The Science of Smell Part 3:
Odor detection and measurement

As perceived by humans, odors have five basic properties that can be quantified: 1) intensity, 2) degree of offensiveness, 3) character, 4) frequency, and 5) duration, all of which contribute to the neighbor's attitude towards the odor as well as the business generating the odor. It is generally accepted that the extent of objection and reaction to odor by neighbors is highly variable. The reaction can be based on previous experience, relationship to the odor-producing enterprise and the sensitivity of the individual. Weather (temperature, humidity, wind direction) affects the volatility of compounds, preventing or enhancing movement into the gaseous phase where an odor can be dispersed downwind.

Most of us will accept even a strong odor for a short period of time, provided we don't have to smell it often. But we have a threshold for the frequency and duration of the odor, above which our tolerance is exceeded and we view the odor as a nuisance. These thresholds, however, are person-specific. While it is the frequency and duration of an odor that often triggers a nuisance complaint, odor measurement procedures typically focus on the first three traits (intensity, offensiveness, and character). From a human health standpoint, exposure time is an essential measure in predicting any negative effects that may occur and this encompasses frequency and duration as well as concentration (intensity). As a result, regulatory procedures often include concentration, frequency, and duration as part of the compliance protocol.

Defining odor

An *odorant* is a substance capable of eliciting an olfactory response whereas *odor* is the sensation resulting from stimulation of the olfactory organs. *Odor threshold* is a term used to identify the concentration at which animals respond 50 percent of the time to repeated presentations of an odorant being tested. Most often, however, odor "threshold" is used to describe the *detection threshold*, which identifies the concentration at which 50 percent of a human panel can identify the presence of an odor or odorant without characterizing the stimulus. The *recognition threshold* is the concentration at which 50 percent of the panel can identify the odorant or odor.

Although the detection threshold concentrations of substances that evoke a smell are low, often times in the parts per billion (ppb) or parts per trillion (ppt) range, a concentration only 10 to 50 times above the detection threshold value often is the maximum intensity that can be detected by humans. This is in contrast to other sensory systems where maximum intensities are many more multiples of threshold intensities. For example, the maximum intensity of sight is about 500,000 times that of the threshold intensity and a factor of 1 trillion is observed for hearing. For this reason, smell is often concerned with identifying the presence or absence of odor rather than with quantifying intensity or concentration.

Perception of a mixture of odorants, such as those in livestock odor, is very different from how each chemical would be perceived independently. Odorants can act as additive agents, counteractants, masking agents, or be synergistic in nature. The combination of two odorants can have an odor equal to that of either one of the components, have an odor less than that of one of the components, have an odor equal to the sum of the components, or even have an odor greater than the sum of the components. This makes odor quantification and characterization a challenging process.

Odor can be evaluated subjectively in terms of intensity (strength) or in terms of quality (i.e., offensiveness). Odor quality is evaluated by describing the odor or comparing the sample odor to familiar odors. Evaluation of odor quality is difficult because of the challenges that come with trying to describe odors.

Odor measurement techniques

Dilution-to-threshold methods

Dilution-to-threshold techniques dilute an odor sample with odorless air at a number of levels and the dilution series is presented in ascending order of odor concentration. From one level to the next, the dilution

IOWA STATE UNIVERSITY
University Extension

PM 1963c October 2004

decreases and the amount of odorous air increases. The first few levels include the sample diluted with a large amount of odorless air so evaluation can begin below the threshold of detection. Preferably, multiple presentations (two odorless air samples and the diluted odor sample) are made at each level of dilution.

When a forced-choice method is used, a panelist, typically trained to conduct these evaluations, must identify the presentation that is different from the others at each level, even if it is a guess. This permits use of all the data. The threshold of detection is the dilution level at which the panelist can determine a difference between the diluted and the odorless samples. After the detection threshold is reached, the panelist continues the evaluation at the next level or two to be certain the identification was not made by chance. Examples of the dilution-to-threshold methods include use of scentometery and olfactometery.

