Measuring Outdoor Air Quality (OAQ) Components

Olfaction: the sense of smell

The sense of smell is complex, but 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 in the rear of the nasal cavity. Figure 40-3 shows the human nasal region and how the physical act of sniffing redirects the air flow pass the sensitive olfactory epithelium.

Odors evoke a wide range of physiological and emotional reactions; they can be either energizing or calming, and can stimulate very strong positive or negative reactions and memories. The development of aromatherapy 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.

Odors evoke a wide range of physiological and emotional reactions… .

Even though humans can detect over ten thousand different odors, they are sometimes simply categorized as being either pleasant or unpleasant. However, they are also often described using terms like 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.

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Most odors consist of a mixture of many different gases at extremely low concentrations. The composition and concentration of the gas mixture affects the perceived odor. To completely measure an odor, each gas would need to be measured. Some odorous gases can be detected (smelled) by humans at very low concentrations (Table 40-3). Because most odors are composed of many different gases at extremely low concentrations, it is very difficult and expensive to determine an odor's exact composition.

Table 40-3. Odor threshold for select chemicals often found in livestock odors.

Chemical	Odor Threshold, ppm
Aldehydes	
Acetaldehyde	0.21
Propionaldehyde	0.0095
Volatile Fatty Acids	
Acetic acid	1.0
Propionic acid	20.0
Butyric acid	0.001
Nitrogen containing	
Methylamine	0.021
Dimethylamine	0.047
Trimethylamine	0.00021
Skatole	0.019
Ammonia	46.8
Sulfur containing	
Methanethiol	0.0021
Ethanethiol	0.001
Propanethiol	0.00074
t-Butythiol	0.00009
Dimethy sulfide	0.001
Hydrogen sulfide	0.0072

Source: Kreis 1978.

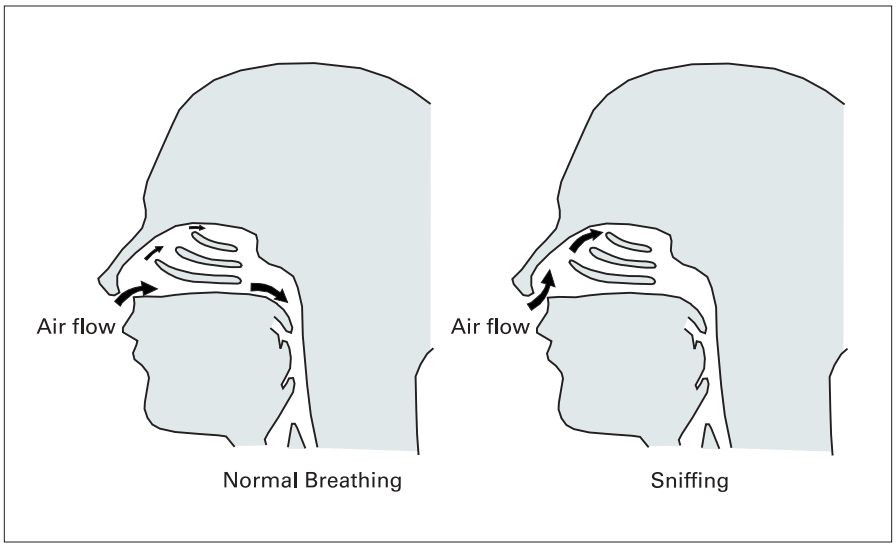

Figure 40-3. Sniffing technique used with olfactometry.

Gas measurement vs. odor measurement

Two general approaches are used to measure odor: either individual gas concentrations or 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 known 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.

The key advantage of olfactometry is the direct correlation with odor and its use of human's highly sensitive sense of smell. Another advantage of olfactometry is that it analyzes the complete gas mixture so the 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. The lack of precision in olfactometry is due in part to the variability in each person's sense of smell and their 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 for directly measuring odors at this time.

