumes of carbon-filtered air to one volume of odorous air:

$$\frac{7+1}{1} = 8 \quad \text{(Z value)}$$

Two commercially available field olfactometers include the original Scentometer, developed in the late 1950's, and the Nasal Ranger®, introduced to the market in 2002.

4.4.2 Scentometer Field Olfactometer

The Barnebey Sutcliffe Corporation Scentometer is a rectangular, clear plastic box (15.25cm x 12.7cm x 6.2cm) containing two activated carbon beds. The box contains two ½" diameter air inlets to the activated carbon beds (one on top and one on the bottom of the box). There are six odorous air inlet holes on one end of the box for six different D/T values (2, 7, 15, 31, 170, and 350). The opposite end of the box contains two glass nostril tubes for sniffing. The Scentometer is sold for approximately $650. Figure 4.2 shows a photo of a Scentometer.

Figure 4.2. The Scentometer Field Olfactometer (Barnebey Sutcliffe Corp.). Note the two glass nostril ports to the left and the series of orifice holes at the back of the unit to the right in this photo.

4.4.3 Nasal Ranger Field Olfactometer

The St. Croix Sensory - Nasal Ranger Field Olfactometer operates based on the same principles as the original Scentometer Field Olfactometer. Carbon-filtered air is supplied through two replaceable carbon cartridges. An orifice selector dial on the Nasal Ranger contains six odorous air inlet orifices for six different D/T values (2, 4, 7, 15, 30, and 60). The dial contains six "blank" positions (100% carbon-filtered air) alternating with the D/T orifices. The dial is replaceable for other D/T series (e.g. 60, 100, 200, 300, 500). Figure 4.3 is a photo of a Nasal Ranger.

Figure 4.3. The Nasal Ranger® Field Olfactometer (St. Croix Sensory, Inc.). The inset picture shows a close-up of the orifice dial, which is located right side of the Nasal Ranger in this photo.

The diluted odorous air is sniffed through an ergonomically designed nasal mask, which is constructed of a carbon fiber/polyurethane blend with a fluoropolymer (Teflon-like) coating. A check valve is placed in both the inhalation and exhalation outlet of the nasal mask in order to control the direction of airflow while using the Nasal Ranger.

The Nasal Ranger is designed with an airflow sensor that measures the sniffing flow rate through the field olfactometer. The measured flow is continually compared to design specifications and feedback is provided to the user through LED's mounted on the top of the unit. The user must sniff at a rate where the LED's show the total airflow is in the Target range (nominal 16-20 LPM). This feedback loop standardizes the sniffing rate for all users of this field olfactometer and allows for certified traceable calibration of the Nasal Ranger. The Nasal Ranger is sold for approximately $1500.

The field olfactometer instrument, the "Dilution to Threshold" (D/T) terminology, and the method of calculating the D/T are referenced in a number of existing state and local agencies' odor regulations and permits. Therefore, a field olfactometer is a realistic and proven method for quantifying ambient odor strength when used by trained air pollution inspectors or monitors.

Common Dilution-to-Threshold (D/T) ratios used to set ambient odor guidelines are: D/T's of 2, 4, and 7. Field olfactometers typically have additional D/T's (dilution ratios) such as 15, 30, 60 and higher dilution ratios.

4.5 Applicability of Field Olfactometry

Field olfactometry with Odor Intensity Referencing Scales (OIRS) and calibrated field olfactometer are cost effective means to quantify odors. Facility operators, community inspectors, and neighborhood citizens can confidently monitor odor strength at specific locations around a facility's property line and within the community when using OIRS's or calibrated field olfactometers.

The following methods are presented in brief exemplary form as an application guide for field olfactometry. These methods describe types of odor monitoring and when it may be appropriate to monitor odors.

(1) **On-Site Monitoring –** Operators have the unique ability to monitor odors throughout the day with field olfactometry. Operator monitoring can include odor observations of arriving materials, outdoor process activities, and fugitive air emissions. Monitoring odors on-site may include following a logical pathway around the facility to determine where odors exits or making odor observations at predetermined locations, i.e. open doorways, driveways, storage areas, and fence lines.

(2) **Random Off-Site Monitoring –** A frequently used method for ambient odor monitoring is the "random inspection" approach. Random monitoring leads to a compilation of data that can be correlated with meteorological information and on-site activities. Managers and regulators alike find that random odor monitoring using field olfactometry is a cost effective protocol.

(3) **Scheduled Monitoring –** Well-planned scheduled monitoring can be limited to a daily walk-about or drive around, or structured with several visits to predetermined monitoring locations. Data from field olfactometry can be used to correlate the many parameters that influence odor episodes, including meteorological conditions and on-site operating activities.

(4) **Intensive Odor Survey –** An in-depth evaluation of on-site odor generation and off-site odor impact may be needed for permit renewal or facility expansion. Extensive data collection using field olfactometry will identify which sources or operations cause odor and which ones do not cause odor off-site. All potential odor sources and operations could be ranked and their relative contributions determined. Short-term trials or tests of odor mitigation measures, e.g. odor counteractants, would also require an intensive period of data collection using field olfactometry.

(5) **Citizen Monitoring –** The implementation of citizen odor monitoring with field olfactometry can be part of an interactive community outreach program. The primary function of citizen odor monitoring is to collect information, through accurate record keeping, which represents real conditions in the community. Citizens recruited and trained to measure odors using OIRS's or field

olfactometers would also report odor descriptors. Citizen odor monitoring will assist in determining prevalent times and prevalent weather conditions of odor episodes. Citizen odor monitoring with field olfactometry will also help in understanding the odor strength at which an odor first becomes a nuisance.

(6) **Complaint Response –** The use of Odor Compliant Hot Lines is a common method used by facilities and communities to respond to odor episodes. A complaint response plan, with designated on-call responders, creates opportunities for verifying odor episodes, tracking odor sources, and quantifying odor strength with field olfactometry.

(7) **Plume Profiling –** Standard and specialized air dispersion modeling predicts the transport and dilution of odors by the wind. A protocol, known as plume profiling, supplements and calibrates air dispersion modeling. Several inspectors using OIRS's or field olfactometers, spaced cross wind and down wind from an odor source, would measure and record the odor strength as butanol intensity or D/T values. The odor plume profile would then be documented and overlaid on the local terrain map. Therefore, the air dispersion modeling and the local topography would be integrated with actual odor measurements from field olfactometry.

These methods are presented in brief exemplary form as guide and are not mutually exclusive, often being combined into a comprehensive odor management program.

5.0 ANALYZING SPECIFIC CHEMICAL ODORANTS (CHEMICALS)

Odor perception occurs when one or more chemical substances in the air come in contact with the human olfactory system. The term odorant refers to any chemical substance in the air that is part of the perception of odor. Odorants may also be irritants to the human receptor and irritants may be co-pollutants with odorants. Therefore, analyzing for specific odorants (and irritants) may be necessary as part of an investigation of odors. Further, specific odorants may be identified as surrogates for the perceived odor and may become the chemical markers used in permitting and enforcement of odor.

Measuring odorous air as odor is accomplished using the standard practices presented in previous sections. However, the investigations and studies of odor sometimes require the analysis of the chemical substances in the odorous air. The chemical substances may include odorants, non-odorants, irritants, air toxics, hazardous air pollutants, criteria pollutants, and other pollutants. Analysis of specific odorants may include the use of on-site real-time monitoring instruments (field analysis) and laboratory based analytical equipment (laboratory analysis).

5.1 Field Analysis of Chemical Odorants

Field analysis of chemical odorants and other chemical substances can be accomplished using a variety of portable analysis methods. These field portable methods include low cost colorimetric detector tubes ($5.00 per tube with a $500 pump) to higher cost portable electronic instruments ($5,000 to $10,000). All of these portable analysis methods have limitations in either sensitivity or specificity, which may affect their value as "portable odor instruments".

Colorimetric detection tubes are low cost ($5.00 per tube) and are available for many specific chemical compounds. However, each tube type has possible interferences with chemical compounds similar to the target analyte. For example, ammonia colorimetric detector tubes have cross sensitivity (interferences) with other basic substances such as organic amines.

The Jerome Hydrogen Sulfide Analyzer, Model 631X, made by Arizona Instruments, has a reported detection limit of 0.001 ppm (1-ppb) hydrogen sulfide, however, almost all of the reduced sulfur gas compounds cause a response which is record as hydrogen sulfide. Therefore, the Jerome analyzer can be considered a hydrogen sulfide analyzer with other sulfur gas interference or considered a survey instrument for all reduced sulfur gas compounds.

Electronic noses are specialized detection instruments with hybrid proprietary sensors that detect many chemical species. Because electronic nose sensors have broad range detection capability, they need to be programmed for specific odorant mixtures. Without programming, an electronic nose instrument cannot report which odorants are being detected. However, with programming, an electronic nose reports the presence of a known (programmed) odorant mixture. Therefore, the application of electronic noses has been successful in manufacturing quality control (i.e. a sample of Product 'A' meets the quality standard for Product 'A'). The use of portable electronic noses in environmental pollution applications is in development.

Table 5.1, Field Analysis of Chemical Odorants, briefly summaries the several portable instrument types and related parameters.

