The Sense of Smell

The sense of smell is complex. The basic anatomy of the human nose and olfactory system is well understood. Odorous compounds are detected in a small region known as the olfactory epithelium located high and in the rear of the nasal cavity. The olfactory epithelium contains millions of neurons, the signaling cells of sensory systems, with hair-like sensors called cilia. The cilia extend outward and are in direct contact with the nearby air. In turn, each neuron is connected to the olfactory bulb through fibers called axons. The olfactory bulb connects to the olfactory cortex and other parts of the brain (Axel, 1995).

When odorous molecules are inhaled and brought near the olfactory epithelium, the molecules bind to specialized proteins, known as receptor proteins, which extend from the cilia attached to the olfactory neurons. There are around 1,000 different receptor proteins. The binding between the odorous molecules and the receptor proteins initiates an electrical signal that travels along the axons to the olfactory bulb where it is processed and sent on to the olfactory cortex (Axel, 1995). Axel (1995) presented a model that describes how the olfactory system in mammals can detect approximately 10,000 odors using only 1,000 different receptor proteins.

Beyond the biology of odor detection within the nose are the pathways that the olfactory signal takes for recognition of odor by an individual. One major pathway is to the emotion and memory response center of the limbic system, and the second is to the frontal cortex for conscious comparison to life situations. That means odor response is interwoven with memory and emotion.

Odors evoke a wide range of physiological and emotional reactions. Different people can have very different reactions to the same odor. Odors can be either energizing or calming. They can stimulate very strong positive or negative reactions and memories. Aromatherapy, which is becoming available, illustrates how important smells can be to people. The power, complexity, and our limited understanding of the sense of smell make olfaction a challenging field.

Continued exposure to an odor or inhalation of a very strong odor can cause olfactory fatigue. When the nose receptor sites become saturated with an odorant, it becomes fatigued, which is a condition that prevents the person from detecting that odor. Even after exposure to the odor ends, it may take 30 to 60 minutes or more for the receptor site to recover. A person experiencing odor fatigue has an impaired sense of smell.

Odorants and Odors

Most odors are a mixture of many different gases (odorants) at extremely low concentrations. The composition and concentrations of these odorants affect the perceived odor. To completely measure an odor, each gas needs to be measured. Some odorous gases can be detected (smelled) by humans at very low concentrations.
Odors evoke a wide range of physiological and emotional reactions.

(Table 3.1) The fact that most manure odors are made up of many different odorants at extremely low concentrations makes it impossible to determine the exact chemical composition of a particular odor.

Because humans can detect over 10,000 different odors, it is helpful to simply qualitatively categorize odors as being pleasant, unpleasant, or neutral. They are often described using terms such as floral, minty, musky, foul, or acrid. The large number of recognizable odors and the general terms used to describe them make it difficult to measure and describe odors consistently and objectively.

Gas Measurement Versus Odor Measurement

Two general approaches are used to measure odor: either measure individual odorous gas concentrations or use the human sensory method of olfactometry. Both approaches have strengths and weaknesses. Future developments will hopefully close the gap between the two approaches.

The specific individual gaseous compounds in an air sample can be identified and measured using a variety of sensors and techniques. The results can be used to compare different air samples. With good sensors and proper techniques, valuable information about the gases that emanate from a source can be collected and evaluated. Gas emission rates and control techniques can be compared rigorously. Regulations can be established to limit individual gas concentrations.

The gas measurement approach has some weaknesses when used to measure and control odors. The greatest weakness of this approach is that there is no relationship between the specific gas concentrations in a mixture and its perceived odor (Ostojic and O’Brien, 1996). As a result, controls based on gas concentrations may reduce specific gas emissions and concentrations but not adequately address the odors sensed by people downwind of a source.

Table 3-1. Odor threshold for select chemicals often found in livestock odors (Kreis, 1978).

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Odor Threshold (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aldehydes</strong></td>
<td></td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.21</td>
</tr>
<tr>
<td>Propionaldehyde</td>
<td>0.0095</td>
</tr>
<tr>
<td><strong>Volatile Fatty Acids</strong></td>
<td></td>
</tr>
<tr>
<td>Acetic acid</td>
<td>1.0</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>20.0</td>
</tr>
<tr>
<td>Butyric acid</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Nitrogen containing</strong></td>
<td></td>
</tr>
<tr>
<td>Methylamine</td>
<td>0.021</td>
</tr>
<tr>
<td>Dimethylamine</td>
<td>0.047</td>
</tr>
<tr>
<td>Trimethylamine</td>
<td>0.00021</td>
</tr>
<tr>
<td>Skatole</td>
<td>0.019</td>
</tr>
<tr>
<td>Ammonia</td>
<td>46.8</td>
</tr>
<tr>
<td><strong>Sulfur containing</strong></td>
<td></td>
</tr>
<tr>
<td>Methanethiol</td>
<td>0.0021</td>
</tr>
<tr>
<td>Ethanethiol</td>
<td>0.001</td>
</tr>
<tr>
<td>Propanethiol</td>
<td>0.00074</td>
</tr>
<tr>
<td>t-Butythiol</td>
<td>0.00009</td>
</tr>
<tr>
<td>Dimethy sulfide</td>
<td>0.001</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>0.0072</td>
</tr>
</tbody>
</table>
People have proposed using “indicator” gases to quantify livestock odors. Hydrogen sulfide and ammonia are among the most common chemicals proposed. Unfortunately, hydrogen sulfide or ammonia concentrations do not correlate well to livestock odor (Spoelstra, 1980; Pain and Misselbrook, 1990; Jacobson et al., 1997; Zahn et al., 1997). Livestock odors consist of many gases at extremely low concentrations, which are very difficult and expensive to measure. Odorous sulfur compounds (including hydrogen sulfide), odorous volatile organic compounds (VOCs), and ammonia are the three primary groups of odorous compounds. The lack of correlation of indicator gases with overall odor is likely due to the influence of various VOCs in the airstream. Measuring some of the gases may not be enough to describe the odor.

