Emissions from Animal Production Systems

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Chapter 1: The Science of Odors and Emissions

In the past, airborne emissions were considered only a minor drawback for livestock and poultry production operations. However, with the trend toward larger, more concentrated production sites, odors and other airborne emissions are rapidly becoming an important issue for all animal producers. Shifting population distributions; the unwillingness of many to tolerate odors, gases, and dust emitted from animal production; and the economic importance of animal agriculture in the United States all contribute to the urgent need for stakeholders to find adequate solutions to this problem. A prerequisite to good solutions is a thorough understanding of the problem.

Emissions and Health

Very little information is available on the direct impact of airborne emissions on human health. However, some human health complaints are being made based on certain emissions like odor. A North Carolina study (Schiffman 1995) reported that people living near hog facilities who were exposed to odors experienced more tension, depression, anger, fatigue, and confusion than a group of residents not exposed to hog odors. Another study in Iowa (Thu, et al. 1997) found a higher frequency of mainly respiratory health symptoms in people living within 2 miles of a 4,000-head swine operation compared to a control group in an area with no intensive livestock operations. A different North Carolina study (Wing and Wolf, 1999) found similar results when surveying residents of three rural communities: one a non-livestock area, another with cattle (about 300 dairy cows) operations, and a final area that contained a 6,000-head pig unit. Certain respiratory and gastrointestinal health symptoms (runny nose, sore throat, excessive coughing, and diarrhea) were reported more often in the livestock (mostly hog) communities. Also quality-of-life factors like not wanting to open windows or going outside during pleasant weather were similar in the control (non-livestock) and cattle areas but much lower for residents living in the hog community. Finally, many individuals and/or grass- roots organizations claim negative effects have occurred due to odor and other airborne emissions from livestock operations (Hudson 1998).

Airborne Emissions from Animal Production Systems

***Type of emissions*:** Odor emissions from animal production systems originate from three primary sources: manure storage units, animal housing, and land application of manure. Table 1 summarizes identified odor sources and animal species for justifiable complaints in a 1982 study in a United Kingdom (U.K.) country (Hardwick, 1985). Almost 50% of all odor complaints were traced back to land application of manure, about 20% were from manure storage units, and another 25% were from animal buildings. Other sources included feed production, processing centers, and silage storage. Between the three animal species, pigs were identified as the source of slightly more than half of the complaints (54%), with cattle and poultry being the source of 20% and 24% of the complaints, respectively. Even though these findings are from the U.K. and are nearly 20 years old, general observations in this country seem to agree with this distribution of odor sources. However, with the increased use of manure injection for land application in certain parts of the country and longer manure storage (and larger manure storage structures), there may be a higher percentage of complaints in the future associated with manure storage units and animal buildings.

Table 1. Number and source of odor complaints received during a one-year period in a United Kingdom country

Odor Source	Pigs		Cattle		Poultry		Total	
	No.	%	No.	%	No.	%	No.	%
Buildings	224	22	65	18	163	36	452	25
Slurry storage	169	17	98	28	78	17	345	19
Slurry spreading	526	52	122	34	190	42	838	46
Animal feed production	84	8	4	1	11	3	99	5
Silage storage	10	1	68	19	8	2	86	5
Total	1,013	56	357	20	450	24	1,820	100

Source: Hardwick, 1985

Most of the odorous compounds that are emitted from animal production operations are by-products of anaerobic decomposition/transformation of livestock wastes by microorganisms. Livestock wastes include manure (feces and urine), spilled feed and water, bedding materials (i.e., straw, sunflower hulls, wood shaving), wash water, and other wastes. This highly organic mixture includes carbohydrates, fats, proteins, and other nutrients that are readily degradable by microorganisms under a wide variety of suitable environments. The by-products of microbial transformations depends, in a major part, on whether it is done aerobically (i.e., with oxygen) or anaerobically (i.e., without oxygen). Microbial transformations done under aerobic conditions generally produce fewer odorous by-products than those done under anaerobic conditions. Moisture content and temperature affect the rate of microbial decomposition.

A large number of volatile compounds have been identified as by-products of animal waste decomposition. Kreis (1978) developed one of the earliest lists of volatile compounds associated with decomposition of cattle, poultry, and swine wastes. He listed 32 compounds reported to have come from cattle wastes, 17 from poultry wastes, and more than 50 compounds from swine wastes (Kreis, 1978). O'Neill and Phillips (1992) compiled a list of 168 different compounds identified in swine and poultry wastes. The compounds are often listed in groups based on their chemical structure. Some of the principal odorous compounds, individual and as groups, are ammonia, amines, hydrogen sulfide, volatile fatty acids, indoles, skatole, phenols, mercaptans, alcohols, and carbonyls (Curtis, 1983). Carbon dioxide and methane are odorless.

Some of the gases that are emitted have implications for global warming and acid rain issues. Among these gases are ammonia and non-odorous gases such as methane and carbon dioxide. European countries have instituted strict ammonia emission limits in recent years. It has been estimated that one third of the methane produced each year comes from industrial sources, one third from natural sources, and one third from agriculture (primarily animals and manure storage units). Although animals produce more carbon dioxide than methane, methane contribution to the greenhouse effect is estimated at 15 times that of an equal amount of CO_2

Dust is another airborne emission concern that is difficult to eliminate from animal production units. It is a combination of manure solids, dander, feathers, hair, and feed. It is typically more of a problem in buildings that have solid floors and use bedding as opposed to slatted floors and liquid manure. Dust concentrations inside animal buildings and near outdoor feedlots have been measured and range from 1 up to 10 mg/m^3 (Curtis, 1983). However, dust emission rates are mostly unknown from animal production sites.

Pathogens are yet another airborne emission concern for animal production operations. Although pathogens are present in buildings and manure storage units, they typically do not survive aerosolization well, but some have been transported by dust particles.

Flies are an additional concern from certain types of poultry and livestock operations. The housefly completes a cycle from egg to adult in 6 to 7 days when temperatures are 80 to 90ºF. Females can produce 600 to 800 eggs, and larvae can survive burial at depths up to 4 feet. Adults can fly up to 20 miles. These facts verify that large populations of flies can be produced relatively quickly if the correct environment (moisture and nutrients as when manure is stored) are provided. Studies have shown that flies proliferate in areas not trod by animals. To prevent flies, special care should be taken to keep spoiled feed and manure from under feeders and waterers, under fences, and other areas that the animals do not reach. Compost piles make excellent fly habitat if not managed correctly.

Airborne Emission Movement or Dispersion

The movement or dispersion of airborne emissions from an animal production site is difficult to predict and is affected by such factors as topography, prevailing winds, and building orientation. Odor plumes decrease exponentially with distance (Brembery 1994), but long distances are needed if no odors, gases, or dust are to be detected downwind from a source. A number of models are being developed to more accurately predict setback distances from livestock operations based on animal units (Schauberger and Piringer 1997) or actual emission values (Jacobson, et al. 1999).