Parameter	**Sampling/Analytical Method**	**Instrument**	**Instrument Costs $**
Mixtures	Electronic Noses	Cyranose	10,000
Reduced Sulfur Gases	Gold Film Analyzer	Jerome by AZI	10,000
Selected Analytes	Colorimetric Detector Tubes	Draiger or MSA	500
VOC's	FID and PID	Various Manufacturers	5,000

Table 5.1 Field Analysis of Chemical Odorants

5.2 Laboratory Analysis of Chemical Odorants

The collection of odorous air samples and the laboratory analysis of chemical odorants can be cost-effective depending on the Data Quality Objectives (DQO's) for investigation, enforcement action, or compliance verification. Data Quality Objectives

(DQO's) are statements that specify the type and detail of the sample collection and analytical method utilized to satisfy the end use or purpose. Following the USEPA's approach to document the planning and quality control aspects of Superfund Cleanup programs, i.e. Quality Assurance Project Plan (QAPP), five Data Quality Objective (DQO) Levels are used:

DQO Level 1 – Screening: includes field analysis with portable instruments/methods and grab samples of odorous air for preliminary laboratory analysis. Even though Level 1 is the lowest data quality it is the most rapid and often is the first necessary step in planning further testing.

DQO Level 2 – Field Analysis: includes slightly more complex sampling procedures (i.e. composite sampling) and can incorporate mobile laboratory instrumentation or fixed point monitors. Level 2 is often needed to develop sufficient information (i.e. base line data) prior to planning odor control mitigation measures.

DQO Level 3 – Engineering: includes planning and sampling to document mass emission rates as well as selection of specific laboratory analysis to identify the specific odorants that may be surrogates for the odorous air. Level 3 is a cost-effective data quality approach when measuring performance or success of odor control mitigation efforts, i.e. process changes, odor control equipment.

DQO Level 4 – Conformational: includes the full use of compliance testing protocols and Contract Laboratory Programs (CLP) in accordance with EPA recognized protocols. Level 4 is needed to document conformance to standards or permit conditions.

DQO Level 5 – Non-Standard: includes all non-standard protocols or experimental protocols that may be needed to detect unusual or unregulated chemical compounds. Level 5 quality control is similar to Level 4 after the method or protocol has been fully adapted or developed.

Table 5.2, Laboratory Analysis of Chemical Odorants, presents the most common chemical odorant parameters: aldehydes, amines, organic acids, sulfur gases, and VOC's and the sampling and analytical methods for each parameter.

The cost of analysis for each analytical method varies from $100 to $400. For example, the analysis of ammonia utilizing the NIOSH S347 method cost approximately $75 compared to the more expensive VOC analysis utilizing EPA Method TO-15 in the full scan mode (75 VOC library of compounds) and reporting Tentatively Identified Compounds (TIC's) costs approximately $375. These cost estimates do not include the costs of sample containers and sample collection. Further, the necessary incorporation of "field duplicates" and "field blanks" add to the cost of sampling and analysis.

Parameter	Sampling Method	Analytical Method	Instrument	IDL	MDL/MRL
Aldehydes/Ketones	Sorbent Tube	EPA TO-11	HPLC	1.0 ug/ml	250 ug/m3
Amines, Aliphatic	Sorbent Tube	NIOSH 2007/2010	IC	1.0 ug/ml	250 ug/m3
Ammonia	Sorbent Tube	NIOSH S347	IC	0.5 ug/tube	50 ug/m3
Organic Acids	Sorbent Impinger	EAS 01.Acid.311	HPLC-UV	1.0 ug/ml	250 ug/m3
Reduced Sulfur Gases	Tedlar Bag	ASTM D5504-98	GC-SCD	N/A	5-ppbv
Volatile Organics	Canister/Tedlar Bag	EPA TO-15	GC-MS	1.0 ug/m3	1.0 ug/m3

Note: Cost of analysis for each analytical method varies from $100 to $400
Key:
IDL - Instrument Detection Limit
MDL - Method Detection Limit
MRL - Method Reporting Limit

Table 5.2 Laboratory Analysis of Chemical Odorants

6.0 COMMUNITY ODOR STUDIES

6.1 The Citizen Complaint Pyramid

A conceptual model for what makes an odor episode lead to a citizen complaint is the "Citizen Complaint Pyramid," shown in Figure 6.1. Four parameters make up the hierarchy in this pyramid: 1) Character, 2) Intensity, 3) Duration, and 4) Frequency. This assumes an odor episode exists when an odorant is present above the detection threshold.

The "Character" of the odor is the actual descriptions of what the odor smells like. This parameter is sometimes called the "quality" or "offensiveness" of the odor. More offense odors will be more annoying.

"Intensity" of the odor refers to the overall strength or power of the odor. The more intense the odor, the more likely a citizen is to be annoyed. Even very pleasant odors such as perfumes can be very annoying at high intensities.

"Duration" is the elapsed time of each individual odor episode. Longer duration odor episodes can lead to more drastic changes in plans around a citizen's home or community. Episodes of very short duration may be over before a citizen even thinks about adjusting his or her plans.

Finally, "frequency" refers to how often the citizen experiences odor episodes. The more frequent the intrusion into the citizen's life, the more annoying each experience becomes.

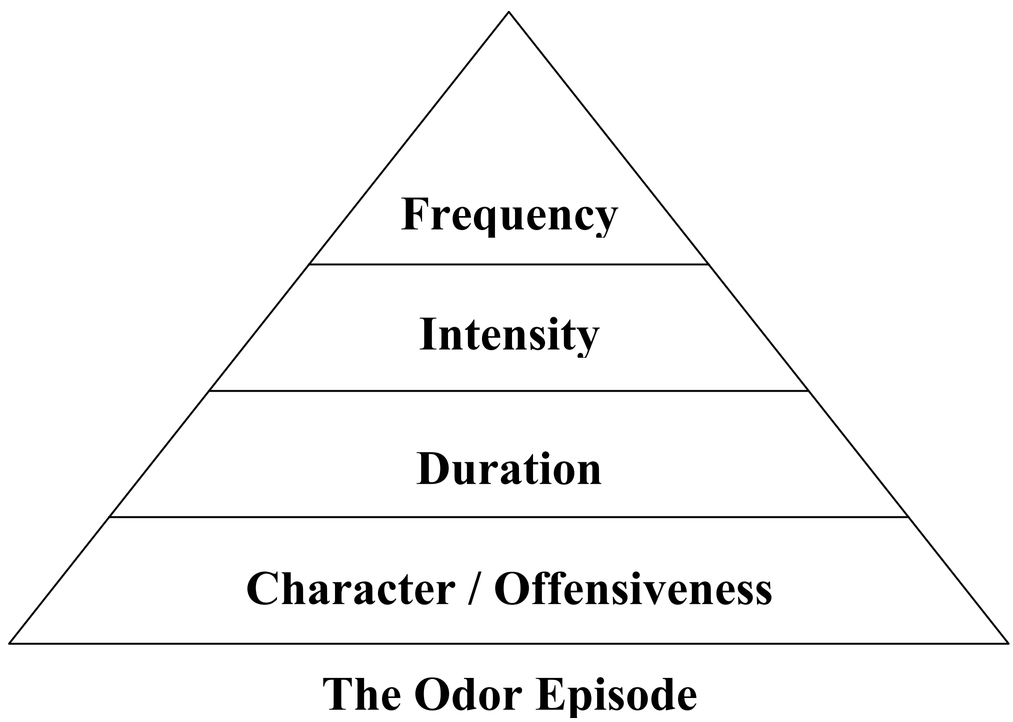

Figure 6.1 The Citizen Complaint Pyramid

This model is sometimes given the acronym "F-I-D-O," frequency, intensity, duration, and offensiveness, with the "offensiveness" term used instead of the "character" term. The cumulative effect of these four parameters creates the nuisance experience and the resulting citizen's complaint.

6.2 Odor Study Methods

Community odor studies are a tool used to characterize these four parameters and understand the properties of odor episodes around a facility or several facilities in the same area. Five examples of community odor surveys include:

1. Citizen Odor Hotline
2. Surveys of Recruited Citizens
3. Citizen Odor Log Books
4. Inspectors working for the jurisdiction (county, city, or township)
5. Inspectors working for a third party (e.g. local engineering firm)

6.2.1 Odor Hotlines

Odor hotlines provide an immediate method for citizens to call a telephone number to report an odor episode. There are several forms of odor hotlines:

1. Sponsored by Government Entity
2. Sponsored by Community Group
3. Sponsored by Facility

A government agency may provide an odor hotline similar to a spill response line for chemical spill scenarios. Citizens would call the phone number and provide information about the odor episode taking place or which took place recently. The government agency could document the episode information in a database for future consideration, or a response could be initiated by sending an investigator to the citizen's location.

A citizen group may organize an odor hotline in order to document odors from one or more facilities in a community. This hotline provides one location for citizens to take their complaints and allows the citizen group to organize information about odor episodes for future presentation to a government agency or to the facility management.

A facility may provide an odor hotline for citizens to call and report odor episodes. This allows the facility direct contact with the citizens and provides immediate information about the effects of odors from their facility. The facility may document the episode information in a database for future consideration, or a response could be initiated by sending an investigator to the citizen's location.

6.2.2 Citizen Surveys

Two types of citizen surveys used most often include mail-in questionnaires and telephone questioning. Each of these surveys can be varied in different ways depending on the depth of the study and the availability and involvement level of the community.

<u>6.2.2.1Mail-in Questionnaires</u>. The mail-in questionnaire can be used to investigate the history of community annoyance or to gather data on a series of current odor events. The advantage of this survey is that it allows the citizen to record events more completely and accurately. However, as with the dependence of citizen complaints, this method of data collection is at the mercy of the citizens for they must be annoyed enough to take the time to return the questionnaire.