Scentometry

One method of odor concentration evaluation that is available on-site employs the use of a Scentometer® (Barneby and Cheney, Columbus, OH) or a Nasal Ranger® (St. Croix Sensory, St. Elmo, MN). The Scentometer® is a plastic box with a number of air inlets and two sniffing ports. Two of the air inlets have activated charcoal filters to remove odors and provide clean air. The remaining inlets are of varying diameter to permit a range of dilutions of odorous air to be sampled. An observer begins by opening the port of smallest diameter to start with the largest dilution (lowest concentration) of the odor.

As successively larger ports are opened, the dilution of the odorous air decreases and the odor concentration increases. When the evaluator can first detect the odor, the odor threshold has been reached. Odor concentrations are expressed as dilutions to threshold. The range of dilutions to threshold possible for the Scentometer includes 1.5, 2, 7, 15, 31, 170, and 350. The Nasal Ranger® operates on the same principles and has selectable dilution ratios of 2, 4, 7, 15, 30, and 60. Inhalation or airflow rate is controlled on the Nasal Ranger®. For both instruments, an individual observer or a couple of people rather than a larger panel of evaluators frequently conducts measurements.

Olfactometry

Olfactometers operate much like the Scentometer® and the Nasal Ranger®. The primary differences are that olfactometers are not portable and an operator closely controls sample delivery. Larger dilution-to-threshold ranges are available. The AS'CENT International Olfactometer® (St. Croix Sensory, St. Elmo, Minn.), for example, allows samples to be presented at 14 dilutions that represent a range in dilution-to-threshold of 8 to 66,667. These units are often used in a laboratory setting by 7 to 10 panelists to evaluate each sample rather than the small number of evaluators that are used in the field measurements (See Photo 2). Efforts to establish the relationship between olfactometer readings and that from the portable units are currently underway at Iowa State University.

Photo 1. Using a Nasal Ranger® to detect odors.

Ranking methods

Odor can be evaluated using panelists to rank samples, a procedure in which an arbitrary scale is used to describe either the intensity or offensiveness of an odor. Typically, a scale of 0 to 10 is used, with 0 indicating no odor or not offensive and 10 representing a very intense or offensive odor. Such methods use either odor adsorbed onto cotton or a liquid sample that has been diluted. Manure can be diluted with water to a range of concentrations and then evaluated by a panel.

One study, for example, diluted stored dairy manure with water to create five dilution levels. For each level, two blank samples of water and one diluted manure sample were presented in flasks that had been painted black to avoid bias based on appearance of the diluted manure. Panelists evaluated the samples in an ascending series; the dilution decreased and odor increased from one level to the next. At each dilution level, panelists identified the flask in each set of three that contained the odorous sample (forced-choice). A separate study analyzed panelist variability when this procedure was used and observed that each panel member had a distinct and repeatable odor probability distribution.

Photo 2. The AS'CENT International Olfactometer®.

Referencing methods

This method uses different amounts of 1-butanol as a standard to which sample odor intensity is compared, again using a human panel. The range of 1-butanol concentrations is often from 0 to 80 ppm. As the concentration of butanol is changed, the sample odor is compared to the butanol to determine at what concentration of butanol the sample's intensity is equivalent. The use of butanol as a reference standard is widely accepted as common practice in Europe and has been incorporated into portable and laboratory scale instrumentation. Most of the methods currently used in the United States employ butanol as a means of assessing panelist suitability rather than as the sole means of determining an odor's strength or acceptability.

Challenges with current methods

Challenges with current methodology include the use of humans for assessment. Work has shown that the same panelist's response from one day to the next can vary by as much as three-fold, possibly due to health or mood of the individual. Variability in the sensitivity of the individual conducting the evaluation and odor fatigue are further concerns that are commonly addressed in procedural protocol.

Odor fatigue is a temporary condition where a person becomes acclimated to an odorant or odor to the point that they are no longer aware that the odor is present. An example would be when you walk into a barbeque restaurant and by the time you leave, you are unaware of the aroma that attracted you in the door. Onsite methods are complicated by the influence that visual perception might have in an evaluation (smelling with your eyes, so to speak). Each of us has a unique odor acuity. While methods try to minimize panelist variation, the difference in sense of smell from one person is another consideration in human assessment methods.