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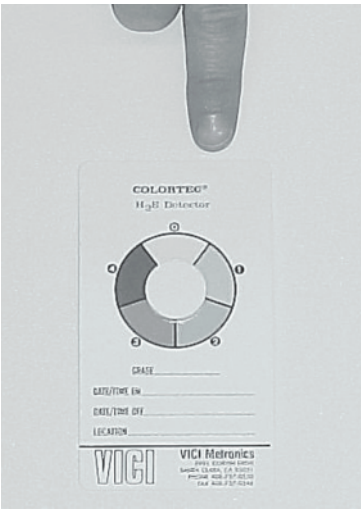

Figure 40-4. Hydrogen sulfide patches.

Gas measurement methods

Many analytical methods measure individual gas concentrations in the air. The following section briefly describes some of the more common methods used to measure select gases in the air around livestock facilities.

Some measuring techniques or instruments give a single instantaneous reading at a specific place and point in time. Another measurement using the same method some time later will probably give a different value. A series of instantaneous readings can be used to indicate how a gas concentration fluctuates. Some people combine individual readings and report average concentrations.

Other measuring techniques sample air for several minutes or more and give an average concentration over the sampling period. When comparing results, it is important to recognize that instantaneous readings will vary more and have higher and lower individual readings than average readings over a sampling period.

Technique precision or detection limit is an important measurement characteristic. Some devices or methods can measure concentrations to within ±1 part per million (ppm) of the true concentration. Others may only be able to measure concentrations to within ±20 ppm of the true concentration. Devices with greater precision can be used to detect small differences in concentrations that less precise devices cannot detect. However, devices with greater precision usually cost more.

Patches. Patches are single-use pieces of cardboard or plastic coated with a chemical that changes color when exposed to the gas being measured. Both the amount of time exposed and the amount of color change are important. Patches give an integrated or average value but are not very precise. They can be hung in a space, worn by workers, or combined with small fans for different applications. Hydrogen sulfide patches are the most commonly used patches in livestock odor work (Figure 40-4).

Indicator and diffusion tubes. Different types of indicator tubes are available to measure a wide range of gases. Indicator tubes are glass tubes with both ends sealed. To take a reading with an indicator tube, the tips on both ends of the tube are broken off, and the tube is attached to a hand-held pump. The pump pulls a known amount of air through the tube. The media in the tube reacts and changes color with select gases in the air sample. A scale on the tube is used

Figure 40-5. Indicator tube for gas analysis.

to measure the amount of media that reacted with the gas and indicates the concentration. Tubes come with limited scales; precision is around 10% of the full-scale reading on the tube. Indicator tubes give nearly instantaneous readings. Tubes cost around $5 each, and the hand-held pump costs from $100 to $250.

Diffusion tubes that provide an average concentration are also available for some gases. To take a reading, one end of the tube is opened and the tube is hung in the space to be monitored. Some known time later, usually six to eight hours, a reading is taken by noting the amount of media that changed color. The amount of color change in the tube and the time exposed are used to calculate an average concentration over the sampling time. Tubes cost around $8 each.

Jerome® meter. The Jerome® meter is a portable electronic device for measuring hydrogen sulfide concentrations that gives a nearly instantaneous reading. The meter can measure hydrogen sulfide concentrations down to 3 parts per billion (ppb). It detects hydrogen sulfide concentrations by measuring the difference in the electric resistance of a gold leaf cover metal strip, which is exposed to the air sample. Jerome® meters cost around $10,000.

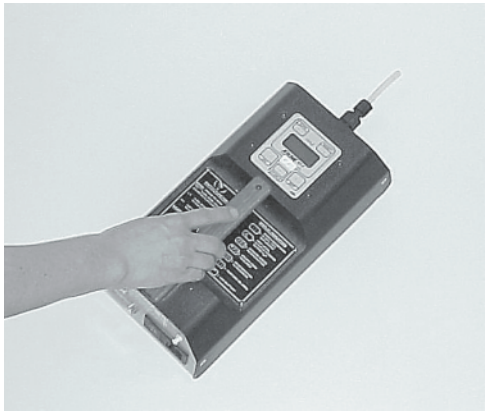

Figure 40-6. Jerome Meter for hydrogen sulfide analysis.