<u>6.2.2.2 Telephone Surveys</u>. Like mail-in surveys, the telephone survey can be conducted in order to investigate the history of the odors in a community or they can be used to gather data on a series of event episodes. At least one survey has even incorporated calling citizens and obtaining the immediate status of odors by asking the citizen to step outside and describe what they smell. The telemarketing approach gives the citizen the open invitation to praise or condemn the odor conditions in the neighborhood without having to fill out any forms. Unfortunately, one negative of this survey is the intrusion

felt by the citizens when they are interrupted from their daily routine to answer the questions. There are many telemarketing organizations calling citizens on a nightly basis to sell different services, which cause citizens to counteract the telemarketers by screening callers with answering machines, voice mail, and caller I.D. For this reason it is beneficial to recruit a sample of volunteer citizens who will accept the periodic telephone calls to provide information about episodes over a period of time (McGinley, 1995).

6.2.3 Citizen Logbooks

Citizens can be trained to document odor episodes on report forms in a logbook following standard procedures. The citizens are recruited through community organizations or through direct phone calls or home visits. The citizens keep the logbook in an easily accessible location in their home. When they notice objectionable odors at their residence, the citizen completes the report form in the logbook. Generally, one logbook is associated with one location, i.e. citizens may have one log book at home and another at work.

These log books are then returned to a central location where the data would be entered into a database for further analysis and review.

6.2.4 Inspector Working for a Jurisdiction

Odor surveys are often conducted by inspectors who work for a specific jurisdiction (i.e. city, county, state, etc.). For a detailed odor survey, these inspectors will identify observation locations around one or more facilities and out in the potentially effected community. These locations will normally coincide with street intersections or specific receptor locations and will be documented with exact longitude and latitude from a GPS (Global Positioning System) unit. The locations need to be chosen for the inspectors to efficiently visit each observation point in a reasonable amount of time (e.g. one hour).

The observations locations should include permanent ("fixed") locations, which the inspector will visit during each round of observations, and optional locations where the inspector will only stop to make observations if noticeable odors are present.

These inspectors can be trained to observe the odors following standard practices and procedures. The inspectors document their observations on log forms, which are entered into a central database for future review and analysis. See Appendix G for a simple case study involving community odor survey techniques by inspectors.

6.2.5 Third-Party Inspectors

The same inspections can be carried out using third-party observers. Local environmental engineering or industrial hygiene firms usually serve as the third-party inspectors/monitors. These inspectors can be trained to make the same observations following the same standard practices and procedures. See Appendix G for an example case study involving community odor survey techniques by inspectors.

7.0 CONCLUSIONS

Odor is measurable using standardized scientific methods in odor-testing laboratories with laboratory olfactometry and in the ambient air with field olfactometry. Point, area and volume emission sources can be sampled and tested for odor parameters such as odor concentration, intensity, persistence, and descriptors. Odor can also be measured and quantified directly in the ambient air using one of two standard practices by trained inspectors. One method uses standard odor intensity referencing scales (OIRS) made up of the standard odorant, n-butanol, to quantify odor intensity. The second method utilizes calibrated field olfactometers, which dynamically dilutes ambient air with carbon-filtered air in distinct dilution ratios known as Dilution-to-Threshold dilution factors (D/T's).

Presently, international standards are in place, which dictate the scientific methods and practices of odor measurement. These international standard methods for measuring odor are: objective, quantitative, dependable, and reproducible.

From ASTM International:

- ASTM E679-91: *Standard Practice for Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits*

- ASTM E544-99: *Standard Practice for Referencing Suprathreshold Odor intensity*

From the Comité Européen de Normalisation (CEN)

- EN13725:2003: *Air Quality – Determination of Odour Concentration by Dynamic Olfactometry*

With these standard odor measurement practice odor limits may be incorporated into odor regulations or into facility permits as compliance determining criteria with confidence:

Ambient Odor Limits
- Odor concentration, D/T
- Odor intensity, ppm butanol

Source Odor Limits
- Odor concentration, odor units per cubic meter
- Odor emission rates, odor units per second

Note: these basic odor limits are <u>not</u> mutually exclusive and are sometimes combined.

The stakeholders for standardized odor measurement are:

- Regulators
- Industries
- Citizens
- Manufacturers of environmental control equipment
- Consultants
- Researchers

With the knowledge of fundamental odor testing methods and practices, an objective approach can be taken to addressing community nuisance odors and problematic odorous emissions. The subjectivity of "nuisance odors" can be replaced with objective, scientific methods of odor measurement with laboratory olfactometry and field olfactometry.

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Appendix I. Odor Terminology

acceptability/unacceptability: Degree to which a stimulus is judged to be favorable or unfavorable. [ASTM E253-97]

acuity: The ability to repeatedly detect or discriminate sensory stimuli. [ASTM E253-97]

accepted reference value: A value that serves as an agreed upon reference for comparison, and which is derived as a consensus value, based on collaborative experimental work under the auspices of a scientific or engineering group. [ISO 5725, part 1]

adaptation (sensory): A decrease in sensitivity to a given stimulus which occurs as a result of exposure to that stimulus. [ASTM E253-97]

anosmia: Lack of sensitivity to olfactory stimuli. [ISO 5492:1992] Absence of the sense of smell.

aroma: Perception resulting from stimulating the olfactory receptors; in a broader sense, the term is sometimes used to refer to the combination of sensations resulting from stimulation of the nasal cavity. See also "odor." [ASTM E253-97]

ascending concentration series: A method of presentation in olfactometry. The assessor (panelist) is presented with a series of dilution ratios (one or two blanks and one odorous presentation) increasing in odor concentration (decreasing dilution ratio). The increase in concentration is usually 2-3 fold. [ASTM E679-91]

assessor: A participant in odor testing (e.g. panelist, panel member, judge, respondent, etc.).

ASTM / ASTM International: An international voluntary standards development organization. The ASTM acronym stands for the original name of the organization, American Society for Testing & Materials. The organization changed their name to ASTM International in 2001.

aversion: A feeling of dislike provoking avoidance of a stimulus. [ASTM E253-97]

best estimate criteria: In olfactometry this is the estimated threshold of an individual assessor (panelist) calculated as the geometric mean of the last dilution ratio where the odor was not detected and the next higher concentration (the first dilution ratio where the odor was detected). [ASTM E679-91]

best estimate threshold (BET): The threshold calculated using the best estimate criteria.

bias: The difference between the expectation of the test results and an accepted reference value. [ISO 5725 part 1] Bias is also known as Systematic error.

binary forced choice: A method of olfactometry testing comprising of two presentations, one blank and one with a diluted odor sample. The assessor is forced to select the one with the odor, even if they must guess.

CEN: Acronym which stands for the Comité Européen de Normalisation, which is a standardization organization comprised of all countries in the European Union.

character (quality): Word descriptions of what the odor "smells-like."

detection: The assessor (panelist) is certain one presentation (the odor sample presentation) is different from the two blank presentations.

detection threshold (for a reference material): The *odorant concentration* which has a probability of 0.5 of being detected under the conditions of the test. [EN13725:2003]

detection threshold (for an environmental sample): the *dilution ratio* at which the sample has a probability of 0.5 of being detected under the conditions of the test. [EN13725:2003]

determination limit: The odor concentration (or dilution ratio) where 84% of the assessors (panelists) "detect" the odor. [VDI 3881, Part 1]

dilution-to-threshold (D/T): The highest dilution ratio of carbon filtered (odor-free) dilution air to the odor sample air where the ambient odor is just noticeable.

dilution level: A presentation level on the olfactometer which is set at a specific dilution ratio.

dilution ratio: the ratio of total diluted sample flow volume to the odor sample flow volume. (example: 2 cc/min of sample flow and 20L/min of total flow gives a dilution ratio of 10,000)

DT: see "detection threshold"

D/T: see "dilution-to-threshold"

dynamic olfactometer: An olfactometer designed to continuously dilute odorous gases in order to present known dilution ratios to an assessor through a common presentation mask.

dynamic olfactometry: Olfactometry work performed with a dynamic olfactometer.

dysosmia: A dysfunction in the olfactory sense; an impaired sense off smell.

ED50: see "detection threshold (for an environmental sample)"

EN: Acronym which stands for Norme Européenne. These letters precede all European Standards developed through CEN, Comité Européen de Normalisation.

European Odour Unit: That amount of odorant(s) that, when evaporated into one cubic meter of neutral gas at standard conditions, elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one European Reference Odour Mass (EROM), evaporated in one cubic meter of neutral gas at standard conditions. [EN13725:2003]

European Reference Odour Mass (EROM): The accepted reference value for the European odour unit, equal to a defined mass of a certified reference material. One EROM is equivalent to 123µg n-butanol (CAS 71-36-3) evaporated in one cubic meter of neutral gas. This produces a concentration of 0.040 µmol/mol. [EN13725:2003]

field olfactometer: A hand-held dilution device which dynamically mixes carbon-filtered air with odorous ambient air at discrete ratios as a user sniffs through the device and determines the dilution-to-threshold value of the odorous ambient air.

field olfactometry: Term used to describe any evaluation of ambient odors by an individual observer or group of observers including Odor Intensity Referencing Scales (OIRS) and field olfactometer dilution-to-threshold (D/T) measurements.

forced-choice method: A method of olfactometry where the assessor is forced to choose which one of the three presentations, one diluted odor sample presentation and two blank presentations, has the odorous sample, even if no difference is found between the three. [ASTM E679-91]

guess: The assessor (panelist) does not perceive a difference between the odorous and blank presentations and therefore makes a “guess” as to which presentation contained the odor.

group threshold: The average threshold of a group of assessors.

hedonic scale: a scale on which liking or disliking of a stimulus is expressed. [ASTM E253-97]

hyperosmia: An increase in olfactory sense. Having a lower threshold to odors and odorants.

hyposmia: A decrease in olfactory sense. Having an increased threshold (diminished sense of smell).

individual threshold: The detection threshold of one individual assessor.

individual threshold estimate (ITE): The detection threshold of one individual assessor calculated from one dilution series. In olfactometry this value is the best estimate threshold (BET) calculated using the best estimate criteria.

instrument detection limit: The minimum detection limit due to the instrument design.

intensity: The perceived magnitude of a stimulus. [ASTM E253-97]

kakosmia (cacosmia): Dysfunction where there is a presence of unusually unpleasant odors when pleasant odors exist. Usually found in the elderly.