The measurement of odor concentration by dilution is more direct and objective than that of odor quality or intensity. However, each of the above procedures requires the use of the human nose as a detector, so not one is completely objective. The imprecision that results from the large difference between the dilution levels has been identified by researchers as a concern as well. Use of a forced-choice method, such as that used with dynamic olfactometers, in which a panelist must simply identify the presence or absence of an odor is generally a better method than ranking, as the human nose cannot distinguish small differences between levels of intensity.

Emerging methods

Efforts are underway across the United States to develop evaluation methods that can be used onsite and without the influence of human subjectivity with the goal of providing an objective and affordable means of quantifying odors.

Surrogate compounds

Odors from livestock facilities contain hundreds of different compounds, all interacting with each other and their environment in additive and non-additive (counteractant, masking) manners. From the standpoint of odor control, it is desirable to know which compounds are most important in defining an odor, so that those few compounds can be targeted with control strategies.

Compounds that have been well-correlated to odor measures in studies led by Iowa State University and elsewhere, and might be useful as surrogates in determining odor, include volatile fatty acids (acetate, butyrate, propionate) and phenolics (phenol, cresol, indole, skatole).

In order to identify and quantify the constituents of odor, gas chromatography-mass spectrometry (GC/MS) is most frequently employed. Samples are commonly trapped (adsorbed) onto some type of sorbent material that concentrates compounds of interest then quantified by GC/MS. Concentrations of identified compounds and the interactions of the identified compounds are mathematically correlated to odor measurements made using traditional methods, most commonly the dilution-to-threshold methods. Interpretation of the results is complicated because odors that are equal in concentration may not be equal in offensiveness or intensity. Furthermore, two odors of equal concentration may be perceived as having different intensities.

While gas chromatography coupled to mass spectrometry (GC/MS) is frequently used to identify and quantify odorous compounds and the use of surrogate compounds is an objective method, this approach does not represent the experience of odor sensation as perceived by humans. Efforts to combine both instrumental and human methods are under development.

Electronic nose

Electronic nose analysis with a sensor array is a potential technology for odor evaluation. To date, relatively little research has been conducted with electronic noses in the area of agricultural manure odors. The electronic nose has been developed in an attempt to mimic the human sense of smell and is frequently used in the food, beverage, and perfume industries for product development and quality control.

The sensor array of an electronic nose detects the chemicals that humans perceive as odors and records numerical results. The instrument will generate a different pattern of response for different types of samples. Commercially available electronic noses have 32, 64, or 128 sensors. Each sensor has an individual characteristic response, and some of the sensors overlap and are sensitive to similar chemicals, as are the receptors in the human nose. A single sensor is partially responsive to a broad range of chemicals and more responsive to a narrow range of compounds. Multiple sensors in a single instrument provide for responsive to a great number and many types of chemicals, with certain sensors that mix being moderately to extremely sensitive to specific compounds.

The technology is relatively new to the agricultural industry, although the potential for application is certainly great. Recent work demonstrated that an electronic nose can distinguish between pig and chicken slurry and between emissions from swine and dairy facilities because the sensor response patterns between the comparisons were different. At the current point of development, the electronic nose appears to be less sensitive than olfactometry measures, though sensor improvements occur routinely. Sensor selection is critical from both the standpoint of sensitivity to compounds that contribute to the offensive odors (malodor) as well as response and durability of the sensors in humid environments.

Conclusions

Odor measurement is a complicated task. While a number of methods are available, none are without drawbacks. However, dilution-to-threshold methods are the most widely accepted methods at the current time.

Resources

Additional information regarding measurement of odor can be found in PM 1990 Instruments for Measuring Concentrations and Emission Rates of Aerial Pollutants from AFOs available on the Air Quality and Animal Agriculture Web page at:
http://www.extension.iastate.edu/airquality

This publication along with PM 1963a, *Science of Smell Part 1: Odor perception and physiological response;* PM 1963b, *Science of Smell Part 2 Odor Chemistry;* and PM 1963d, *Science of Smell Part 4 Principles of Odor Control* can be found on the Air Quality and Animal Agriculture Web page at:
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File: Environmental Quality 4-1