The Jerome® meter is a portable electronic device for measuring hydrogen sulfide concentrations that gives a nearly instantaneous reading.

MDA single-point monitor. The MDA single-point monitor is used to monitor ambient air concentrations of individual compounds (like H_2S) over extended periods of time. The units use the Chemcassette® Detection System. The cassette tape reacts, causing a color change, with the chemical being monitored. The color change is measured and used to indicate the gas concentration in the ambient air. MDA monitors can be used to measure ambient hydrogen sulfide concentrations over a variety of ranges, depending on the "key" being used. The key with the lowest detection levels can measure H_2S concentrations between 2 and 90 ppb over 15-minute periods. Units with different electronics and cassettes can be purchased to monitor other gases. Units cost around $7,000.

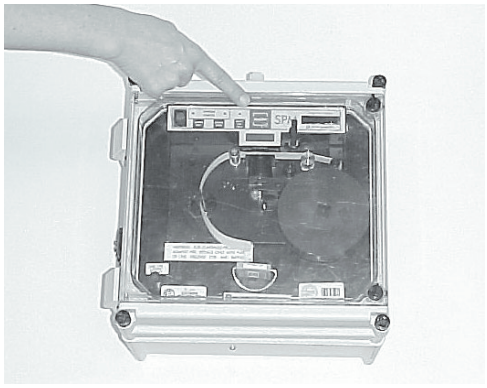

Figure 40-7. MDA Chemcassette gas monitor.

The MDA single-point monitor is used to monitor ambient air concentrations of individual compounds (like H_2S) over extended periods of time.

Electronic sensors. Many different electronic sensors are available for measuring gas concentrations. Their method of action and precision vary. Some units have multiple gas sensors; some units are used in the safety field to monitor gas concentrations and sound alarms if safe concentrations are exceeded in confined spaces. Many of these units cannot measure gas concentrations at low enough levels that are needed for odor monitoring.

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Figure 40-8. GC/MS laboratory instrument.

Gas chromatograph/mass spectrometer. A gas chromatograph/mass spectrometer (GC/MS), generally considered a research laboratory device, can be used to both identify and measure gas concentrations. Very small air samples are injected into a carrier (nitrogen or helium) gas stream passing through a GC/MS column. The column adsorbs and desorbs the chemicals in the air at different rates to separate them. After separation, the carrier gas stream with the separated chemicals passes through a detector. The detector output signal identifies the chemical and the amount in the sample. Portable units for field research are becoming available.

Odor measurement and description: an introduction to olfactometry

Various techniques measure and describe odors, which can be characterized by the following five different characteristics or dimensions that add to the complete description of an odor:

(1) Concentration
(2) Intensity
(3) Persistence
(4) Hedonic tone
(5) Character descriptor

Odor concentration and intensity are the two most common odor characteristics measured. The other three–persistence, hedonic tone and character descriptors–are commonly viewed as more subjective characteristics. As subjective characteristics, they do not lend themselves to objective measurement for scientific or regulatory purposes.

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Concentration. Two odor concentrations (thresholds) can be measured: detection threshold and recognition threshold. They are usually reported as odor units (ou). Odor units are defined as the volume of diluted (non-odorous) air divided by the volume of odorous sample air at either detection or recognition. Odor units are dimensionless numbers.

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 50% of a group of trained panelists can correctly detect a difference compared to non-odorous air. The samples are presented to trained panelists using a dynamic, forced-choice olfactometer, which is described in more detail later. At the detection threshold concentration, the panelists just begin to detect the difference between the odorous and non-odorous air mixture and the two other non-odorous air streams. This is the most common concentration determined and reported.

The 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. The person will not be able to recognize whether the noise is music or people talking. If the volume is again increased in small steps, it will increase to a point where the person will be able to recognize that the noise is either music or people talking. This volume corresponds to the recognition threshold.