Laboratory olfactometry: the practices, methods, and devices used in a controlled setting (laboratory) to measure the responses of assessors to olfactory stimuli.

odor / odour: Organoleptic attribute perceptible by the olfactory nerves on sniffing certain volatile substances. [ISO 5492] See “aroma.”

odorant: A substance that stimulates the olfactory receptors (i.e. a chemical gas). [ASTM E253-97]

odor concentration: The number of European Odour Units in a cubic meter of gas at standard conditions.

odor intensity: The perceived (sensory) intensity of the odor based on a butanol intensity referencing scale (ASTM E544-99).

Odor Intensity Referencing Scale (OIRS): A series of reference odorant samples (e.g. n-butanol), at discrete increasing concentrations, used as a scale to match the odor intensity of environmental odors.

Odor Dilution Units (ODU): see “Odor Unit” and “European Odour Unit”

odor panel: see “panel”

odor threshold: see “detection threshold”

Odor Unit (OU): One odor unit is the amount of odorant(s) present in one cubic meter of odorous gas (under standard conditions) at the panel threshold. see “European Odour Unit”

olfactometer: A dilution apparatus which mixes odorous air in specific ratios with odor free air for the presentation to a panel of observers (assessors).

olfactometry: Measurement of the response of assessors to olfactory stimuli. [ISO 5492]

olfactory: Pertaining to the sense of smell. [ISO 5492]

olfactory receptor: Specific part of the olfactory system which responds to an odorant. [ISO 5492]

olfactory stimulus: That which can excite an olfactory receptor. [ISO 5492, modified]

operator: see “panel leader” or “test administrator”

panel: A group of assessors used to analyze an odorous sample by olfactometry.

panel leader: The operator of the olfactometer and the person who supervises and instructs the assessors (panelists) during sample analysis. See “test administrator”

panel member: An individual assessor who is part of an odor panel.

panel screening: Procedure used to determine if the performance of a panelist (assessor) is in compliance with selected criteria.

parosmia: a perceived change in ones olfactory sense. A distorted sense of smell encountered with certain brain tumors or in mental illness.

perception: Awareness of the effects of a single or multiple sensory stimuli. [ISO 5492]

precision: Closeness of agreement between independent test results obtained under prescribed conditions. [ISO 5725, part 1]

presentation: The presentation of either an odor sample or blank at one dilution level.

presentation face velocity: The velocity of the presentation air at the face of the sampling mask or port.

presentation flow rate: The volumetric flow rate of the presentation air to the assessor.

reaction limit: The odor concentration (or dilution ratio) where 16% of the panelists “detect” the odor. [VDI 3881, Part 1]

recognition: The assessor (panelist) is certain one presentation (the odor sample presentation) is different from the two blank presentations and, further, the assessor can identify or describe the odor.

recognition threshold: The odor concentration which has a probability of 0.5 of being recognized under the conditions of the test. [EN13725:2003]

repeatability (r): Precision under repeatability conditions. [ISO 5725, part 1]

repeatability conditions: Conditions where independent test results are obtained with the same method on identical test material in the same laboratory by the same operator (panel leader) using the same equipment within short intervals of time. [ISO 5725, part 1]

repeatability limit: The value less than or equal to which the absolute difference between two test results obtained under repeatability conditions may be expected to be with a probability of 0.95. [ISO 5725, part 1]

reproducibility (R): Precision under reproducibility conditions. [ISO 5725, part 1]

reproducibility conditions: Conditions where test results are obtained with the same method on identical test material in different laboratories with different operators using different equipment. [ISO 5725, part 1]

reproducibility limit: The value less than or equal to which absolute difference between two test results obtained under reproducibility conditions may be expected to be with a probability of 0.95. [ISO 5725, part 1]

resolution: The dispersion of the distribution of individual threshold estimates (ITE's) for one sample. Calculated from the "determination limit" (84%ile) and the "reaction limit" (16%ile).

retrospective screening: A procedure for reviewing olfactometry results where results of assessors that show a deviation from normal due to health or specific hypersensitivity or hyposensitivity are remove from the group test average. Removal of an assessor's results may be based on the standard deviation or the ratio between their individual threshold estimate (ITE) and the group (panel) average.

RT: see "recognition threshold"

sample: The sample is the odorous gas sample.

Scentometer: A brand of field olfactometer originally manufactured by Barneby–Cheney Company as a result of US Public Health Service Grants in 1958-1960. Also a slang term for a field olfactometer (see "field olfactometer").

screening: A preliminary selection procedure. [ASTM E253-97]

sensory adaptation: a decrease in sensitivity to a given stimulus which occurs as a result of exposure to that stimulus. [ASTM E253-97]

sensory fatigue: Form of adaptation in which a decrease in sensitivity occurs. [ISO 5492]

smell: See "aroma" or "odor."

standard conditions: Room temperature (293K), normal atmospheric pressure (101.3 kPa) on a wet basis [ISO 10780].

step factor: The factor by which each dilution level in a dilution series differs from adjacent dilution levels.

sub-threshold: Pertaining to a stimulus below the specified threshold. [ASTM E253-97]

supra-threshold: Pertaining to a stimulus above the specified threshold. [ASTM E253-97 & E544-99]

test administrator: See "panel leader."

three-alternative forced choice (3-AFC): A test presentation used in odor threshold testing by dynamic olfactometry. The assessors are presented with three samples, one of which contains the diluted odor, while the other two contain odorless "blank" air [ASTM E1432-91].

triangle test: A method of difference testing comprising three coded samples, two of which are the same. The assessor is asked to select the odd sample.

triangular forced choice: A method of olfactometry testing where the assessor is given two blank (odor free) presentations and one dilute odor sample. The assessor is forced to choose which of the three presentations contains the odor.

trueness: The closeness of agreement between the average value obtained from a large series of test results and an accepted reference value [ISO 5725, part 1].

yes / no method: A method of olfactometry in which assessors are asked to judge whether an odor is detected or not at multiple dilution levels.

Z: The variable which stands for a dilution ratio [ASTM E679-91].

Appendix II. Collection of Odorous Air Samples – Case Study

Odorous air samples can be collected from point emission sources (i.e. stack or vent) and from surface (area) emission sources (i.e. liquid surface or solid surface). “Whole-air” samples for laboratory odor testing are typically collected in 10-liter Tedlar gas sample bags for transport to the odor-testing laboratory. Note, also, that Teflon gas sample bags are specified in some sampling protocols.

Odor sampling is often part of an odor study; part of an odor control system performance test; or part of a routine performance test at a facility. The purpose of the odor sampling is often to compare odors from various processes at the facility or to determine if the odor control system is performing according to specifications. Therefore, a case study is used in this Appendix to explain and illustrate sampling from a point source, from an area sources, and from the inlet and outlet of an odor control system. The case study includes collecting four “whole air samples” from a typical wastewater treatment plant (WWTP) facility.

The four samples from the facility are:

#101 Digester Sludge Tank Exhaust
#102 Gravity Belt Thickener Exhaust to the Biofilter
#103 Biofilter Surface from the Gravity Belt Thickener Exhaust
#104 Surface of Influent Channel to Primary Clarifiers

Using the WWTP case study example, the sampling protocol would require the samples to be collected under "normal" operating conditions. The planners of the sampling would determine when "normal" operating conditions existed. The person doing the sampling would document the conditions of the processes and buildings (i.e. doors and windows open or closed) at the time of sampling. The conditions at the time of collecting the samples would be documented so that the results would be in context to the sampling plan’s objectives

Prior to the sample taking, the sampler would gather together the sampling equipment that might be needed:

1. Ladder,
2. Pliers or wrench to open sample ports;
3. Pitot tube/inclined manometer to measure velocity and pressure in ducting;
4. Thermometers (wet and dry bulb) to measure temperature of the exhaust air;
5. 10-liter Tedlar gas sample bag with a label;
6. Vacuum case with vacuum pump;
7. Flux chamber for quiescent surface sampling;
8. Tall passive chimney for aerated surface sampling;
9. Teflon sample line (from sample point to vacuum case);
10. Shipping case; and
11. Portable instruments to measure specific chemicals or chemical groups.

In addition to collecting the samples for odor parameter testing, the sampling protocol may require a companion sample (i.e. duplicate) to be collected in a Tedlar gas sample bag or a stainless steel silicate lined or unlined canister for odorant, chemical compound analysis, i.e. reduced sulfur compound gas analysis or volatile organic compound analysis. The protocol may also require testing for specific chemical odorants in the air with portable instruments, i.e. Jerome brand hydrogen sulfide analyzer.

The sampler would also need the following documents ready for use prior to the sampling:

1. Sampling protocol;
2. Air velocity data and calculation sheet;
3. Chain of Custody form(s);
4. Shipping box or case with mailing label;
5. Documents for express shipping; and
6. Phone number of the laboratories and the express shipper.