Research and development of new, better, lower-cost sensors is ongoing. Electronic noses, which use electronic sensors to detect chemical compounds, are being used in some industries for quality control. Most studies indicate that the output of electronic noses does not correlate with livestock odors (Watts, 1992; McFarland and Sweeten, 1994). However, one study suggests that technological developments may make it possible in the future (Misselbrook et al., 1997).

Olfactometry uses trained individuals and standardized procedures to measure odor levels and describe odors. Trained odor panelists can be used to determine an air sample’s odor detection threshold, recognition threshold, intensity, hedonic tone (the pleasantness or unpleasantness of an odor), and characteristic description. (See “Odor Measurement and Description: An Introduction to Olfactometry” below for more details about the way odor is characterized.)

The key advantage of olfactometry is the direct correlation with odor and its use of the human’s highly sensitive sense of smell. Olfactometry also has the advantage of analyzing the complete gas mixture so that contribution of each compound in the sample is included in the analysis. There are different olfactometry techniques. Data collected by different techniques can be neither combined nor directly compared.

McFarland (1995) reviewed many of the current olfactometry techniques being used for odor measurement and concluded that dynamic forced-choice olfactometry appears to be the most accepted method. Olfactometry suffers from a lack of precision compared to some of the sophisticated chemical sensors available. That lack of precision is due, in part, to the variability in each person’s sense of smell and reaction to an odor. Also, olfactometry does not identify the individual compounds that make up the odor. Even though olfactometry has limitations, it still is the best technique available at this time for directly measuring odors.

**Odor Measurement and Description**

**An Introduction to Olfactometry**

Various techniques measure and describe odors. Odors can be characterized in five ways. Each parameter adds to the complete description of an odor. They are:

- concentration,
- intensity,
- persistence,
- hedonic tone, and
- character descriptor.

Odor concentration and intensity are the two most common parameters measured. The other three — persistence, hedonic tone, and character descriptors — are commonly viewed as more subjective measurements and are not typically used for scientific or regulatory purposes.

**Concentration**

Two odor concentrations (thresholds) can be measured — detection threshold (DT) and recognition threshold. They are usually reported as odor detection threshold (ODT). The odor detection threshold is defined as the volume of dilution (non-odorous)
The major sources of bioaerosols are animals, animal wastes, feed, and bedding materials.

Air divided by the volume of odorous sample air at either detection or recognition. Since the ODT is a ratio, it is dimensionless (i.e., it has no dimensions such as mass, length, or time). A European standard defines this dilution concentration a bit differently as ODT/m³.

The detection threshold concentration is the volume of non-odorous air needed to dilute a unit volume of odorous sample air to the point where trained panelists can correctly detect a difference compared to non-odorous air. The samples are presented to trained panelists using an olfactometer, which is described in more detail on Page 10. At the detection threshold concentration, the panelists just begin to detect the difference between the odorous and non-odorous air mixture and other non-odorous airstreams. ODT is the most common concentration determined and reported.

The odor recognition threshold concentration is the volume of non-odorous air needed to dilute a unit volume of odorous sample air to the point where trained panelists can correctly recognize the odorous air.

The difference between detection and recognition thresholds can be illustrated with an analogy using sound and a person in a quiet room with a radio. If the radio is turned down so low that the person cannot hear the radio, the radio is at a level below detection. If the volume is increased in very small steps, it will increase to a point where the person will detect a noise. This volume corresponds to the detection threshold in which the person will not be able to recognize the noise and whether it is music or people talking. If the volume is increased in small steps again, it will increase to a point where the person will be able to recognize that it is either music or people talking. This volume corresponds to the recognition threshold.

**Intensity**

Intensity describes the strength of an odor sample. It is measured at concentrations above the detection threshold. Intensity changes with gas or odor concentration. Intensity can be measured at full strength (i.e., no dilution with non-odorous air) or diluted with non-odorous air. Intensity can be measured against a five-step scale using n-butanol, a standard reference chemical (ASTM E544-10, 2010) that smells like felt-tip markers. Trained panelists sniff containers of n-butanol at different concentrations in water to learn the scale (Figure 3.1). They then are presented diluted or full-strength (diluted is always presented first) odorous air samples that they rate against the n-butanol scale.