Intensity. Intensity describes the strength of an odor sample and is measured at concentrations above the detection threshold. It 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. In either case, it can be measured by a five-step scale using n-butanol, a standard reference chemical (ASTM 1988). To learn the scale, trained panelists sniff containers of n-butanol at different concentrations in water (Table 40-4). They then are presented diluted or full-strength (diluted is always presented first) odorous air samples that they rate against the n-butanol scale.

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 40-9). Persistence values are normally negative.

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Table 40-4. Odor intensity reference scale based on n-butanol.

Intensity Category	Equivalent Head Space Concentration of N-Butanol in Air, ppm*	Mixture of N-Butanol in Water, ppm
0 No odor	0	0
1 Very light	25	250
2 Light	75	750
3 Moderate	225	2,250
4 Strong	675	6,750
5 Very strong	2,025	20,250

*Based on air temperature of 20.3°C.

Inexpensive perfumes and colognes usually have less persistence than more expensive perfumes and colognes.

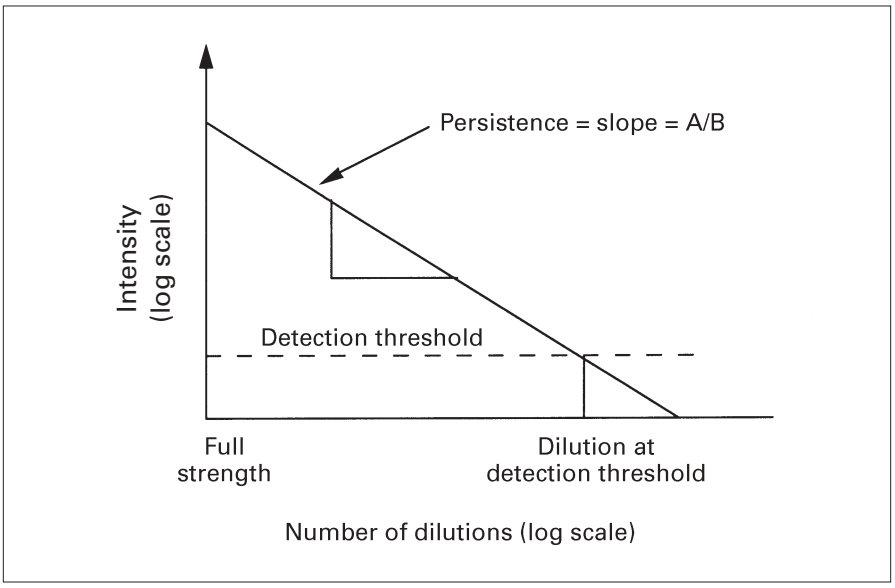

Figure 40-9. Persistence calculated from log-log plot of intensity and dilutions.

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 fresh 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 the air requires more dilution air to reach the detection threshold. Inexpensive perfumes and colognes usually have less persistence than more expensive perfumes and colognes.

Hedonic tone describes the unpleasantness or pleasantness of an odor… .

Hedonic tone. Hedonic tone describes the unpleasantness or pleasantness of an odor (ASCE 1995). It is typically rated using a scale that ranges from –10, which is unpleasant, to +10, which is pleasant. Neutral odors are recorded as zero. Unpleasantness usually increases with odor intensity. Pleasant odors may increase in pleasantness with odor intensity at low intensities but become less pleasant and even unpleasant at relatively high intensities.

Character descriptors. Character descriptors are used to 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.

Odor measurement devices and techniques

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 odor. The devices use a variety of methods for measuring the gas concentrations. Researchers have and continue to evaluate these devices. To date, they have not successfully correlated livestock odors with the output of commercial or current research electronic noses.