Sampling Exhaust Stacks and Vents

Sample #101 from the Digester Sludge Tank Exhaust is taken from a "point source" discharging from a short stack above the exhaust fan. Sample #102 from the Gravity Belt Thickener Exhaust is taken from what was a "point source" before it was ducted to the Gravity Belt Thickener Biofilter. The sampler would take air velocity, pressure and temperature measurements on the exhaust air streams from both exhaust fans. The sampler would prepare the sample tubing, sample bag, vacuum case and pump. The 10-liter Tedlar sample bag would be labeled with a number and date. With the bag valve open, the bag would be connected to the tubing inside the vacuum case. The vacuum case would then be sealed. Acting as a sample probe, the Teflon sample tubing would be held in position inside the exhaust stack or exhaust ducting and connected to the bag inside the vacuum case, see Figure II-1. The vacuum pump would then be connected in order to create a vacuum in the case. The vacuum in the case would cause the sample bag to fill with the odorous air from the exhaust stack. Figure II-2, Vacuum Case for Odor Sampling, illustrates the sampling apparatus. Note that an alternative method for sample collection is to use a peristaltic pump.

Figure II-1 Sampling Probe

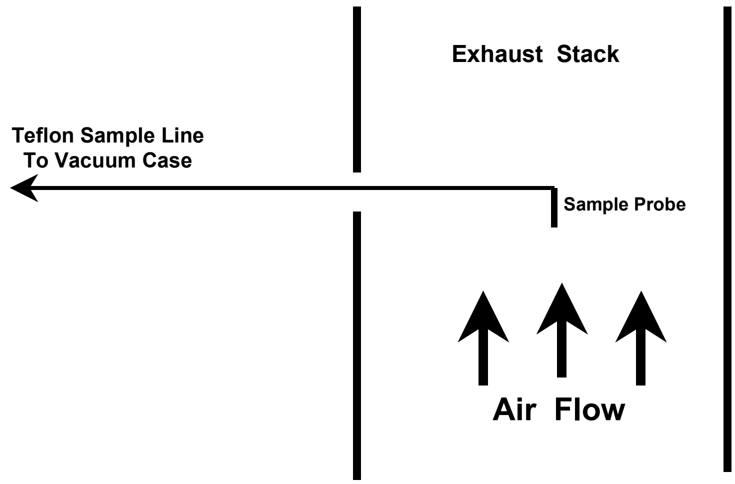
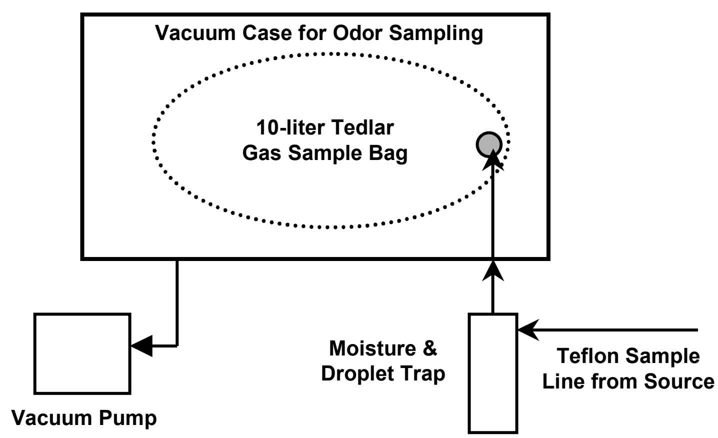


Figure II-2 Vacuum Case Diagram for Odor Sampling

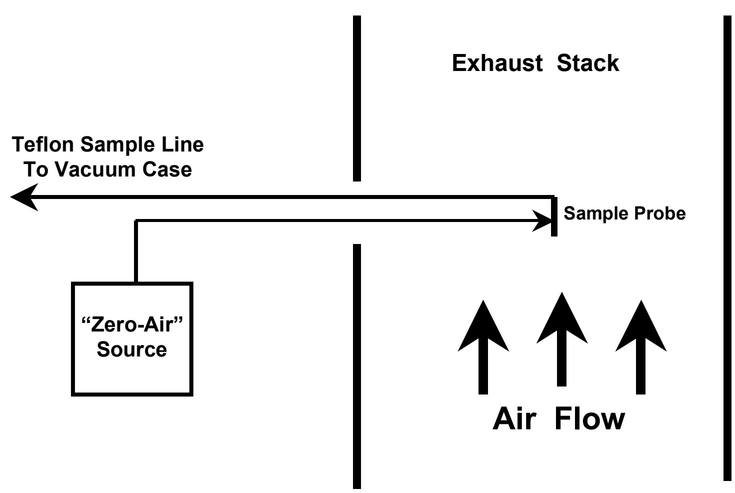


The 10-liter Tedlar sample bag would be first filled with the odorous air for "conditioning" the bag. The bag would be filled to approximately 1/3 full and held for one minute. The bag would then be emptied using the pump to pressurize the vacuum case. The odorous air sample would be discharged back to the exhaust stack through the Teflon sampling line. An alternative method for discharging the odorous air from the sample bag involves removing the bag from the vacuum case and manually “squeezing” the odorous air from the bag. Note that Figure B-2 illustrates the use of a water trap in the sampling line prior to the vacuum case for the purpose of preventing any water droplets from entering the sample bag.

The "whole-air" sample would then be collected in the sample bag using the vacuum case as described above. The sample bag needs to be only 2/3 full (approximately 7-liters) sufficient room must be available in the sample bag to allow approximately 20% expansion when aircraft shipping is used. When the vacuum is stopped to the case the sample flow stops. The sample line would be disconnected and the sample bag would be removed from the vacuum case after the bag valve is closed.

If the exhaust air is saturated with moisture or if the exhaust air dew point is above ambient air temperatures, additional sampling procedures need to be incorporated. A moisture trap in the sampling line, prior to the vacuum case, would be needed to collect droplets of moisture that may condense in the sampling line. Further, the sample bag may need to be prefilled with dry "zero air" or "high purity nitrogen" in order to prevent warm moist exhaust air from condensing in the sample bag. A "dynamic dilution" sampling probe may be needed for certain sample collection situations. A "dynamic dilution" sampling probe, Figure II-3, Dynamic Dilution Sampling Probe, is a device that simultaneously collects and mixes the sample from the exhaust source with a diluting gas, such as "zero air". Sampling specialists would need to be consulted in these cases for the specialized equipment.

Figure II-3 Dynamic Dilution Sampling Probe



The odor of exhaust air that contains oxidizing chemicals, such as ozone or chlorine, may change with time. Extra sampling precautions or procedures may be needed in these cases and the analytical laboratories would need to be consulted.

The collected sample bag needs to be protected from sunlight and from potential puncture with a durable shipping case or box. The Chain of Custody record would be completed for the sample. The date, time and description of the sample would be recorded as well as the analysis requested.

Each 10-liter Tedlar sample bag needs to be protected by placing the bag inside the shipping box on its end. Sample bags must never be shipped on top of one another. Sufficient room must be available in the shipping box for each bag to expand approximately 20% when aircraft shipping is involved.

The final steps of the sampler, prior to dispatching the sample shipment, would involve completing the shipping documents (air bill number), calling the express shipping company (i.e. UPS or FedEx) for a pickup, and calling the odor laboratory to confirm sample collection and to transmit the air bill tracking number.

Odor laboratories recognize the variable and uncontrolled nature of field conditions (i.e. weather and equipment) and typically have flexible policies for cancellation.

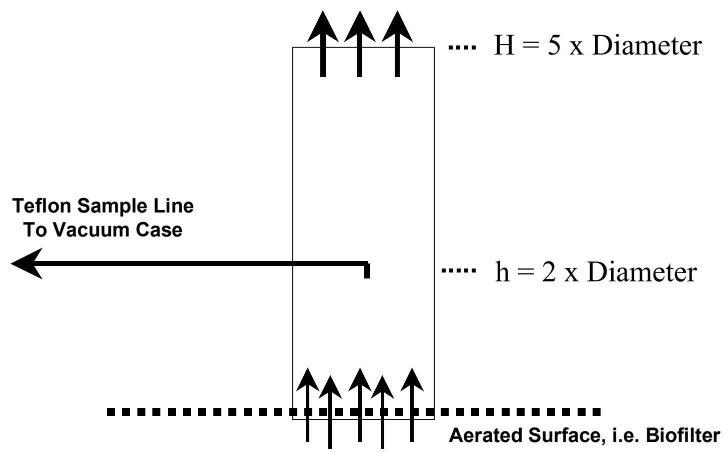
Most odor sampling protocols require the odor evaluations to be conducted within a nominal 30 hour time period after sample taking. When the sample arrives at the odor laboratory, the shipping box and the samples would be inspected with any discrepancies noted, i.e. damage to the sample bags. Review of the sampler's analytical orders on the Chain of Custody Record and comparison of the orders to the original work order would minimize errors and misunderstandings.

Sampling Surfaces

An odorous air sample can be collected from surfaces, sometimes called area sources. Wind speed and direction, air temperature and relative humidity, and solar radiation all affect the odorous emission rate from a quiescent surface, i.e. influent channel of primary clarifier. Aerated surfaces are also affected by the aeration blower flow rate in a diffused air process or the surface of a biofilter. Note that the emission rates for aerated area sources (i.e. aeration basins or biofilters) would be calculated by multiplying the "odor concentration" (i.e. pseudo-dimension of “odor units/cubic meter”) by the blower or exhaust fan flow rate (cubic meters/second).

A “tall passive chimney” or “simulated stack” is an apparatus used to collect aerated surface emission samples. Figure II-4, Tall Passive Chimney Sampler, illustrates the sampling method to isolate an aerated surface. Sample # 103 from the Gravity Belt Thickener Filter Biofilter is taken from the surface of the biofilter that has an upward flow of exhaust air. The tall passive chimney sampler minimizes the effects of cross flow winds at the time of sample collection. A vacuum case would be used to collect the whole-air sample of exhaust air from the biofilter surface using the same bag filling procedure described for the point source sample collection.