Odor intensity also may be measured using the labeled magnitude scale (LMS) as shown in Figure 3.2. An odor assessor marks the scale on the left near or between descriptive term(s) representing the sample. The numerical values are not included on the panelist assessment sheets. After assessment, the researcher processes the responses by assigning appropriate numerical scores to allow quantification (Green et al., 1996).

**Persistence**

Persistence is a calculated value based on the full-strength intensity and the detection threshold concentration. The slope of the line connecting these two points (on a log-log graph) is the persistence (Figure 3.3). Persistence values are normally negative.

Persistence indicates how easily the full-strength odorous air is diluted to below the detection threshold. Odorous air that has a low persistence (more negative) will have a steep slope, which indicates that it does not take much dilution air to dilute the odorous air to below the detection threshold. Odorous air with a higher persistence (less negative) will have a shallow slope, which means that more dilution air is required to reach the detection threshold. Inexpensive perfumes and colognes usually have less persistence than more expensive perfumes and colognes.
Most odors are a mixture of many gases at extremely low concentrations.

Figure 3-1. Scale used for ASTM E544-10 (2010) Odor Intensity Referencing Scale Method (OIRS) in combination with known concentrations of five reference odor intensities such as n-butanol in water at room temperature.

Table: Odor Intensity via OIRS Method

<table>
<thead>
<tr>
<th>Odor Intensity</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5+</td>
<td>Strongest</td>
</tr>
<tr>
<td>5.0</td>
<td>Very Strong</td>
</tr>
<tr>
<td>4.5</td>
<td>Strong</td>
</tr>
<tr>
<td>4.0</td>
<td>Moderate</td>
</tr>
<tr>
<td>3.5</td>
<td>Weak</td>
</tr>
<tr>
<td>3.0</td>
<td>Barely Detectable</td>
</tr>
<tr>
<td>2.5</td>
<td>Odorless</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>Odorless</td>
</tr>
</tbody>
</table>

Figure 3.2. Labeled magnitude scale (LMS) for odor intensity (Green et al., 1996).

Figure 3.3. Persistence calculated from log-log plot of intensity and dilutions (Schmidt, 2005).
Two general approaches are used to measure odor: measure individual gas concentrations or use olfactometry.

**Hedonic Tone**

Hedonic tone describes the unpleasantness or pleasantness of an odor (ASCE, 1995). It is typically rated using a scale that ranges from negative numbers, which are unpleasant, to positive numbers, which are pleasant. A typical hedonic tone scale is presented as Figure 3.4. Scales vary among research sites and range from -4 to +4 or -11 to +11. Neutral odors are recorded as zero. Unpleasantness usually increases with odor intensity. Pleasant odors may increase in pleasantness at low odor intensities, but become less pleasant and even unpleasant at relatively high intensities.

![Pleasantness Scale](image)

**Figure 3.4. Assessors noting the subjective pleasantness (hedonic tone) using a scale such as this 22-unit scale, typically without the quantifying numbers, for each sample**

**Character Descriptors**

Character descriptors describe the character of the odor. For example, an odor might smell like mint, citrus, earth, or any other select terms used by trained panelists. Character descriptors are used on samples at or above the recognition threshold concentration. Character descriptors are presented by St. Croix in an odor wheel as shown in Figure 3.5.

**Odor Measurement Techniques and Devices**

All the measurement devices and techniques discussed here, with the exception of the Electronic Nose that is discussed at the end of this section, use the human nose as the sensor. The measurements involve having a human interact with an odor in a controlled and repeatable manner with the difference among techniques being the type of device used to present the odor.

Olfactometry involves collecting odor samples, presenting those samples to an odor panel, recording the panel responses, and analyzing the resulting data. Field olfactometry takes the odor panel assessors to the site of interest for odor evaluation for an on-site sample evaluation. An odor sample for laboratory odor evaluation is collected in a volume of air or adsorbed onto a media, such as cotton or specialized fibers.

**Odor Sampling Techniques**

Currently, the most common sampling technique for laboratory odor evaluation uses specialized bags for collection and transport of odorous air to an assessment panel. Odor measurement requires that representative samples of the odorous air be drawn into a specially-prepared sample bag and rapidly transported to an odor laboratory (within 36 hours, preferably less) for evaluation. Odor samples are obtained using Tedlar™ sampling bags fed by Teflon™ tubing. Both of these proprietary materials are used to reduce gases “sticking” to sampling equipment, therefore obtaining a more representative sample that has all its components and reducing the chance for tainting...
subsequent samples. Air is drawn through the tubing into the sample bag by means of a vacuum pump on the downstream side of the sample bag (i.e., odorous sample air does not go through the pump). The open tubing is inserted into an odorous area or airflow at predetermined points. Often, a composite sample is collected from several locations in the odorous airstream.