Prevailing winds should be considered so facilities are sited to minimize odor transport to close or sensitive neighbors. For many existing facilities, this is impossible. For those situations, odor reduction techniques may be needed to reduce the odor emission rate or disperse odors faster and more effectively before they reach a sensitive neighbor or individual.

There is ample evidence that rural air quality issues have become a major concern in the siting of animal production units. A variety of livestock and poultry producers, from various areas of the United States, have reported difficulty in obtaining permits to construct new or expand existing livestock operations due to RAQ complaints from neighbors. Odors typically lowered property values of residential homes although one study in Minnesota actually reported a slight appreciation of real-estate values near livestock production units. Another often mentioned concern is the reduced value of land near livestock and poultry units for outdoor recreational activities.

In a 1999 survey of states by the North Dakota Attorney General's office, a total of 31 states reported various types of airborne emission regulations. Many of these states either exempt or chose not to enforce the regulations for agricultural operations. Most states and local units of government deal with this issue through zoning or land use ordinances. Typically, certain setback distances are required for a given size operation or for land application of manure. Also, setbacks from lakes and public waterways are common. A few states (for example, Minnesota) may have an ambient gas concentration (H_2S in the case of Minnesota) standard at a property line that may impact animal agriculture. Another possibility is an odor standard that only a few states have adopted (North Dakota, Colorado, Wyoming, and Missouri) that is again measured at the property line. Gas and odor standards are difficult to enforce since gases and especially odor are hard to measure on-site with a high degree of accuracy.

Measuring Outdoor Air Quality Components

Olfaction: 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 in the rear of the nasal cavity.

Odors evoke a wide range of physiological and emotional reactions. Odors can be either energizing or calming. They 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. Even though humans can detect over ten thousand different odors, they are sometimes simply categorized as being either pleasant or unpleasant. They are 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.

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 2). The fact that most odors are made up of many different gases at extremely low concentrations makes it very difficult and expensive to determine the exact composition of an odor.

Odor vs. Gas Measurement: Two general approaches are used to measure odor: either measure individual gas concentrations or use 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 the gas measurement 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 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 the human's highly sensitive sense of smell. Olfactometry also has the advantage that it analyzes the complete gas mixture so that 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.

Table 2. 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.

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.

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 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 have an accuracy of " 1 part per million (ppm). Others may only be accurate to " 20 ppm. 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.

Tubes–Indicator and Diffusion: Indicator tubes are available to measure a wide range of gases. To take a reading with an indicator tube (a sealed glass 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 to measure the amount of media that reacted with the gas and indicates the concentration. Indicator tubes give nearly instantaneous readings, but they come with limited scales, and precision is around 10% of the full-scale reading on the tube. They 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. It samples the air for several seconds to give 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.

MDA-Single-Point Monitor: The MDA s-p m is used to monitor ambient air concentrations of individual compounds 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 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.

Electronic Sensors: A number of 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 levels needed for odor monitoring.

Gas chromatograph/Mass spectrometer: A gas chromatograph-/-mass spectrometer (GC/MS) is generally considered a research laboratory device. It 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 to do field research are now 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.

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

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. At the detection threshold, a trained panelist just begins to detect the difference between odorous and non-odorous air. 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 barely 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 the noise, whether it 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 against 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 3). They then are presented diluted or full-strength (diluted is always presented first) odorous air samples that they rate against the n-butanol scale.

Table 3. 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	2250
4	Strong	675	6750
5	Very strong	2025	20250

* Based on air temperature of 20.3EC.

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 the 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 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 trained individual breathes through the scentometer. All of the odorous air inlets are initially closed so that the inhaled air must pass through the activated carbon and is deodorized. The individual begins sampling by opening the odorous air inlets one at a time until an odor is detected. The number and size of open holes 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).

Dynamic, triangular forced-choice olfactometer: Most laboratories measuring odors from agricultural sources use a dynamic, triangular forced-choice olfactometer to determine detection and recognition 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 four hours of panelist training are used to achieve repeatable olfactometer results. Panelists are required to follow strict rules which help them use their sense of smell to obtain consistent results and develop a professional attitude about their work.

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 air stream with the odor is randomly changed each time. The detection threshold is the non-odorous airflow rate divided by the odorous airflow rate at the time the panelist correctly recognizes which air stream is different. A panel of eight trained people is normally used to analyze each odor sample.

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 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. 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 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 the livestock/poultry and human health risks. Finally, 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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Chapter 2: Emissions Control Strategies from Buildings and Storage Structures

Odors and gases are emitted from the buildings that house animals and poultry through ventilation fans, or by buoyancy or wind forces in naturally ventilated barns. Methods to reduce these odors and gas emissions are less well documented than either manure storage units or land application control methods. Of the three sources, buildings are believed to release a relatively constant amount of the total odor and gas emissions generated. Building emissions, combined with releases from the manure storage unit, form the "baseline" emission levels from an animal production operation. Two approaches to minimizing odors from buildings and storage structures are first, minimize the odor generation, and second, treat an odor that is generated as it exits the building. Both approaches will be discussed in this text.

General management strategies

Swine production and manure management facilities should be planned as a total system that reduces environmental impacts while promoting animal performance and worker safety. Proper adjustment of feeders to minimize spillage will also reduce odors and save money on feed. An orderly system for manure collection and storage or treatment reduces potential pockets of odor production. All surfaces on which manure may collect and on which animals are maintained should be as clean and dry as possible. Manure, wet feed, and other products that could produce odors in the building should be removed regularly. This includes dust buildup both on the inside and on the outside of buildings, but especially inside animal housing facilities and on fan housings. Dirty, manure-covered animals promote accelerated bacterial growth and the production of gases that are quickly vaporized by animal body heat. Odor from floor surfaces will be reduced if the floors are kept clean and dry. Minimizing the floor surface area on which manure can accumulate reduces the gases and odors emitted from these surfaces. All components of the production/manure treatment system should be maintained and operated in good functional order. Proper disposal of dead animals and good fly and rodent control programs are also essential.

Ventilation system: A properly designed and well managed ventilation system will keep animals and surfaces dry and thereby reduce odor emissions. Clean fans, shutters, and air inlets will improve the efficiency of the ventilation system and simultaneously prevent "odor episodes" that can occur when atmospheric conditions exist that encourage odor generation. Hanging a brush near exhaust fans will make cleaning more convenient and thus encourage it.

Relationship between dust and odor: Dust on livestock farms affects odor measurement and control in several ways. Dust particles adsorb odorous compounds. As the dust particles are carried by the wind, so is odor. Most of the dust generated on a farm comes from feed, fecal matter, hair, and in the case of poultry, from feathers and litter. Dust also comes from animal skin, insects, and other sources. Some of the dust particles, such as those from manure and feed, omit odorous compounds as a result of bacterial decomposition. Odorous dust can increase the transport of some odor compounds. Dust concentrates odorous compounds, and as a result, odorous dust can cause an intense odor sensation. An understanding of the role dust plays in concentrating and transporting odor is important if we are to develop economical methods of controlling odor because some methods of removing dust from the air are less expensive than direct methods of treating the air to remove odorous compounds.