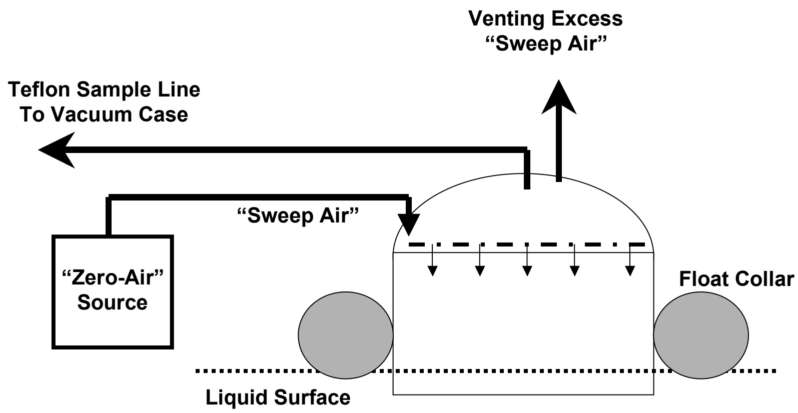
Figure II-4 Tall Passive Chimney Sampler



Sample #104 from the Influent Channel to the Primary Clarifiers was taken using a “flux chamber” floating on the surface of the influent channel. The "flux chamber" or the “surface emission isolation chamber” was originally developed in the 1970's to quantify emissions of inorganic gases from soils. In the 1980's, the U.S. EPA studied flux chambers for measuring the emission of volatile organic compounds from contaminated soil and water surfaces at hazardous waste sites. Figure II-5, Flux Chamber Sampler, illustrates the method to collect whole-air samples from quiescent liquid or solid surfaces. The flux chamber uses a flotation collar to float the chamber on a liquid surface. A clean, odor-free carrier gas (i.e. dry “zero air” or high purity nitrogen) is metered into the flux chamber at a known flow rate (i.e. 5 liters/minute). This flow is known as the “sweep air” for the flux chamber. After an equilibration period of three to four residence times, a sample is withdrawn from the flux chamber at a flow rate less than the sweep airflow rate (i.e. 2 liters/minute). Similar to sampling a point source, a vacuum case and Tedlar sample bag are used to collect the sample from a flux chamber.

The odorous emission rate for an area source would be calculated by multiplying the "odor concentration" (odor units/cubic meter) by a “sweep air” flow rate (cubic meters/second/square meter) of the “flux chamber” used to collect surface emission odor samples.

Figure II-5   Flux Chamber Sampler



Appendix III. Determination of Odor Concentration using Dynamic Olfactometry

This example outlines the calculations from a laboratory test used to determine the odor concentration by dynamic olfactometry. All odorous air samples described in Appendix II were shipped overnight to an odor evaluation laboratory. The laboratory received the samples the next morning and prepared the samples for processing following olfactometry standard ASTM E679-91 EN13725. Following these standard, five assessors were randomly selected from a larger pool of assessors. Each assessor met the butanol threshold and repeatability criteria set forth in EN13725.

All five assessors completed the threshold test (series of dilutions) twice (two rounds). Figure C-1 is an example of an Odor Evaluation Data Sheet for Sample 101 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] (CEN, 2003).

As an example, follow the results of Assessor 1 in Figure III-1. This assessor did not indicate "detection" of the odor at Dilution Level 5, which is a dilution ratio of 4000, but did correctly indicate "a detection" at the next highest odor concentration (lower dilution ratio) of 2000 (two times more odor than 4000). The assessor's individual estimated detection threshold is the geometric mean between 4000 and 2000, or 2820. The result of this statistical method is called the "best-estimate" threshold.

$$\frac{(\log 4000 + \log 2000)}{2} = \frac{(3.60 + 3.30)}{2} = 3.45$$

$$10^{3.45} = 2820$$

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].

Sample No.: 101 Digester Sludge Tank Exhaust

Dilution Level	4	5	6	7	8	9	10	11
Dilution Ratio	8000	4000	2000	1000	500	250	125	63
Log Dilution Ratio	3.90	3.60	3.30	3.00	2.70	2.40	2.10	1.80
Geometric Mean		5657	2829	1414	707	354	177	88
Log (Geo. Mean)		**3.75**	**3.45**	**3.15**	**2.85**	**2.55**	**2.25**	**1.95**

Assessor No.	Responses								Log D	Log R
1	2	1	6	8					3.45	3.15
2	1	1	6	8					3.45	3.15
3	2	2	1	6	8				3.15	2.85
4	1	1	6	8					3.45	3.15
5	1	2	2	8	8				3.15	3.15
1	2	1	6	8					3.45	3.15
2	1	1	6	8					3.45	3.15
3	1	1	1	6	8				3.15	2.85
4	1	2	1	8	8				3.15	3.15
5	2	1	6	8					3.45	3.15

Average Log Value	3.33	3.09
Std. Dev.	0.15	0.13
Detection Threshold	**2140**	
Recognition Threshold		**1230**

Key:
1= Incorrect Guess
2= Correct Guess
5= Incorrect Detection
6= Correct Detection
7= Incorrect Recognize
8= Correct Recognize

Figure III-1 Example Odor Concentration Data Sheet

The individual estimated thresholds of the five assessors over two rounds are averaged to determine the detection threshold. In the example in Figure III-1, this average transformed detection threshold estimate of the 10 tests is 3.33 or 2140 Odor Units (antilog of 3.33 = 2140 O.U.). The recognition threshold is 1230 Odor Units (antilog of 3.09). The "detection threshold" and "recognition threshold" values that are obtained from odor testing are actually derived from dilution ratios, and are 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."

APPENDIX IV. Statistical Review of Odor Concentration Data

Confidence Interval of Odor Results

It is important to highlight the necessity of the logarithm base 10 transformations that are used in odor testing calculations. 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 "dilution factor" (dilution ratio) values 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 (Mac Berthouex, 1994).

When odor testing is conducted on a number of odor 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 odor testing (CEN, 2003).

An olfactometry laboratory may develop a repeatability record with a standard deviation for replicates of 0.05. This is the standard deviation on the transformed scale of logarithms based on n = infinity. A confidence interval can be calculated for a typical odor concentration value (detection threshold) of 2140 (See Appendix C example for Sample No. 101) using the standard deviation of 0.05. The logarithm base 10 value for 2140 is 3.33.

The 95% confidence interval for the value 3.33 is then defined as:

95% C.I. = 3.33 ± 2.0 x 0.05 / square root of '1'

where: t = 2.0 the Student's t-factor for n = infinity (t = 2.0 for 95% C.I.)

This yields a symmetrical confidence interval for the transformed scale:

3.33 ± 0.10 or 3.23 to 3.43

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

Antilog_{10} (3.23) = 1,700 and Antilog_{10} (3.43) = 2,690

Therefore, for the odor value of 2140:

the 95% Lower Confidence Limit (LCL) is 1,700 (approx. 20% less than 2140)
the 95% Upper Confidence Limit (UCL) is 2,690 (approx. 25% greater than 2140)

Note that narrower confidence limits can be achieved with replicate sampling for each sample location, i.e. three samples for each location.

Annex I of the European Olfactometry Standard, EN13725, contains a discussion on how to compute confidence intervals and to determine the number of replicates needed for a defined precision (CEN, 2003). Figure IV-1 plots the upper and lower confidence intervals calculated for increasing number of replicates of the sample analysis. The graph is plotted from data presented in Annex I of EN13725. The data shows the most improvement in precision occurs from increasing from one to three replicates.

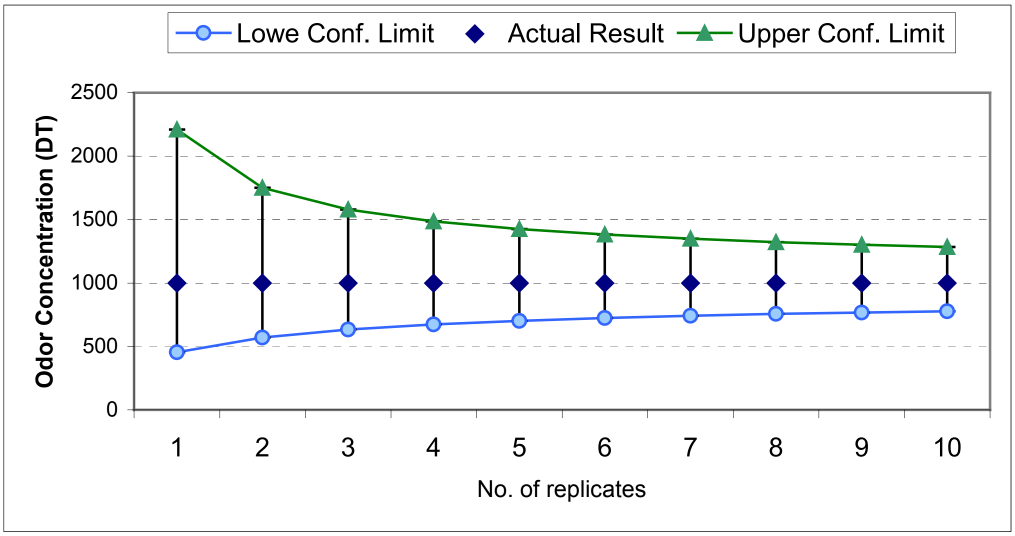


Figure IV-1 95% Confidence Intervals for different numbers of odor concentration measurements (replicates).