Odors originate from various sources within a livestock facility such as ventilation exhaust fan discharge, manure storage/stockpile structures, feedlot surfaces, mortality composting site, or during land application of manure as fertilizer. Each type of source has special sampling requirements dependent upon how odorous gases are emitted and how they can be best captured for analysis. Specifics of sampling strategies and techniques depend on emission source characteristics. When emissions of odors are desired, additional data needs to be collected at sampling time. For emission samples, the gas flow rate is adjusted and reported as at NTP (Normal Temperature and Pressure, i.e., 20°C and 1 atmosphere) or STP (Standard Temperature and Pressure, i.e., 0°C and 1 atmosphere) conditions.

Figure 3.5. Odor characterization — environmental odor descriptor wheel (St. Croix Sensory, 2003)
There is no known relationship between specific gas concentrations in a mixture and their perceived odor.

The Specific Odor Emission Rate (SOER) is the quantity (mass) of odor emitted per unit time from a unit surface area. This quantity is not determined directly by olfactometry but is calculated from the concentration of odor (as measured by olfactometry), which is then multiplied by the volume of air passing through the fan/stack (point source) or flux-chamber/wind-tunnel (area source) per unit time.

Point sources typically will be a stack or fan with a known flow rate so that the odor emission rate can be determined along with other odor descriptions. Where key factors are unknown, observations can be conducted to access gas flow and concentration fluctuation patterns on a daily, monthly, or yearly basis. The number and location of sampling points is based on the point discharge geometry and use. As a rule of thumb, an appropriate number of odor sampling points can be the same needed to conduct a traverse of the cross section of a stack or fan to determine an average air velocity.

For building sources, such as animal shelters, odor samples are normally taken from several points within the enclosed airspace. Experience indicates that one composite sample is sufficient to represent a single shelter at a particular time. Additional samples can be taken at different times of the day or week to understand the periodic fluctuation of the odor concentration levels. Similarly, sampling may be carried out for different weeks during a grow-out cycle or for different seasons during a year or longer.

Area sources typically have a liquid or solid surface, such as the surface of a slurry storage tank or a cattle feedlot covered with manure, but not a defined emission point. A portable wind tunnel or flux chamber system can be used to determine relative odor emission rates at different points on the area source surface. A wind tunnel system uses a controlled air volume with entering air often filtered by activated carbon or from a known source (gas cylinder of clean air).

Flux chambers can operate similarly with air flowing through an enclosed chamber until equilibrium is reached (typically 30-60 minutes), known as a steady-state flux chamber. The flux chamber or wind tunnel environment allows a constant air flow over a defined liquid or solid surface. Convective mass transfer takes place above the emitting surface, mixing odorous air with clean air. Samples are easily taken from the chamber/tunnel discharge either periodically or at a slower rate for longer duration.

**Odor Measurement Devices**

Until recently, odor quantification via olfactometry lacked standardized methods. In the 1980s, several European countries launched an effort to develop international standards to provide uniform, objective, and repeatable olfactometry observations. In 2003, the Comité Européen de Normalisation (CEN) published the standard, CEN EN13725, which has been adopted by the European Union and has received widespread acceptance for threshold olfactometry evaluation (St. Croix Sensory, 2003). This standard provides criteria for equipment design and materials, calibration, sample sizes, and strategies for capture of whole-air samples. Standards for odor panel selection, qualification, and size were specified. Procedures for calculation of DT from a set of panel responses and exclusion of outlier observations (different from the main observations) are detailed.

Requirements for triangular-forced choice (TFC) odor sample presentation (the preferred method) and replications are specified. Triangular forced-choice olfactometry, in accordance with EN13725, provides objective and repeatable measurements that are comparable across laboratories. However, TFC olfactometry is expensive and time-consuming, and real-time field measurements are not possible.

Panelists are screened to find people with a “normal” sense of smell. Figure 3.6 is a plot of a normal distribution. It illustrates how a normal population would respond to an odor at different concentrations. A small percentage of individuals have a very sensitive sense of smell and are able to detect odors at very low concentrations. They are hypersensitive to odors. Another small percentage of people, described as “anosmic,” have a very poor sense of smell, requiring very high concentrations in order to detect an odor. Research has found that on an individual basis, the most sensitive panelists
Measuring: Odors

were able to detect odors at concentrations four to seven times lower than the least sensitive panelists. However, when averaged over eight-member panels, this variability was reduced to a 25 to 50 percent difference.

The majority of the population falls within the “normal” range. A goal of olfactometry is to have panelists very near the middle of the normal population. To comply with CEN EN13725 standards, panelists must maintain a sensitivity to n-butanol of 20-80 ppm. This is confirmed with regularly scheduled evaluations of each panelist. Panelists are trained to use proper sniffing (breathing) techniques to increase the contact between the air sample and their olfactory epithelium. Figure 3.7 illustrates how air flows through the nasal cavity with different sniffing techniques.

Despite efforts to be objective, human odor evaluation can be influenced by anxiety, distraction, fatigue, health status, personal comfort, and/or visual cues. Special techniques are required for sensory evaluation of odors. For outdoor environments, local weather conditions play an important role in odor release and transport, and the ability to control/manage factors that may differentially influence odor assessors is limited.

Olfactometry uses trained individuals and standardized procedures to measure odor levels and describe odors.