Facility siting: Where swine facilities are located can play a significant role in whether odors become nuisance. Swine facilities should be located as far as practical from residential developments, commercial enterprises, recreational areas, or other prime areas for non-agricultural uses. A site may seem ideal with respect to transportation, feed supply, accessibility, or land ownership but may present challenges because of existing or proposed development. Where possible, production facilities should be located near the center of a tract of land large enough to allow manure to be applied to the land at agronomic rates. Pollution control and manure treatment facilities should be located as far as practical from areas of high environmental sensitivity such as drainage ditches, streams, or estuaries. Elevating buildings several feet above ground will direct surface drainage away from the building, allow good natural air circulation, and allow manure to flow by gravity to the lagoon or other treatment units.

Dietary manipulation: Data in the scientific literature documents the reduction of odor and nutrients in animal excreta or alteration of the microbial population in an animal's digestive tract as a result of diet manipulation or from adding specific, odor-reducing materials to the diet. In general, this research has shown that nutrients such as nitrogen, phosphorus, copper, and zinc can be reduced through dietary manipulation without impacting the animal's growth and health. This alone is a positive impact on environmental parameters. Dietary manipulation has also been shown in some cases to reduce the odor concentration and offensiveness of freshly excreted manure. After the storage or treatment of manures under anaerobic conditions, the positive impact of dietary manipulation on odor might not persist. However, odor controls through dietary manipulation hold promise and may revolutionize animal feeding practices within the next few years.

Management of under-floor manure pits: Control of odors from under-floor manure pits depends on the type and storage time. Manure stored longer than five days will generate more offensive gases. Undiluted liquid manure has a large odor production potential. Therefore, to reduce odors from shallow gutters with pull plugs, the manure should be removed at least once a week. Often, weekly cleaning is not a standard practice but may become so if odor control is the main objective.

One method of shallow gutter management to enhance odor control that is still being debated is the practice of using recharge water. Some facilities use clean recharge water, some recycle recharge water, and others do not recharge their gutters. Anecdotal evidence suggests that using clean or "treated" recycled recharge water may reduce odorous emissions compared to using no recharge water. Reductions are likely to be very dependent on the quality of recharge water.

Management of lagoons: One of the best ways to reduce emissions from lagoons is to properly manage the lagoon to promote healthy bacterial populations. Precharging the lagoon with dilution water before start-up, steady charging with waste rather than slug charging, and pumping or removing material from beneath the surface to avoid removal of purple sulfur bacteria are examples of good management practice. Fill pipes should empty waste below the surface to avoid stirring the surface and increasing odor emissions.

Management of manure slurry storage structures: Probably the best way to reduce emissions from these structures is to cover them, either with the natural crust that sometimes forms, with a biological cover (chopped straw, etc.) or with a synthetic cover. Biological covers are relatively inexpensive, but add to the amount of organic matter that must be removed each year and sometimes do not hold together in windy conditions, especially on large structures. Synthetic covers cost more initially, but last longer. Total annual cost is similar for both systems. Ozonation of slurry as it enters the storage also reduces odors and helps retain nutrients by lowering bacterial activity, but its economic feasibility has not been proven at this time.

Natural windbreaks: Rows of trees and other vegetation known as shelterbelts, which have historically been used for snow and wind protection in the Midwest, may have value as odor control devices for all species and systems. Similarly, natural forests and vegetation near animal facilities in other sections of the country may serve the same purpose. These shelterbelts also create a visual barrier. A properly designed and placed tree or vegetative shelterbelt could conceivably provide a very large filtration surface (Sweeten 1991) for both dust and odorous compound removal from building exhaust air and odor dispersion and dilution, particularly under stable nighttime conditions (Miner 1995; NPPC 1996). Currently, a few studies are addressing the total impact of vegetative barriers on odor reduction from animal farms, but many people already attest to their value. Shelterbelts are inexpensive, especially if the cost is figured over the life of the trees and shrubs, but it may take 3 to 10 years to grow an effective windbreak.

It is generally felt that windbreaks reduce odors by dispersing and mixing the odorous air with fresh air, although solid research has not confirmed these effects. Windbreaks on the downwind side of animal houses create mixing and dilution. Windbreaks on the upwind side deflect air over the houses so it picks up less odorous air. Producers should avoid placing dense windbreaks so close to naturally ventilated buildings that cooling breezes and winds exchanging the air in these buildings are eliminated or greatly reduced. A minimum distance of 50 feet, or five to ten times the tree height, from a naturally ventilated building is recommended.

Bedded systems

Using solid manure systems rather than liquid manure systems is generally considered to reduce odor. Although gases and dust are emitted from solid or bedded systems, most people feel that odor from bedded systems is less objectionable than the odor from liquid systems. Using bedding/dry manure systems for animals is generally considered to be more environmentally acceptable from both water quality and outdoor air quality viewpoints.

Anecdotal evidence suggests that organic bedding such as straw, corn stalks, compost, wood chips, or newspaper may reduce odor emissions. European research seems to support the use of some type of bedding (especially sawdust) to reduce odor generation/levels in buildings and subsequent odor release or emission (Nicks et al. 1997). Relatively small bedding levels may be enough to have an effect on odor generation/emission. Until liquid systems were adapted, primarily for convenience, bedding had been used for livestock production for generations. Many dairy and poultry facilities still use dry or solid manure systems.

Hoop structures have recently become popular for some swine and dairy producers, in part due to their odor control effectiveness. They feature a deep-bedded pack system using straw or other crop residues to provide animal comfort and soak up manure liquids. Bedding availability is crucial for solid manure systems except for high-rise layer or swine houses. Hoop structure bedding requirements for finishing swine are estimated to be 200 pounds of baled corn stalks per pig marketed. MWPS Publications AED 41 and 44 give details on using bedded hoop structures for swine production.

Biofilters

Biofiltration is an air cleaning technology that uses microorganisms to break down gaseous contaminants and produce non-odorous end products. It is used successfully around the world for treating a wide range of air emissions from industrial sources. Biofiltration works well for treating odors because most odorous emissions are made up of numerous compounds at low concentrations that are readily broken down by microorganisms.

The microorganisms in a biofilter break down (i.e., oxidize) airborne volatile organic compounds (VOCs) and oxidizable inorganic gases and vapors in the odorous exhaust air. The byproducts of the process are primarily water, carbon dioxide, mineral salts, some VOCs, and microbial biomass.

Description: Figure 1 illustrates a typical, open face biofilter. Odorous air is exhausted from the building with wall or pit ventilation fans that are connected by a duct to the biofilter plenum. The plenum distributes the air evenly across the biofilter media. A supported porous screen holds the media above the plenum. As the air passes through the biofilter, the odorous gases contact the media and are absorbed onto the biofilm where they are degraded by the aerobic microorganisms.