Scentometer. The scentometer, developed in the late 1950s (Barnebey-Cheney 1973), is a hand-held device that can be used to measure ambient odor levels in the field. It is a rectangular, clear plastic box with two nasal ports, two chambers of activated carbon with air inlets, and several different sized odorous

air inlets. A scentometer is used to determine the dilution-to-threshold concentration of ambient air. 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 he or she detects an odor. The ratio of the odor-free dilution air to the odorous air is used to calculate the dilution-to-threshold concentration. Portability and relatively low cost are some advantages of scentometers (Barnebey-Cheney 1992). However, 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.

Dynamic, triangular forced-choice olfactometer. Most laboratories measuring odors from agricultural sources use a dynamic, triangular forced-choice olfactometer to determine detection threshold concentrations. These are designed to be operated in accordance with ASTM Standard E679-91 and proposed European Standard ODC 543.271.2:628.52 (Air Quality Determination of Odour Concentration by Dynamic Olfactometry).

Standardized procedures and at least four hours of initial panelist training are used to achieve repeatable olfactometer results. Panelists are required to follow the rules listed in Table 40-5 (see page 18). The standard procedures and panelist rules help panelist's use their sense of smell to obtain consistent results and develop a professional attitude about their work. Odor panel sessions are limited to avoid odor fatigue and to keep the panelists focused on proper sniffing technique.

A dynamic, triangular forced-choice olfactometer presents three air streams to the trained panelists. One of the air streams is a mixture of non-odorous air and an extremely small amount of odorous air from a sample bag. The other two air streams have only non-odorous air. Panelists sniff each air stream and are forced to identify which air stream is different (i.e., has some odor) than the other two non-odorous air streams. Initially, panelists must guess which air stream 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 air streams is doubled until the panelist correctly recognizes which air stream is different. The

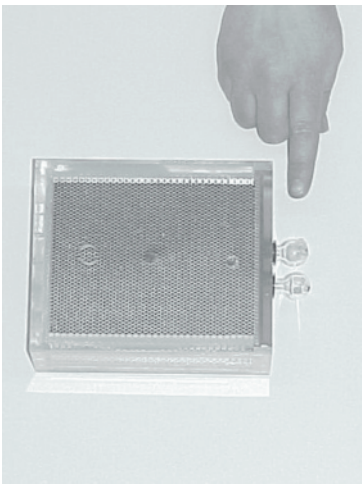

Figure 40-10. Scentometer for field odor measurements.

Most laboratories measuring odors from agricultural sources use a dynamic, triangular forced-choice olfactometer to determine detection threshold concentrations.

Figure 40-11. Panelist, olfactometer, and panel leader.

...“field sniffer” refers to a trained panelist who determines odor intensity in the field.

Table 40-5. Odor panel rules.

Before an Odor Panel session, panelists must
• Be “fragrance-free” by not using perfume, cologne, shampoo, hand lotion, and deodorant or scented aftershave **the day of** odor panel work. • Not consume alcohol or eat spicy foods for at least **six hours prior** to odor panel work. • Not eat, chew gum, or consume coffee, tea, or beverages for at least **one hour prior** to odor panel work.
During an Odor Panel session, panelists must
• Sign an attendance sheet at the beginning of each session. • Be free of colds or other physical conditions affecting the sense of smell. • Demonstrate “professional behavior” at all times. • Drink only bottled water. • Not smoke or use smokeless tobacco. • Not discuss their odor selections and answers with other panel members or the public.
Each year, panelists must
• Attend a training session to be recertified.