Figure 3.6. Normal distribution of olfactory sensitivity (Schmidt, 2005)

Figure 3.7. Sniffing technique used with olfactometry (Schmidt, 2005)
Olfactometry suffers from a lack of precision but even with its limitations, it is still the best technique available at this time for directly measuring odors.

Dynamic, Triangular, Forced-Choice Olfactometer

Olfactometers are essentially dilution machines that very accurately present a combination of odorous and non-odorous air to the human nose for evaluation. A dynamic, triangular, forced-choice olfactometer presents a series of sample airstreams to trained panelists (Figure 3.8). One of the airstreams is a mixture of non-odorous air and an extremely small amount of odorous air from a sample bag. The other two airstreams have only non-odorous air. Panelists sniff each airstream and are asked to identify which airstream is different (i.e., has some odor) than the other two non-odorous airstreams.

Initially, panelists must guess which airstream is different because the amount of odorous air added is below the detection threshold. In steps, the amount of odorous air added to one of the airstreams is doubled until a panelist correctly recognizes which airstream is different. In this case, the panelist indicates that he or she detects the odor. The airstream with the odor is randomly changed each time. Figure 3.9 illustrates the process. In the name of this olfactometer, “Dynamic” refers to the instrument’s ability to mix the sample airstreams during the measurement session rather than having to prepare samples in advance. “Triangular” refers to the set of three airstreams that are presented to the panelist. “Forced-choice” notes that with the presentation of each set of three airstreams, the panelist is forced to choose one of the airstreams as containing the odorous air, even if that choice is a guess.

The detection threshold is the non-odorous airflow rate divided by the odorous airflow rate when the panelist correctly recognizes which airstream is different. A panel of eight trained people is normally used to analyze each odor sample. The panel’s average concentration is reported and used in statistical analysis.

Standardized procedures and four hours of panelist training are used to achieve repeatable olfactometer results. Panelists are required to follow the rules listed in Table 3.2. The standard procedures and rules help panelists use their sense of smell to obtain consistent results and develop a professional attitude for their work. Odor panel sessions are limited to avoid odor fatigue and help keep the panelists focused on proper sniffing techniques.

Figure 3.8. Panelist, triangular forced-choice dynamic olfactometer, and panel leader (source: Penn State)
Odor concentration and intensity are the two most common odor characteristics measured.

Table 3.2. Odor Panel Rules (Schmidt, 2005).

<table>
<thead>
<tr>
<th></th>
<th>Must be free of colds or other physical conditions affecting the sense of smell.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Must not smoke or use smokeless tobacco.</td>
</tr>
<tr>
<td>3</td>
<td>Must not chew gum, eat, or consume coffee, tea, or beverages for at least one hour prior to odor panel work.</td>
</tr>
<tr>
<td>4</td>
<td>Must not eat spicy foods for at least six hours prior to odor panel work.</td>
</tr>
<tr>
<td>5</td>
<td>Must be “fragrance-free” by not using perfume, cologne, deodorant, scented aftershave, shampoo, or hand lotion the day of odor panel work.</td>
</tr>
<tr>
<td>6</td>
<td>Must not consume alcohol for at least six hours prior to odor panel work.</td>
</tr>
<tr>
<td>7</td>
<td>May drink only bottled water during odor panel work.</td>
</tr>
<tr>
<td>8</td>
<td>Must not discuss odor selections and answers with other panel members or public.</td>
</tr>
<tr>
<td>9</td>
<td>Must attend a training session and recertification each year.</td>
</tr>
<tr>
<td>10</td>
<td>Must demonstrate professional behavior at all times.</td>
</tr>
</tbody>
</table>
The detection threshold concentration is the volume of non-odorous air needed to dilute a unit volume of odorous sample air to the point where trained panelists can correctly detect a difference compared to non-odorous air.

Laboratory-based triangular forced-choice olfactometry measurement is presently considered to be the best available technology (Zang et al., 2002) and is the undisputed “gold standard” for sensory quantification of odors. Laboratory TFC evaluation is believed to give “better accuracy, reproducibility, and statistical reliability” than other methods (USEPA, 1996). However, sample preservation and potential adulteration introduced by sample bags (typically Tedlar™) are continuing challenges.

A TFC olfactometer costs about $50,000. Labs offering odor evaluations charge $200 to $1000 per sample to cover the costs of maintaining a trained panel, paying panelists for their time spent conducting the odor assessment, and calibration costs prior to each panel session.

Field Olfactometer

In the late 1950s, the U.S. Public Health Service sponsored research leading to the development of a relatively inexpensive, handheld device for sensory detection of odors in the field, using the same fundamental dynamic dilution approach as laboratory olfactometry. A field olfactometer produces known odor dilutions by mixing ambient (odorous) air with carbon-filtered (odor-free) air, which is sniffed and directly evaluated in the field. Field olfactometry is attractive because of the relatively low cost and convenience (Miner, 1995).

Field olfactometry dilution-to-threshold (D/T) observations offer several advantages over laboratory TFC measurements: (1) lower detection levels (most dynamic olfactometer labs advertise a detection floor of 20-30 D/T); (2) real-time measurements; (3) elimination of sample collection, transport, and the attendant sample preservation issues; and (4) lower cost per sample (McGinley and McGinley, 2003).