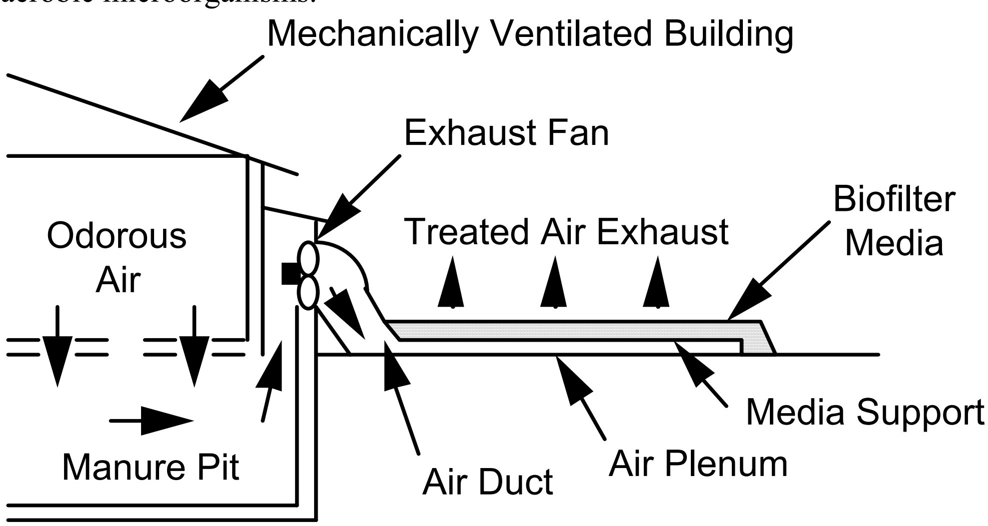

Figure 1. Typical open face biofilter layout.

Biofiltration use on livestock facilities began in Germany in the late 1960s and in Sweden in 1984 (Zeisig and Munchen 1987; Noren 1985). Biofilters on pig and calf sheds had average efficiencies around 70% (Scholtens et al. 1987). Nicolai and Janni (1997) reported an average odor reduction of 78% (minimum of 29% in April and maximum of 96% in August) from a pilot-scale biofilter built to treat air exhausted from a pit fan on a farrowing barn in Minnesota. Hydrogen sulfide and ammonia concentrations were reduced an average of 86% and 50%, respectively. The pressure drop across the media, which indicates how much the filter media restricts airflow, ranged between 0.10 and 0.19 in. of water (25 to 47 Pa). Data from a full-sized biofilter used to treat all of the ventilating air exhaust from a 700-sow gestation/farrowing swine facility were recently reported (Nicolai and Janni 1998b, 1998c). Average odor reduction was 82% over the first 10 months of operation. During the same period, average hydrogen sulfide reduction was 80% and ammonia reduction was 53%. Total pressure drop across the fans reached a maximum of 0.4 inches of water, 0.2 inches of that could be attributed to the building's ventilation inlet system.

The amortized construction and operating costs over three years for this full-sized biofilter were $0.22 per piglet produced per year. Rodent control costs were $275 per year. Additional operating costs of $125 per year included sprinkling costs and costs of operating the higher power ventilating fans (Nicolai and Janni 1998b, 1998c). In general, initial costs for a biofilter are approximately $0.10/cubic foot per minute (cfm) of ventilation air with annual operating costs of $0.02/cfm.

Recent research has led to the following recommendations concerning biofilters used to treat air from swine and dairy facilities:

- A residence time (amount of time the ventilation air is in contact with the media) of at least 5 seconds should be provided. This amount of time has resulted in 80% to 90% odor reductions; longer times do not increase this already high level of efficiency.
- The minimum depth of the biofilter media should be 10 inches.
- Fans need to be purchased with the capability of moving sufficient air exchange at a total static pressure (includes pressure drop of the barn air inlets as well as the biofilter's media) of 0.4 inches of water. When designing a biofilter, this pressure drop and its impact on the ventilating system must be considered.
- The Proper moisture control of the biofilter media is essential.
- A rodent control program is necessary.
- Vegetative growth on the biofilter surface must be limited.

Many common materials can be used for a biofilter, including dark red kidney bean straw and compost (Nicolai and Janni 1997), shredded wood and compost (50% by weight) (Nicolai and Janni 1998a, b, c), and even shredded wood and soil (50% by weight). Shredded wood is used to increase porosity, making it easier for the air to flow through the biofilter. Compost and soil are a source of microorganisms and nutrients.

Continual excessive moisture can lead to increased airflow resistance (pressure drop) and limited oxygen exchange that could create anaerobic zones. Insufficient moisture leads to drying, microbe deactivation, and channeling, which reduce contaminant removal efficiency. If present, mice and rats will burrow through the warm media in cold winter months, causing channeling and poor treatment. Rabbits, woodchucks, and badgers have also been suspected of burrowing through and nesting in biofilters. Finally, excessive vegetative growth on the biofilter surface can reduce its efficiency by causing channeling and limiting oxygen exchange. Root systems can cause plugging, and noxious weeds need to be removed before they produce seed. Excessive vegetative growth may also detract from the site's aesthetic appearance.

Summary: Biofilters effectively reduce odor, hydrogen sulfide, and ammonia emissions from mechanically ventilated livestock buildings. While simple in appearance, they are rather complex biological systems that need to be designed properly to perform well and prevent ventilation problems. Research is continuing to demonstrate their performance and to develop better design and management recommendations.

Vegetable oil sprinkling: Airborne dust, a common problem inside animal housing facilities, has been linked to both human and animal health concerns. Since suspended dust particles can and often do absorb toxic and odorous gases, the reduction of the airborne dust concentrations inside buildings will lower odor and gas emissions from these animal housing units. Research studies have shown that sprinkling various types of vegetable oil inside pig buildings will reduce indoor airborne dust levels.

Detailed information on sprinkling vegetable oils in pig barns is given in the MidWest Plan Service (MWPS) publication AED-42 (Zhang et al. 1997). Oil can be applied manually with a hand-held sprayer or automatically with a permanently installed sprinkler system. Once-a-day application is recommended. It is important to operate the oil-sprinkling equipment so the droplets are properly sized, and distributed evenly. Operating the spray nozzles within pressure and temperature limits of the suggested vegetable oils can control droplet size. The MWPS publication gives the recommended levels for such oils as canola, corn, soybean, and sunflower.

Research Data: Oil-sprinkling research (Takai et al. 1993) indicates reductions in dust levels, and in one case (Zhang et al. 1996), reduction of odorous gases like hydrogen sulfide and ammonia. Dust levels were lowered 80%, while hydrogen sulfide and ammonia concentrations were reduced 20% or 30%, respectively, in this study.