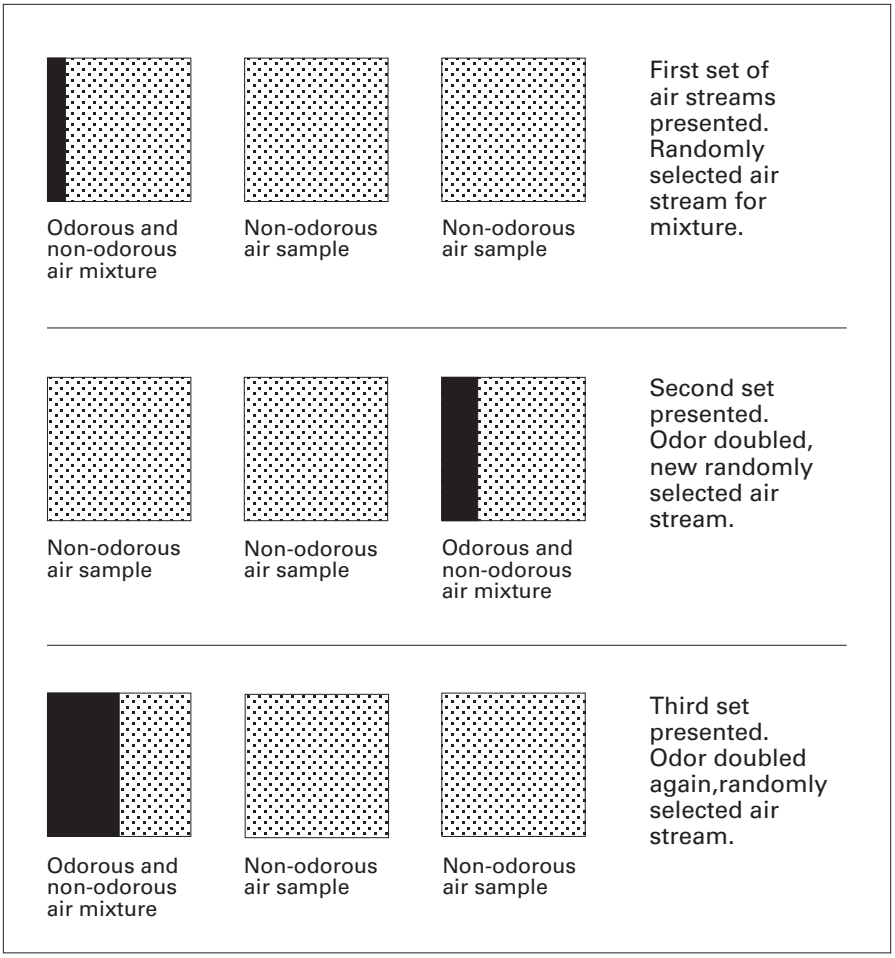

Figure 40-12. Olfactometer dilution sequence example.

air stream with the odor is randomly changed each time. Figure 40-12 illustrates the process.

The detection threshold is the non-odorous airflow rate divided by the odorous airflow rate at the time the panelist correctly detects which air stream 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.

Field sniffer. The term "field sniffer" refers to a trained panelist who determines odor intensity in the field. The panelists calibrate their noses with the n-butanol intensity scale mentioned earlier (Table 40-4) before going into the field to sniff. This calibration is done as a group so consistent intensity levels are established among the individual sniffers. Between readings, they use charcoal filter masks to breathe non-odorous air and thus avoid nasal fatigue. At specified times, the field sniffers remove their masks, sniff the air, and record the air's intensity. The results are generally used to validate odor dispersion models.

Dust and pathogen measurements

The measurement of dust concentrations in and near animal facilities is typically performed using gravimetrical methods. This is accomplished by weighing a collection filter before and after a known quantity of sample air is passed through the filter inside or near the animal unit. The results are generally given in units of mg of dust per cubic meter of air (mg/m^3). Certain filters are designed to collect all of the dust and are reported as total dust concentrations, while a certain device collects only particles small enough to enter the human respiratory system, which are reported as respirable dust. Another method of dust measurement is electronic particle counters. These devices report the number (not mass/weight) of particles per volume of air ($particles/m^3$). Often these instruments can categorize dust into particle diameter, which is beneficial in assessing livestock, poultry, and human health risks.

Pathogen detection and measurement is still conducted by plating them on petri dishes. The pathogens can be collected in the air either directly on agar plates in a device like an "Anderson Sampler" or trapped in a liquid by an "all-glass impinger" and then placed on petri dishes in the laboratory. After incubation, the colony-forming units are counted with the results usually reported as the number of colony-forming units per volume of air.

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