Scentometer™: The original field olfactometer, called a Scentometer, was developed by the Barneby-Sutcliffe Corporation. It is a rectangular, clear plastic box with two nasal ports, two chambers of activated carbon with air inlets, and several different size odorous air inlets (Figure 3.11).

A trained individual places the two nasal ports up to his or her nostrils and begins to breathe through the Scentometer. All of the odorous air inlets are closed so that the inhaled air must pass through the activated carbon and is deodorized.

The individual begins sampling by opening the smallest odorous air inlet. More and larger odorous air inlets are opened until the individual detects an odor. The ratio of the odor-free dilution air to the odorous air is used to calculate the dilution-to-threshold concentration. Typical dilutions for a six-hole meter are 2, 7, 15, 31, 170, and 350 parts filtered air to one part odorous air.

Figure 3.11. Scentometer (Wheeler, Penn State)
Portability and relatively low cost are some of the advantages of Scentometers. The Scentometer is not known for high accuracy (Jones, 1992). It requires a sufficient number of panelists to get more accurate measurements and panelists often suffer odor fatigue if not isolated from the ambient odorous air. A respirator mask is recommended between odor evaluations in the field.

Although there are no recommendations for describing Scentometer D/T levels, the odor can be described as “very strong” at 170 D/T, moderate at 31 D/T, significant at 7 D/T, and weak but noticeable at 2 D/T (Sweeten and Miner, 1993).

Since there is no standard method for quantifying Scentometer users, it is difficult to statistically evaluate results with confidence. Some user bias can be mitigated by having a second person activating the dilution sampling holes without the knowledge of the assessor.

Nasal Ranger™: This portable field olfactometer was developed to be more user-friendly and repeatable in its measurement protocols than the Scentometer. The Nasal Ranger quantifies odor in terms of dilution-to-threshold, in a manner similar to a dynamic olfactometer, resulting in a commonly recognized scale of odor evaluation. Carbon-filtered air is mixed with small volumes of ambient air containing the odor of interest in D/T ranging from 60 to 500. A dial on the front of the instrument is used to specify the dilution prior to sniffing by a trained assessor. An ergonomically designed mask with a foam seal is designed for both operator comfort and to ensure fit that allows minimal air leakage.

The Nasal Ranger includes a calibrated flow sensor to increase consistency in the amount of air drawn into the unit during each assessment. This reduces the variability among assessor “sniff” rates and provides consistency throughout a lengthy measurement session. Arrangements may be made for panelist training by the Nasal Ranger manufacturer (St. Croix Sensory, Minn.) in proper field odor evaluation protocols. Nasal Ranger units cost about $1,800 each.

A recent study by Brandt et al. (2007; 2008) found that the Nasal Ranger field olfactometer (Figure 3.10) can be a very useful management tool to aid producers and agricultural advisers in decision-making processes involving the odor potential of production units and practices, and in evaluating odor reduction strategies. These researchers note that meaningful results are contingent upon strict methodological protocols and data analysis.

Since field observations are influenced by a number of uncontrollable factors (e.g., wind direction, wind speed, and visual suggestions), minimizing the influence of such factors improves confidence in findings (Agnew et al., 2006). Brandt et al. (2007) recommend multiple odor assessors and observations, and Best-Estimate Dilution Threshold (ASTM-679-04) data evaluation for decisions involving costly management strategies. Panelists need to wear masks that filter ambient air to avoid odor fatigue.

Figure 3.10. Nasal Ranger field olfactometer (source: Penn State)

Intensity describes the strength of an odor sample. It is measured at concentrations above the detection threshold.
Cotton Swatch

The cloth swatch method of static olfactometry, developed by Miner and Licht (1981), offers an effective and inexpensive procedure to measure odor. In this technique dry cotton flannel swatches are used to absorb odors.

Grab samples of odorous liquid are collected from odor sources (manure pit, composting facility, etc.) and then placed into glass quart jars to provide two replicates for each sample. Cloth flannel swatches of 10 cm × 10 cm (4 in × 4 in) dimensions are heated to 92°C (198°F) for four hours prior to sampling to remove absorbed volatile gases and solids. Prepared swatches are attached to jar lids by a loop of Teflon™-coated galvanized steel wire, then sealed in the jars for 30 minutes to absorb sample odor. Then the swatches are removed and enclosed in 60 mL glass bottles for another 30 minutes to allow headspace gas to generate.

These jars are then immediately brought to an odor testing laboratory with trained panelists. Panelists evaluate the odor by removing the bottle cap and then sniffing each swatch for approximately 3 seconds. Panelists then assign an odor rating to that sample. Each panelist should rest for several seconds after each sniff to minimize odor fatigue. Prior to any odor evaluation, the panelists first sniff two reference odors to calibrate their sense of smell. The references are swatches placed above distilled water (reference 1) or a strong odor of similar character to the samples (reference 2). For example, reference 2 might be swine facility wastewater from an underground storage pit. Reference 1 is considered a “0” and reference 2, a “5” on the odor level scale.