Research conducted at the University of Minnesota (Jacobson et al. 1998) showed total dust concentrations were reduced considerably by oil sprinkling. Dust levels in the oil treatment room were about 40% of the dust levels in the control room. Respirable dust levels (the fraction that reaches the human lung), however, did not follow this trend, showing similar concentrations for both the control and treatment rooms. Reasons for the inconsistent results are difficult to determine, but may be related to the fact that once-a-day sprinkling may only reduce the large particulate (feed and fecal) materials and not smaller airborne particles. Also during this same study, an average odor reduction of 60% was seen in the oil-treated room compared to a control room for a pig nursery. Oil sprinkling in the pig nursery barn did not have the same effect on individual gas concentrations. Hydrogen sulfide levels were reduced about 60%, in the rooms sprinkled with oil, but ammonia levels were unaffected by the oil treatment.

Challenges: Compared to the control room, extra labor was needed to clean the oil treatment room after each group was moved out of the building. Producers may want to add a "presoak" segment to their cleaning protocol to aid the cleanup of surfaces in these facilities, which will lead to additional wash time. To be used at the farm level, an automated system is needed to deliver the oil in the building, as opposed to using hand-held sprayers. Existing presoak sprinkling systems may potentially be modified to accomplish this with the aid of timers and appropriate nozzles.

Summary: As outlined in MWPS-42, daily sprinkling of very small amounts of vegetable oil inside an animal facility reduced the odor, hydrogen sulfide, and total dust levels of the air inside the barn and in the exhaust ventilation air. Oil sprinkling was not effective in reducing ammonia concentrations or respirable dust levels inside the treated barn.

Windbreak walls*:* Walls erected downwind from the fans that exhaust air from tunnel-ventilated poultry buildings are being used on more than 200 farms in Taiwan to reduce dust and odor emissions onto neighboring land. These structures, known as windbreak walls, provide some blockage of the fan airflow in the horizontal direction. They can be built with various materials covering a wood or steel frame; plywood and tarps are common. The walls are placed 10 to 20 ft downwind of the exhaust fans of tunnel ventilated barns (Figure 2).

Another variation of the windbreak wall is called a straw wall. These systems have been used in North Dakota and elsewhere. They are made with wooden structures and "chicken wire." Straw is placed inside the structures, providing a barrier to dust and other air emissions. They may also offer some filtration capability.

Windbreak walls work by reducing the forward momentum of airflow from the fans, which is beneficial during low-wind conditions, because odorous dust settles out of the airflow and remains on the farm. In addition, the walls provide a sudden, large vertical dispersion of the exhausted odor plume that acts to entrain fresh outside air into the odor plume at a faster rate than would naturally occur, providing additional dilution potential.

The data and observations taken by Bottcher et al. (1998) using scentometers at a full-scale windbreak wall site in North Carolina showed that

- Dust builds up on the wall surfaces.
- The walls redirect airflow from the building exhaust fans upward.
- When wind speeds are low and blowing from the buildings toward the lagoon, the walls move the fan airflow upward so that it blows 10 ft or more above the lagoon surface. Without the windbreak wall in place, the fan air flows directly on top of the lagoon surface.
- Dust and odor levels are greater in the airflow from the fans than they are 10 ft downwind of the windbreak wall, because the fan airflow is deflected upward.

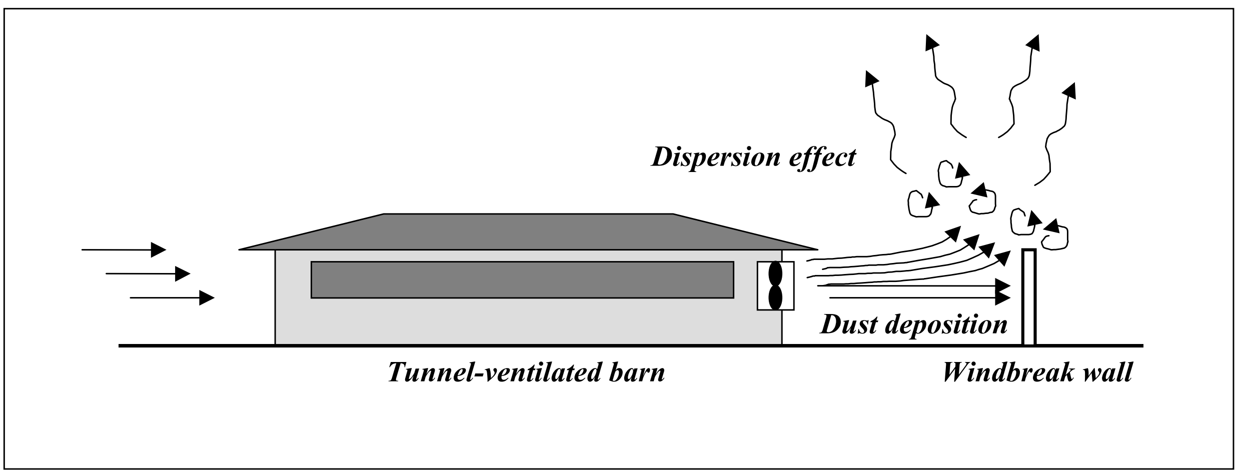

Figure 2. A tunnel-ventilated barn with a windbreak wall.

A model study done in Iowa predicted that tall wind barriers placed around a manure storage or lagoon would reduce odor emissions (Liu et al. 1996). Anecdotal evidence suggests a swine farm located in Minnesota benefited when a steel wall was built around an earthen storage basin. Although the operating cost of windbreak walls is relatively low, periodic cleaning of odorous dust from the walls is necessary for sustained odor control, unless rainfall is sufficient to clean the walls. Installation of windbreak walls is estimated to cost at least $1.50 per pig space (e.g., $1,500 for a building that houses 1,000 pigs).

Research to evaluate windbreak walls for dust and odor control is continuing. However, it is difficult to determine the effectiveness of windbreak walls due to several factors. As wind speed and direction shift, the airflow from building fans changes direction. As a result, it is difficult to measure odor downwind. Also, windbreak walls may not be suited for animal buildings equipped with multiple fans at non-uniform locations around the building.

Washing walls and other wet scrubbers: Using water to scrub odorous dust, ammonia, hydrogen sulfide, and other gases from the airflow of swine building ventilation fans can be an effective method of controlling odor. Many industrial air pollution control systems use sprays of water to scrub dust, ammonia, SO_x, and NO_x from various polluting air streams. In a wet scrubber, an alkali is usually added to react with acidic pollutants. A wet scrubber design that recirculates most of the water through the system has been tested in North Carolina (Bottcher et al. 1999). This design involves a wetted pad evaporative cooling system installed in a stud wall about 4 feet upwind of ventilation fans and downwind of the pigs in a tunnel ventilated building (Figure 3).