Odor Reduction Efficiency

Testing of an odor control system may be used to determine the odor reduction efficiency (η_D). If the inlet or "before" to the odor control system was 1560 (Sample 102, Biofilter Inlet) and the treated or "after" from odor control system was 100 (Sample 103, Biofilter Outlet), then the odor reduction efficiency is determined by:

$$E = \frac{1560 - 100}{1560} \times 100\% = 94\ \%$$

Note that the efficiency calculations can be conducted using the odor "dilution factor" values and need not use the logarithm transformation (CEN, 2003).

Appendix V. Determination of Odor Intensity and Persistency

This example outlines the calculations from a laboratory test used to determine the odor intensity and persistency using a trained panel of assessors. All odorous air samples described in Appendix B were shipped overnight to an odor evaluation laboratory. The laboratory received the samples the next morning and prepared the samples for processing of odor intensity and persistency following olfactometry standard ASTM International E544-99.

ASTM E544-99, "Standard Practice for Referencing Suprathreshold Odor Intensity," presents two methods for referencing the intensity of ambient odors to a standard scale: This example illustrates the Dynamic-Scale Method, which utilizes an olfactometer device with a continuous flow of a standard odorant (n-butanol) for presentation to the assessors.

The odorous air sample is presented to the assessor at full strength. The assessor compares the observed intensity of the odorous air sample to a specific concentration level of the standard odorant from the olfactometer device. Therefore, the assessor will report which level on the butanol scale matches the intensity of the odorous air sample, e.g. "Level 3."

Figure V-1 is a data sheet containing the results of five assessors determining the odor intensity of sample 104, "Surface of Influent Channel to Primary Clarifiers," described in Appendix II.

Sample 104: Surface of Influent Channel to Primary Clarifiers

Assessor No.	Intensity (Assessor Response)	butanol conc. (ppm)	Log Value
1	3	48	1.68
2	2.5	34	1.53
3	3.5	68	1.83
4	2	24	1.38
5	3	48	1.68

Ave. Log Value : 1.62

Odor Intensity (ppm n-butanol) : 42

Figure V-1 Example Odor Intensity Evaluation in a Laboratory.

This referencing method of quantifying odor intensity is the most commonly used method in evaluating environmental odors. For this method, the odor intensity result is expressed in parts per million (PPM) of n-butanol. For Sample 104, the odor intensity is reported as 42-ppm n-butanol equivalent.

Assessors also determine the persistency of the odorous air sample by evaluating the odor intensity at three dilution ratios above the threshold of the odor (suprathreshold). The result of this evaluation is four intensity values over four different "concentrations" of the odorous air sample, full strength and three dilution ratios.

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 intensity is related to the odor concentration (dilution ratio) by the "power law" (Steven's Law):

$$I = k\ C^n$$

Where:

I is the odor intensity,
C is the "dilution ratio" and
k and **n** are constants for each odor sample.

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

$$\log I = n \log C + \log k$$

Therefore, the persistency of an odor can be represented as a "Dose-Response" function. Plotted as a straight line on a log-log scale, the result is a linear equation specific for each odor sample. The slope of the line represents the relative persistency. The logarithm of the constant k is related to the intensity of the odor sample at full strength (Dravnieks, 1986), i.e. the y-axis intercept.

Sample 104 was also evaluated for odor intensity at dilution ratios of 50, 12.5, and 5.0. Figure V-2 is a "Dose-Response" function for sample 104, "Surface of Influent Channel to Primary Clarifiers." This graph shows the log Odor Intensity versus the log of the dilution ratio.

This "Dose Response" graph can be converted to a Power Law graph showing how the intensity changes with odor concentration in "Odor Units." This conversion is completed by taking the recognition threshold of the odorous air sample into consideration. First, the full strength sample presentation, 0.0 log value on the "Dose –Response" graph, has an x-axis value equal to the log of the recognition threshold (Log RT). For sample 104, the RT value was 1000, therefore, on the Power Law graph, this point will be plotted at x=3.0.

The other three points are also converted by subtracting the dilution ratio of the presentation from the recognition threshold (RT) dilution ratio:

$$\log I = n (\log RT - \log C) + \log k$$

Where C is the dilution ratio of the odorous air sample presentation. Figure V-3 is the converted "Dose Response" as the Power Law function.

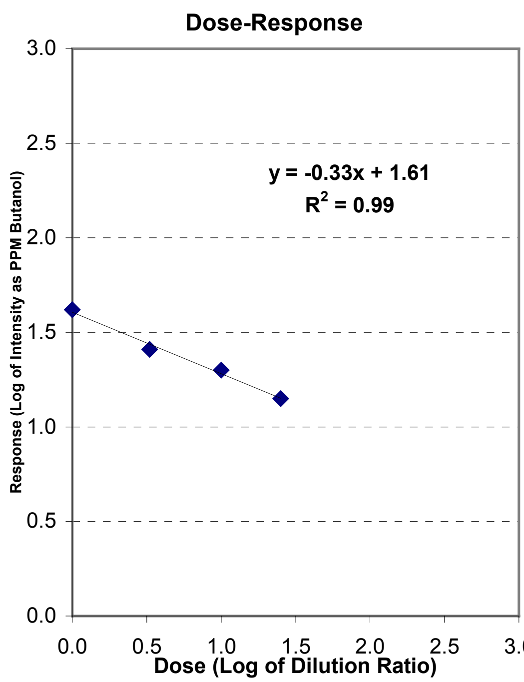


Figure V-2 "Dose-Response" (persistency) graph of odor sample 104

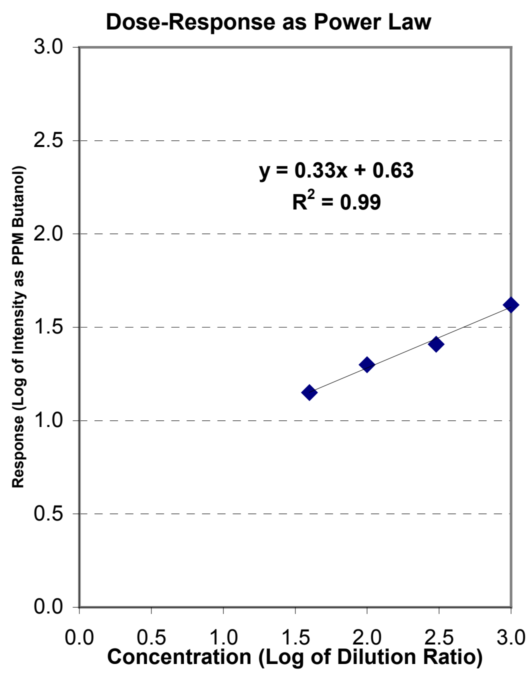


Figure V-3 "Dose-Response" (persistency) converted to "Power Law" graph of odor sample 104

The upward slope of the graph illustrates that the odor intensity of the single odorant increases as the mass concentration increases. The slope of the power law is less than one for odors since it takes a larger and larger increase in concentration to maintain a constant increase in perceived intensity.

Appendix VI. Odor Characterization

Following procedures described in the section titled "Odor Characterization," sample 102 and 103 described in the case study outlined in Appendix B, were evaluated for odor characterization.

Figure VI-1, Odor Characterization – Inlet, represents the results of evaluating Sample 102, Exhaust to the Biofilter. The figure is a spider plot of the eight main odor descriptor categories with the average reported relative strength (0-5 scale) plotted along the lengths of each axis. The further out on the axis the point lies, the stronger the odor character was observed by the assessors. Sample 102, Exhaust to the Biofilter, is highest in "offensive" characters with "Fishy," "Chemical," and "Vegetable" also significantly represented.

Figure VI-1 Odor Characterization: Inlet

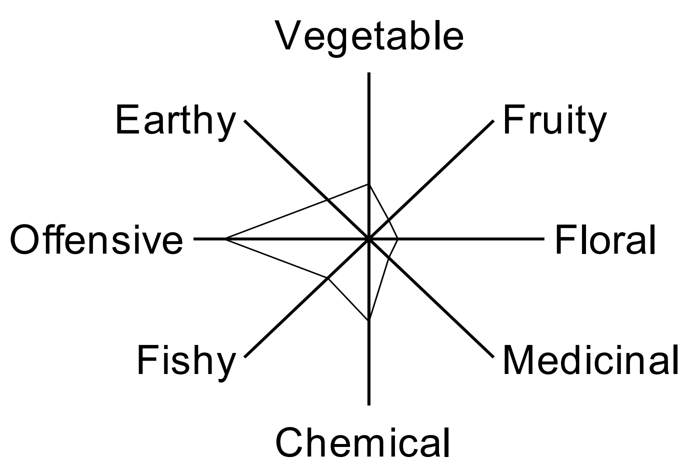
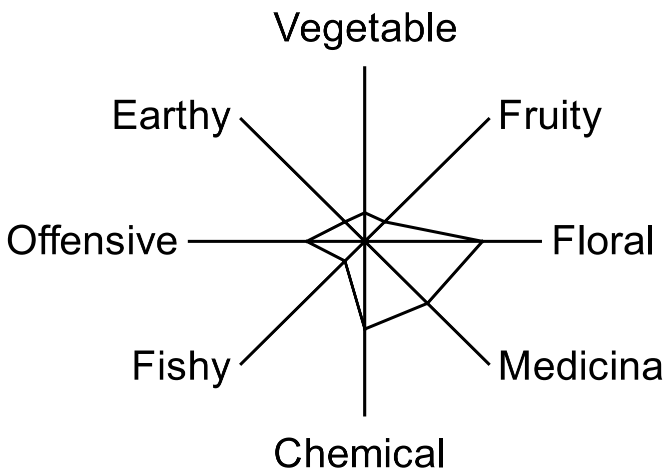


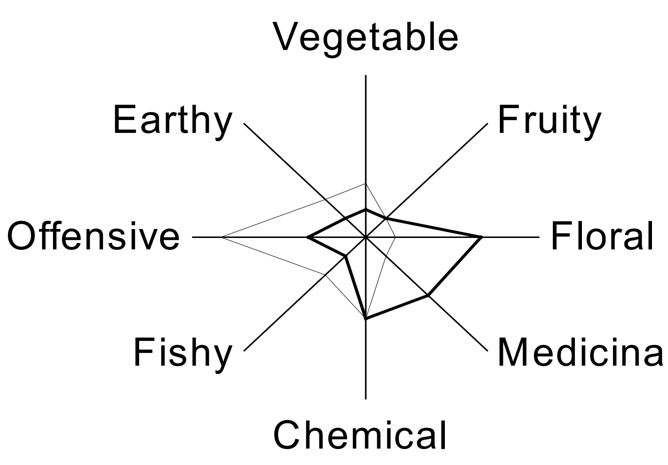
Figure VI-2, Odor Characterization – Outlet, represents the results of evaluating Sample 103, Biofilter Outlet. This sample is highest in relative strength for the "Floral," "Medicinal," and "Chemical" odors with "Offensive," "Earthy," "Vegetable," and "Fishy" also present at lower levels.