Field Sniffer

A “field sniffer” is a term used to describe a trained panelist who determines odor intensity in the field. The panelists calibrate their noses with the n-butanol intensity scale (described above) before going into the field to sniff.

This calibration is done as a group so consistent intensity levels are established among the individual sniffers. They use charcoal filter masks to breathe non-odorous air between readings to avoid nasal fatigue. At specified times the field sniffers remove their masks, sniff the air, and record the air’s intensity. The results are being used to validate odor dispersion models.

Community Monitor

The field sniffer approach also may be used by individuals, farmers, regulators, or others interested in monitoring ambient odors. It is recommended that the person have some basic “intensity” odor training using the reference n-butanol intensity scale to allow the person to calibrate his or her nose. An odor recording form similar to that in Figure 3.12 allows the sniffer to record odor events at the location, and document the occurrence and a relative level of intensity of the odor.

Other important information needed in this monitoring system includes date and time, cloud cover, wind speed and direction, and temperature. It is also helpful to add general comments when recording odor events. These comments might include information on the character or possible source of the odor.

Gas Chromatograph-Mass Spectrometer-Olfactometer (GC-MS-O)

This instrument can simultaneously measure odor and specific odorants. Some versions combine gas chromatography-olfactometry (GC-O), while others have gas chromatography-mass spectrometry-olfactometry, GC-MS-O or GC-MS-Sniffer. Its application to environmental odor analysis is more recent than its well-established use in food aroma and drinking water taste analyses.
Odor Event Recording Form

<table>
<thead>
<tr>
<th>Sky</th>
<th>Precipitation</th>
<th>Wind Direction (Blowing From)</th>
<th>Wind Speed</th>
<th>Odor Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny (SY)</td>
<td>None</td>
<td>N</td>
<td>Calm (CM 0-1 mph)</td>
<td>None=0</td>
</tr>
<tr>
<td>Partly Cloudy (PC)</td>
<td>None</td>
<td>NW</td>
<td>Light Breeze (LB) 1-5 mph</td>
<td>Slight=1</td>
</tr>
<tr>
<td>Mostly Cloudy (MC)</td>
<td>Fog (FG)</td>
<td>NE</td>
<td>Moderate Wind (MW) 5-15 mph</td>
<td>Noticeable=2</td>
</tr>
<tr>
<td>Overcast (OC)</td>
<td>Rain (RN)</td>
<td>W</td>
<td>Strong Wind (SW) 15+ mph</td>
<td>Very Noticeable=3</td>
</tr>
<tr>
<td>Hazy (HZ)</td>
<td>Sleet (ST)</td>
<td>SW</td>
<td></td>
<td>Strong=4</td>
</tr>
<tr>
<td>Night (NT)</td>
<td>Snow (SW)</td>
<td>E</td>
<td></td>
<td>Extreme=5</td>
</tr>
</tbody>
</table>

None=0
Slight=1
Noticeable=2
Very Noticeable=3
Strong=4
Extreme=5

<table>
<thead>
<tr>
<th>Date</th>
<th>Sky</th>
<th>Precip</th>
<th>Wind Direction</th>
<th>Temp °F</th>
<th>Wind Speed</th>
<th>Odor Intensity</th>
<th>Comments</th>
</tr>
</thead>
</table>

Figure 3.12. Odor Event Recording Form (Schmidt, 2005)
The GC-MS-O technique separates individual compounds in gas samples, allowing them to be identified while providing the odor character for each compound. A small sample of air is injected into the instrument after which the airstream is split in two.

One airstream is used to produce the mass spectrometer chromatogram, which is used to identify individual compounds, while the other airstream is directed to the olfactometer for human assessment. The human identifies and records the character, hedonic tone, and intensity of each odorant that is presented.

The results allow construction of an odor wheel, which relates odor description to the chemical compounds in the sample. The advantage of this odor evaluation technique is the link between analytic and sensory measurements of the same sample. Like the GC-MS instrument without the olfactometer, this combination instrument can analyze air samples or odorants collected on SPME fibers (solid-phase microextraction, pronounced “speem-ee”). SPME is a gas sample collection technique that takes advantage of the affinity of compounds to embed on the coating of the micro-fiber.

The instrument can analyze odorants collected in air samples or on SPME fibers, a specialized, delicate filament that is used to collect an odor sample. The SPME fiber is inserted into the instrument, and then the adsorbed gases are extracted to create a sample airstream.

**Electronic Nose**

The term “electronic nose” describes a family of devices, some commercially available, that measure a select number of individual chemical compounds to measure the odor. The devices use a variety of methods for measuring the gas concentrations. Also called an artificial nose, the instrument is generally composed of a chemical sensor array and a pattern recognition system, typically an artificial neural network.

Electronic noses are currently being used in environmental and medical applications to automate the identification of volatile chemicals. Electronic noses can be used for real-time analysis of odor and produce a qualitative output that allows for easier automation than the use of human odor panels. But human odor panels are still necessary in the “training” of an electronic nose under various conditions so the instrument is reliable in producing the same responses that represent human responses. This is difficult and time-consuming.