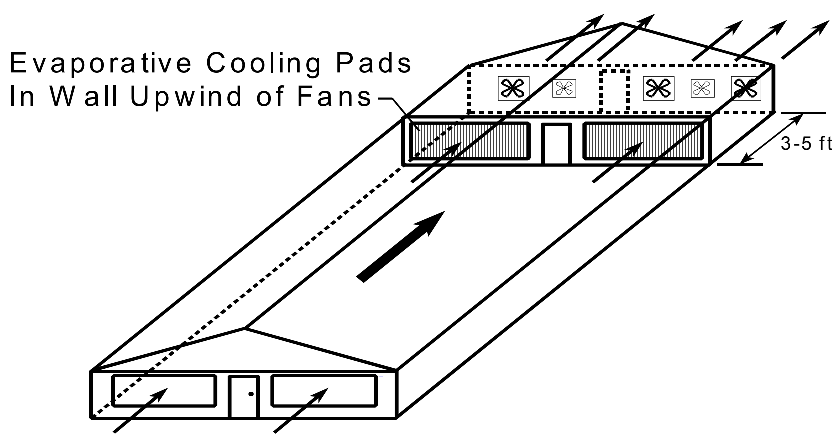

Figure 3. Evaporative cooling pad installed as a wet scrubber in a tunnel-ventilated swine building.

Source: Bottcher et al. 1999.

Recent measurements taken by Bottcher et al. (1999) show that the system can apparently reduce total dust levels as much as 65% at a relatively low ventilation rate but only by about 16% at a high airflow rate typical of maximum hot weather ventilation. Although the changes in odor levels across the wetted pad scrubber were not as great as desired at the high ventilation rate, the data does indicate a modest odor reduction, consistent with the dust reduction. These results agree with other observations that dust removal from swine building airflow is associated with odor reduction. The wetted pad wall also reduced ammonia levels in the ventilation airflow by 50% at low ventilation rates and by 33% at medium ventilation rates.

Wetted pad wall installation costs are approximately $5.70 per pig space for an 880-head finishing building (Swine Odor Task Force 1998). The main operating cost is the 1-hp water pump, which will cost about $600 annually. The wetted pad wall does not impose a significant airflow restriction on the building fans. Maintaining adequate airflow is important if a healthy indoor environment is to be provided for the animals in warm weather.

Biomass filters: Researchers at Iowa State University have tested biomass filters as a means of removing odorous dust from swine buildings (Hoff et al. 1997a). Biomass filters use the principle that dust, if removed from the ventilation exhaust stream, will capture a large portion of the odors with it. Hoff et al. (1997b) were able to demonstrate a relationship between scrubbing dust and odors in controlled laboratory experiments and in a full-scale field trial. Using inexpensive material, a biomass filter removes odorous dust from the air stream. The biomass consists of either chopped corn stalks or corn cobs (Figure 12-6), but other materials can be used. Both odor and dust levels significantly reduced: odor by up to 90% and dust by up to 80%. These reductions occurred with low resistance to airflow at cold weather ventilation rates.

Chemical additives: In some instances, chemical additives are an option for odor or gas emission control. One application where additives were shown to be effective is the addition of alum to poultry litter. Moore et al. (1995) reported on a number of products that reduced ammonia volatilization from poultry litter, including alum, which provided a 99% reduction in ammonia volatilization when 200 g/Kg (20%) was added to the litter in broiler houses. Many other additives for both liquid and solid manure are on the market. A review of products tested across the United States and Europe for ammonia reduction revealed 39 products that worked versus 18 that did not. Of the products tested for odor reduction, 22 were reported to help while 33 did not. Many products worked for only a short time. Until the mechanisms for the various products are understood so reliable performance can be predicted, the additional costs for additive products may be hard for producers to justify.

Ozonation: Ozone is a powerful oxidizing agent and a very effective natural germicide. Ozone high in the atmosphere protects the earth from solar radiation. At ground level, however, the gas can be toxic at high levels. The current OSHA permissible exposure limit for ozone is 0.1 ppm for an 8-hour, time-weighted average exposure (OSHA 1998). Ozone has been used to treat drinking water on a municipal scale since 1906, when it was installed in the treatment facilities for the city of Nice, France (Singer 1990). More than 2,000 water treatment works, primarily in France and other European countries, now use ozone for disinfecting, taste, and odor control (Tate 1991). Currently, about 100 plants in the United States and Canada use ozone (Droste 1997). Ozone generators are sold to “freshen” the air in offices and industrial facilities. A number of commercial ozone generators are currently being sold as residential air cleaning devices.

The molecular arrangement of ozone is three atoms of oxygen (O_3). Ozone is unstable and reacts with other gases, changing their molecular structure. At low concentrations of 0.01 to 0.05 ppm, ozone has a “fresh or outdoor smell” associated with it. At higher concentrations, it begins to smell like an “electrical fire.” The decomposition of ozone to oxygen is very fast. The half-life of ozone can reach 60 minutes in a cool, sterile environment and is near 20 minutes in typical conditions. In dusty animal houses, however, it may be much less. The most common products of the complete oxidation process are water vapor and carbon dioxide. Ozone reacts with and oxidizes most organic material. Thus, the relatively high level of indoor odors in livestock buildings, the ability of ozone to oxidize gas pollutants, and the potential for ozone to be rapidly depleted continue to make the ozonation of indoor air an attractive but controversial technology for reducing emissions from animal facilities.

Application in animal facilities: Only a limited number of published studies have evaluated the use of ozone for odor reduction in animal production facilities. Ozonation can potentially reduce odors in livestock facilities by killing the odor-producing microorganisms and by oxidizing the odorous metabolites. When oxidized, most compounds are reduced in odor intensity. The American Society for Heating Refrigeration, and Air-Conditioning (ASHRAE, 1989) determined that ozone is **not** an effective means of eliminating odors in ventilated air inside of buildings, but several ozone systems are on the market, and some are being tested on livestock farms with encouraging results. In a 16-month experiment, Priem (1977) found that ozone (at concentrations up to 0.2 ppm) reduced ammonia levels in a swine barn by 50% under winter ventilation conditions and by 15% under summer ventilation conditions. Researchers at Michigan State University reduced odorous compounds and disease-causing bacteria by treating swine manure slurry with high concentrations of ozone (Watkins et al. 1996). In this study, ozone was bubbled directly into fresh and stored swine manure in a continuously stirred batch reactor. Ozone concentrations of 1, 2, and 3 mg/l were used. Olfactometry determinations showed a significant odor reduction in ozonated manure samples in comparison to raw and oxygenated samples. More specifically, hydrogen sulfide concentrations were reduced slightly, while sulfate concentrations concurrently increased.

Researchers are evaluating a commercial ozone air treatment system in a tunnel-ventilated swine finishing house (Keener et al. 1999). Preliminary results suggest that a significant decrease in ammonia ($P < 0.01$) and total dust ($P < 0.02$) occurred in the ozonated building. The concentration of dust particles with optical diameters less than 1 cm were lower in the ozonated house than in the control house. However, an olfactometry panel did not measure significantly different levels of odor in the air samples from the ozonated and the control buildings. The reason for the difference between field observation and laboratory evaluation is still being investigated, but may be related to the fact that dust is removed from air samples before testing in the olfactometry lab. More testing is needed before the ozonation of lagoons or of the air inside swine facilities can be recommended.