Figure VI-2 Odor Characterization: Outlet



Finally, Figure VI-3, Odor Characters – Inlet & Outlet, presents the Biofilter Inlet and Outlet odor descriptors with 2 spider graphs overlapping. This figure shows the reduction in strengths of the "Offensive," "Vegetable," "Earthy," and "Fishy" odors, as well as the increase in "Medicinal" and "Floral" odors.

Figure VI-3 Odor Characters: Inlet & Outlet



In addition to spider graph plots, the odor descriptors reported by an odor panel can be listed or plotted in other formats, i.e. histogram.

Appendix VII. Example Case Study Involving Community Survey Techniques

This case study is intended to provide an example of an odor survey conducted by city personnel investigating ambient odors around several industries in one area of the community.

Five city inspection and enforcement personnel were trained in the topics of odors and odor observation techniques. The personnel learn how to observe the odors following standard practices and procedures. The training also involves field exercises for the personnel to practice these techniques.

A map of the study area is used to plot the observation locations. The inspectors will drive the observation route and stop and make observations at all permanent ("fixed") locations and any predetermined optional locations where they notice an odor.

A data sheet is used to collect the data at each observation point. The data sheet includes weather condition information as well as information specific to each observation point (time of observation, location, D/T value identified, odor intensity based on an odor intensity referencing scale (OIRS), odor character descriptors, identified potential sources of the odor, and any other comments regarding the observation.

Attached to this appendix are an example of a completed data sheet and a map of observation locations around a facility.

The information from the inspection data sheets are entered into a data base for future review and analysis.

EXAMPLE

NASAL RANGER

COUNTY ENVIRONMENTAL DEPT. Date: 1/4/03

Time	Location	D/T 60	30	15	7	4	2	<2	Descriptors	Comments
7:05 AM	1 - INDUSTRIAL PARK							X		
7:10 AM	2 - " "						X		718	FACTORY 'A'
7:15 AM	3 - " "							X		
7:20 AM	4 - " "				X				718, 723	FACTORY 'A'
7:25 AM	5 - INTERSECTION					X			705	FACTORY 'A'
7:30 AM	6 - INTERSECTION							X		
7:35 AM	7 - CO. RD. 20		X						718, 723, 515	'A' & WWTP
7:40 AM	8 - INTERSECTION			X					718, 723	FACTORY 'A'
7:45 AM	9 - JUNCTION RD.				X				718, 723, 515	'A' & WWTP
7:50 AM	10 - CO. RD. 28			X					718, 515, 601	'A' & WWTP
7:55 AM	11 - DIVISION AVE.					X			718, 601	'A' & WWTP
8:00 AM	12 - INTERSECTION							X		
8:05 AM	13 - PARKING LOT					X			104, 304	VEGETATION
8:10 AM	14 - INTERSECTION						X		707	HIGHWAY
8:15 AM	15 - INTERSECTION							X		
8:20 AM	16 - INTERSECTION							X		
8:25 AM	17 - HOUSING DEVEL.						X		201	APPLE TREES
8:30 AM	18 - 3RD & OAK					X			706, 404	COFFEE SHOP

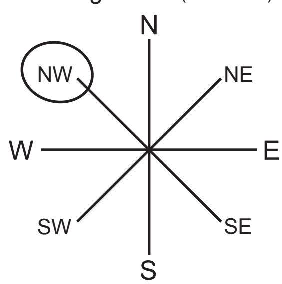
Weather Conditions

- ☐ Sunny
- ☐ Partly Cloudy
- ☐ Mostly Cloudy
- ☒ Overcast
- ☐ Hazy

Precipitation:

- ☐ None
- ☒ Fog
- ☐ Rain
- ☐ Sleet
- ☐ Snow

Wind Direction
Blowing From: (circel one)



Wind Speed:

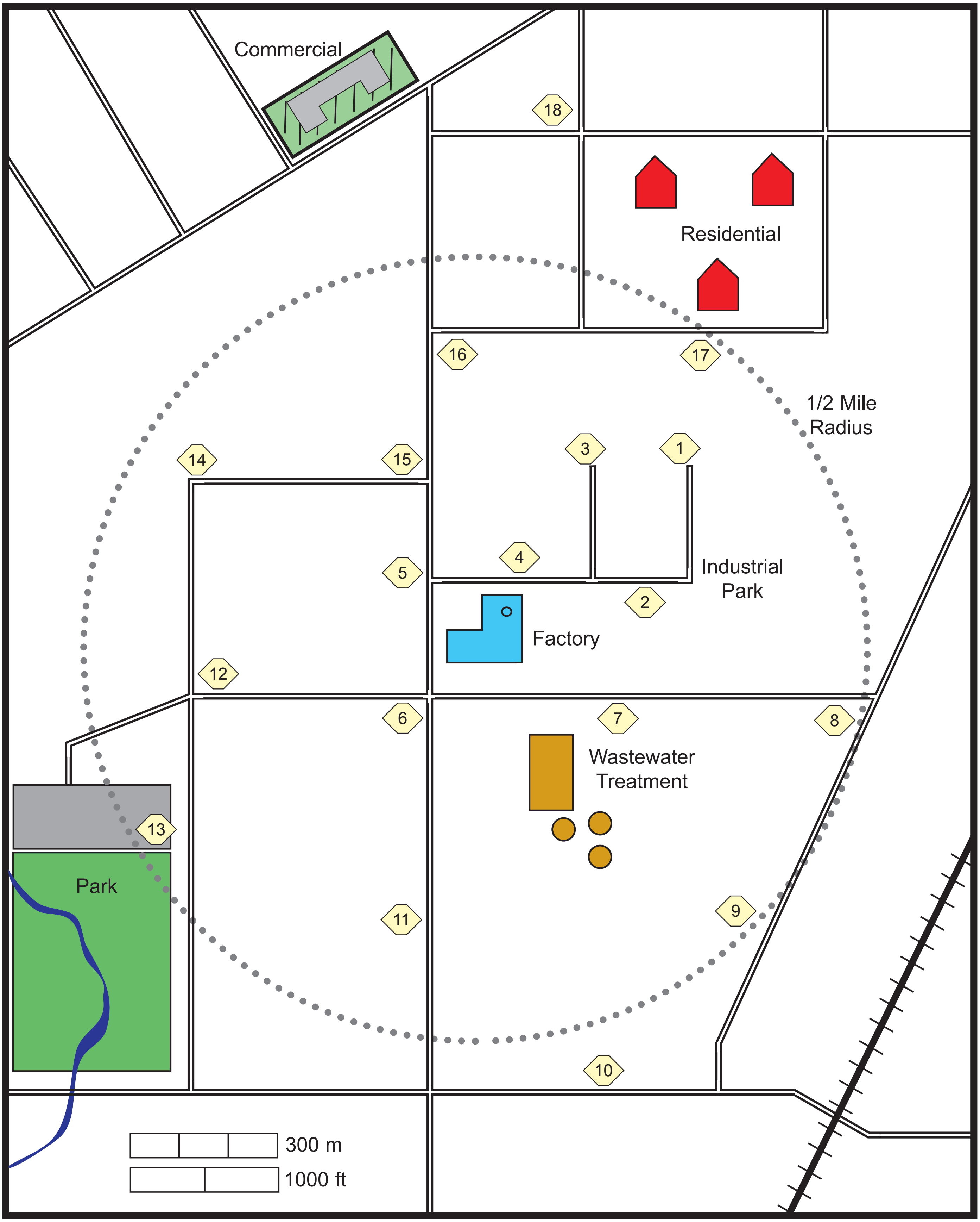
- ☐ Calm
- ☒ Light Breeze (1-5 mph)
- ☐ Moderate Wind (5-15 mph)
- ☐ Strong Winds (15 or higher mph)

Temperature: 55 °F/°C Relative Humidity: 60 % Barometric Pressure: 30.1

Comments: ____________________

008	NIGEL MACKENZIE	Nigel MacKenzie
Code	Name	Signature

EXAMPLE


Commercial
18
Residential
16
17
1/2 Mile
Radius
3
1
14
15
4
5
Industrial
Park
2
Factory
12
6
7
8
Wastewater
Treatment
13
Park
11
9
10
300 m
1000 ft