Researchers continue to evaluate these devices. To date researchers have not successfully correlated livestock odors with the output of commercial or research electronic noses. An instrument that could perform simple odor discrimination without the subjectivity of humans would be very useful. Attempts to mechanically or electronically mimic the abilities of the human olfactory system are ambitious because of the many types of odors that may be presented to the instrument through odor assessments. Persaud (2003) stated that many electronic noses are applicable to specific tasks, but none emulate the human nose.

Electronic nose technology has been applied to several situations related to agriculture. These applications include odor detection, produce and meat quality evaluation, and food safety. Omotoso et al. (2005) used an electronic nose integrated with hydrogen sulfide and ammonia sensors to correlate concentrations of these with odors from swine manure.

The researchers found that integrating the sensors provided better odor concentrations than the individual sensors alone. Qu et al. (2001) used an electronic nose and neural networks to predict odor concentrations of n-butanol samples and compared the results to human panel assessments. Their results showed good correlation, with less than 20 percent mean error between the predictions and panel measurements, but this was only evaluating one odorant, not a complex mixture of odorants.

Li et al. (2004) also used an electronic nose and neural networks to predict the concentration and intensity of n-butanol samples and compared these predictions with a human panel, yielding good correlation.
Powers and Bastyr (2002) assessed odors from simulated swine storage units using an odor panel, electronic nose, and gas chromatography. Electronic nose response was not highly correlated ($r^2 = 0.20$) with human panel scores, although a prediction equation developed from headspace constituents correlated much better with electronic nose response ($r^2 = 0.76$). Some current work is using an electronic nose to evaluate odors on a hedonic tone scale in the same manner as a human odor panel by training neural networks using electronic nose response as input and human assessment values as outputs (Williams et al., 2009).

**Summary**

Odor measurement is difficult because no practical instrument has been developed that measures all the various aspects of odors. Agricultural odors are complex and transient. More than 160 compounds have been identified in manure or the surrounding air (O’Neill and Phillips, 1992). Each individual compound contributes to the overall character either by making the emission more offensive, easier to detect, or harder to measure.

Reduction of odor offensiveness may not be directly correlated with efforts to suppress individual components such as ammonia or hydrogen sulfide. Thus, methods that directly measure odors are needed. Odor records are useful in solving an odor problem because they provide data that can be used to determine the source of odor and verify whether control technologies are effective.

Employing the human nose as the sensor (olfactometry) is considered the most reliable means of quantifying odors (Miner, 1995). The human nose is exquisitely equipped to detect odor, but personal preferences affect what is considered acceptable or offensive. Modern instruments can measure many compounds that make up an odor. However, odor is a combination of numerous compounds with interactive effects that influence human perception. Despite inherent limitations, olfactometry has the ultimate benefit of capturing the total effect of human experience (Gostelow et al., 2003).

**Sources for Odor Instrumentation**

Field Olfactometer
Nasal Ranger
St. Croix Sensory
P.O. Box 313
3549 Lake Elmo Ave. N.
Lake Elmo, MN 55042
800-879-9231
www.nasalranger.com

Triangular Forced-Choice Olfactometer
St. Croix Sensory
P.O. Box 313
3549 Lake Elmo Ave. N.
Lake Elmo, MN 55042
888-444-ODOR
www.fivesenses.com

Yes/No Olfactometers
Odournet
Air quality and odour research consultants
www.odournet.com
**Additional Resources**

Animal Agriculture and Air Quality, 2005. 205 pages. Approximately $35
Editor, David Schmidt
Department of Biosystems and Agricultural Engineering
University of Minnesota Extension Service

Editors, Robin C. Brandt and Herschel A. Elliott
Pennsylvania State University and Pennsylvania Department of Agriculture
Department of Agricultural and Biological Engineering
University Park, PA

Sampling Agricultural Odors, PNW 595. 2007. 8 pages. Free.
R.E. Sheffield and P. Ndegwa. Pacific Northwest Extension publication, PNY 595.
University of Idaho.

Ronald Sheffield and Robert Bottcher
North Carolina Cooperative Extension
Biological and Agricultural Engineering

St. Croix Sensory, Inc.
Prepared for the Air Quality Bureau of Iowa Department of Natural Resources


**References**


Adapted from:
Animal Agriculture and Air Quality, 2005.
Department of Biosystems and Agricultural Engineering
University of Minnesota Extension Service
Editor, David Schmidt

Incorporating text from:


© The Pennsylvania State University 2012

Reviewer
Greg Zwicke
USDA-NRCS

United States
Department of Agriculture

National Institute of Food and Agriculture

The Air Quality Education in Animal Agriculture project was supported by National Research Initiative Competitive Grant 2007-55112-17856 from the USDA National Institute of Food and Agriculture.

Educational programs of the eXtension Foundation serve all people regardless of race, color, age, sex, religion, disability, national origin, or sexual orientation. For more information see the eXtension Terms of Use at eXtension.org.

Reference to commercial products or trade names is made with the understanding that no discrimination is intended and no endorsement by eXtension is implied.