Summary of technologies for odor control

Process/System		*Description*	*Advantages*	*Disadvantages*	*Cost*
Exhaust air treatment	***Biofilters***	**Odorous gases are passed through a bed of compost and wood chips; bacterial and fungal activity help oxidize organic volatile compounds**	**Reduces odors and hydrogen sulfide emissions effectively**	**May need special fans because of pressure drop**	**$0.50 to $0.80/pig**
Dust reduction	Windbreak walls	A wall made of tarp or with any other porous material is placed 10-20 ft. from exhaust fans. The walls provide some blockage of the fan airflow in the horizontal direction. Dust and odor levels downwind of the windbreaks can be lower since the plume is deflected.	May reduce dust and odor emissions effectively	Periodic cleaning of dust from the walls is necessary for sustained odor control.	$1.50/pig space of bldg capacity
	Shelterbelts	Rows of trees and other vegetation are planted around a building, creating a barrier for both dust and odors from building exhaust air. Trees can absorb odorous compounds, and create turbulence that enhances odor dispersion	May reduce dust and odor emissions effectively	It may take several years to grow an effective vegetative wind-break	$0.20/pig space of bldg capacity or more
	Washing walls	A wetted pad evaporative cooling system is installed about 1.5 m upwind of ventilation fans and downwind of hogs in a tunnel-ventilated building. Exhaust air passes through the wet pad before being pulled through the fans	Reduces about 50% of dust and 33% of ammonia at medium ventilation rate	Residence time inside the pad is very small; thus odor removal may not be highly effective.	$5.70/pig space of bldg capacity installation cost
	Oil sprinkling	Vegetable oil is sprinkled daily at low levels in the animal pens.	Helps reduce airborne dust and odors	Creates a greasy residue on the floor and pen partitions if too much oil is used	$2.50/pig space of bldg capacity
Diet manipulation	Phytase	Product (enzyme) is mixed into the feed	Lower P content in the manure	Not known yet	N/A
	Low-phytate corn	Use low-phytate corn for feed	Lower P content in the manure	Not known yet	N/A
	Synthetic amino-acids and low crude protein	Products are mixed into the feed	Lower N content in the manure, may reduce odor and ammonia emissions	Not known yet	N/A
	Feed additives (Yucca schidigera)	Product is mixed into the feed	May reduce odor and ammonia emissions	Not known yet	$.20/pig marketed or more
Bedding		Dry carbon source added to animal pens to promote comfort and soak up manure	Reduced less obnoxious odors. Works for all species	Must harvest or buy bedding, and add it throughout the year. Increased volume of manure to haul	$3.00/head capacity for swine buildings
Manure additives		Chemical or biological products are added to the manure	May reduce odor and ammonia emissions	Usually questionable results.	$0.25 to $1.00/pig or more

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Chapter 3: Emission Control Strategies for Land Application

The land application of manure from livestock and poultry facilities is the most frequent source of odor complaints from the public (Pain 1995, Hardwick 1985). Land application of manure to cropland is an important component to the long-term sustainability of animal agriculture. Manure application returns nutrients and organic matter to the soil, keeping it healthy and productive. Unfortunately, manure application to cropland does present some environmental risk. Over application of manure can lead to nitrate leaching into groundwater, phosphorus runoff into surface water, and a variety of other pollution problems. Proper manure application requires knowledge of the nutrient content of manure, the nutrient requirements for the crops, the availability of the manure nutrients, the physical limitations of the application equipment, and some understanding of the critical environmental hazards associated with manure application.

Along with water quality problems are nuisance odor concerns. Odor from manure is, in general, offensive to most people. One of the key factors in odor control is the surface area of the emitting source. The larger the surface area, the more odors are emitted. As such, manure applied on the surface of cropland presents one of the most significant sources of odor for any livestock or poultry operation. Applying manure at low rates to avoid over applying nutrients may in fact exacerbate odor problems since the manure must be spread on larger land areas.

Odor may last for a few hours to as much as two weeks, depending on weather conditions and the manure source. Manure that is applied beneath the soil surface (injected) or covered immediately after spreading (incorporation) eliminates most of the odor because the odorous gases must then travel up through a soil layer before being emitted into the atmosphere. The soil layer acts as both a trap for odorous gases and an aerobic treatment system, changing odorous gases into less odorous gases through microbial processes. Manure injection or incorporation also reduces manure nitrogen losses to the atmosphere by reducing ammonia volatilization. Field research suggests odor and ammonia emission reductions of 90% are attainable using shallow or deep injector manure systems versus surface application (Phillips et al. 1988).

Liquid Manure Odor Control Techniques

As indicated previously, reducing odor from the land application of liquid manure offers special challenges. Several methods of reducing odor from liquid manure land applications include incorporating the manure into the soil either during or shortly after it is spread, placing the liquid manure on the surface but in the crop canopy, or treating the manure in the storage unit before it is spread on land.

Injection and incorporation: Manure injection into the soil is the most effective way to reduce odor during the land application of untreated liquid manure (Figure 1). Table 1 shows odor dilution thresholds for various land application methods. One can see that the injection and the unmanured (control) methods have essentially the same odor units. The other common option is to simply spread liquid manure on the surface and immediately incorporate (plow or harrow methods in Table 1) into the soil. This method also reduces the odors considerably compared to the broadcast method. However, incorporation after spreading on the surface does not result in as great a reduction as direct injection since some manure remains on the soil surface. Another study (Berglund and Hall 1987) found the odor intensity (measure of odor's strength) from surface application at 400 meters downwind was perceived to be equal to that from injection at only 50 meters. A more recent study at Iowa State University showed odor reductions from 20% to 90% by immediate incorporation of manure into the soil. This study looked at five different types of incorporation or injection devices, with all resulting in significant odor and hydrogen sulfide reductions compared to broadcast manure left on the surface (Hanna et al. 1999).

Figure 1. Injection of liquid manure into the soil.

Table 1. Odor thresholds for various land application methods.

Application Method	Odor Detection Threshold[a]
Broadcast	2818
Plow	200
Harrow	131
Inject	32
Unmanured	50

[a]Ratio of fresh air to odorous air (fresh:odorous) to dilute the odor to where it is just detectable.

The types of injectors used today include narrow tines, sweeps, disk covers, and conventional chisel plows. Besides their ability to achieve complete manure coverage for odor control, it is also important that these injector methods leave crop residue on the surface to minimize erosion and limit energy (tractor horsepower) requirements. Sweeps require more horsepower than simple tines for a given depth, but the sweeps more than compensate for this by operating at a shallower depth, permitting complete coverage. The disk covers, when set properly, require the least horsepower while still providing complete coverage, but they may also cover more crop residue. When the manure is placed on top of the soil surface and a conventional chisel plow is used for incorporation, complete coverage cannot be achieved. Thus a high level of odor control may be at the expense of higher energy requirements and the potential for greater erosion. The additional cost of manure incorporation or injection for odor control is offset somewhat by the savings in manure nitrogen. An Iowa study suggests that injecting the manure from a storage system increases costs $0.49 per year per breeding sow and $0.17 per finish hog while injecting the manure from a lagoon system increases costs $1.39 per year per breeding sow and $0.68 per finish hog (Fleming et al. 1998). However, these cost increases did not consider reduced nitrogen losses with the injection system. An Iowa survey of commercial manure applicators showed an average difference of 1/10 of a cent per gallon more for injection versus broadcast (see http://www.ae.iastate.edu/manurdir99.htm).

Drop hoses: Another method of application, used in northern European countries, is to simply place liquid manure on the surface through a series of drop hoses much like a sprayer hose or boom (Figure 2).

Figure 2. Drop hose liquid manure applicator.

This technique has been used to spread manure slurry (liquid manure from under barn pits) on tilled cropland and on growing crops (especially small grains), producing minimum odor and minimum potential runoff and/or erosion. The system has been used with manure tanks but could be adapted to drag hose technology on pastures or some crops such as forages. Adoption of this technology may be limited in the United States because of the prevalence of row crops and the difficulty of matching tanker tire size with rows and wheel spacing.

Pretreated manure: Treated liquid manure may be less offensive than raw or untreated manure, although this depends on the degree of treatment. Liquid manure can be treated either aerobically or anaerobically (anaerobic digestion) to significantly reduce odors. Research indicates odor reductions of 80% or more during anaerobic treatment of manure (Pain et al.1990). In such cases, manure can be surface applied or even irrigated with very little odor emissions. The same can be said for solid manure that is applied frequently (hauled daily), dried, or composted since it will generate less odor during land application.

Surface application by irrigation: Applying liquid manure with irrigation (both surface and spray) systems (Figure 3) remains a popular and efficient method to distribute manure nutrients onto crop land in some sections of the United States. As mentioned previously, it can produce considerable odors if not managed properly and/or the liquid manure is untreated or has a high nutrient content. Characteristics of irrigation systems that reduce odor include use of nozzles and pressures that produce large droplet sizes, installing drop nozzles on center pivot systems, and the addition of dilution water to the liquid manure before applying.

Droplet size is of importance because of the much higher surface area per unit volume associated with smaller droplets as well as the potential for greater drift of smaller droplets. In general, larger droplets are better for odor control. Droplet size is determined by a combination of nozzle size and pressure. To overcome their tendency to drift, droplets generally must be greater than 150 microns in size, depending on wind speed. Traveling guns must operate at high pressures, but the nozzle size is large, resulting in primarily large droplets. Center pivot irrigation units have wide latitude for nozzle size and pressure combinations. To minimize droplet drift and odor emissions from irrigation and other broadcast application systems, maximize nozzle size and minimize spray pressures.

Figure 3. Spreading liquid manure with a traveling gun irrigation system.

Equipping center pivot irrigation systems with drop lines and downward spraying nozzles will reduce odors as well as reduce water evaporation. Drop lines can extend from 8 feet down to only 2 or 3 feet from the ground with appropriate nozzles and nozzle spacings to give good water distribution.

Fresh water dilution can also be used to reduce manure odors and nitrogen loss during irrigation applications. A Midwestern state (Iowa) requires a 15:1 dilution with fresh water if untreated slurry is to be irrigated. Burton (1997) reported that 3:1 fresh water additions to manure slurry reduced ammonia losses from 20% to 90%. Lagoon liquid is often mixed into irrigation water in states that commonly use irrigation for crop production. The lagoon effluent is then spread in a very dilute and greatly odor reduced manner.

Treating manure in pits: One other factor that contributes to odor and gas emission during manure application is the agitation or mixing of the manure before pumping (Figure 4). This mixing is necessary to remove the solids that have built up in the bottom of the storage and to distribute the nutrients evenly throughout the manure. Odor and gas emissions during agitation and pumping are difficult to control. The best method for reducing the impact of these odor emissions is to agitate during times when the outside air is heating (sunny clear mornings), causing the odorous air to rise and disperse.

Figure 4. Agitation and pumping equipment for a deep pit manure storage under a pig-finishing barn.

Other techniques to reduce these emissions, such as the addition of chemical additives to the manure, are also being evaluated. Research has shown reductions in hydrogen sulfide emissions of over 90% with additions of calcium hydroxide, ferric chloride, ferrous chloride, ferrous sulfate, hydrogen peroxide, potassium permanganate, or sodium chlorite (Clanton et al. 1999). Although these reductions in emissions do not guarantee reductions in odor emissions, odor reductions are likely.

Solid Manure Odor Control Techniques

Technologies that reduce the odors released during land application of solid manure parallel those of liquid manure, namely, treating solid manure before it is spread and incorporating surface-applied solid manure into the soil as soon as possible after it is applied.

Incorporation: Solid manure is not injected, because unlike liquid manure, it will not flow through the pipes and tubes common to injectors. It therefore requires another pass with a disk or other tillage equipment before being incorporated into the soil. The simple recommendation is to use a tandem disk or field cultivator as soon as possible after the solid manure is spread. New equipment needs to be designed that will both apply and incorporate solid manure with a single piece of equipment or spread solid manure on grasslands.

The loading or transfer of solid manure from buildings, stacks, or storage areas can produce odor emissions. This can be a problem when solid manure is temporarily stored near cropland and then applied after the crop is removed in the fall or before the crop is planted in the spring. One way of minimizing odors from stacked manure, however, is by covering it with plastic. Using black plastic may also help minimize fly production due to the high temperatures that occur beneath the cover.

Treatment: As with liquid manure, treating solid manure (such as composting, Figure 5) can reduce odors. Some chemical treatments can reduce gas emissions. For example, alum has been shown to significantly reduce ammonia volatilization from poultry litter (Moore et al. 1995).

Figure 5. Mechanical turner used in composting solid manure

Time and location constraints: When applying manure, always consider wind direction especially if you are broadcasting. Select days when the wind is blowing away from neighbors and dwellings. If feasible, spread manure on weekdays when neighbors are likely to be away from their home; avoid weekends, especially Sundays and holidays. Before spreading manure, check with neighbors to be sure that they do not have a social event planned for the same day that you are planning to spread. If they do, change your plans. Finally, one of the most effective practices is simply to tell your neighbors or those who may be affected that you plan to apply manure to your farmland. Typically, people will object less if they know ahead of time and feel that they have some control or at least some input into what is happening around them.

Summary: Manure application can cause significant odor emissions. Several methods of reducing odor from both liquid and solid manure land applications include incorporating the manure into the soil either during or shortly after it is spread, placing manure on the surface but beneath the crop canopy, or treating the manure before it is spread on land. The agitation and/or loading of manure from long or short-term storage facilities will also create odors that need to be managed to avoid complaints during the application process.

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