Generic Environmental Impact Statement on Animal Agriculture:

A Summary of the Literature Related to Air Quality and Odor (H)

Prepared for the Environmental Quality Board

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ENVIRONMENTAL QUALITY BOARD

September, 1999

To Interested Minnesotans:

The GEIS on Animal Agriculture is a statewide study authorized and funded by the 1998 Minnesota Legislature and ordered by the EQB. The Legislature directs the EQB to "...examine the long-term effects of the livestock industry as it exists and as it is changing on the economy, environment and way of life of Minnesota and its citizens."

The intent of the GEIS is twofold: 1) to provide balanced, objective information on the effects of animal agriculture to future policymakers; and 2) to provide recommendations on future options for animal agriculture in the state. The success of the GEIS on Animal Agriculture will be measured by how well it educates and informs government officials, project proposers, and the public on animal agriculture, and the extent to which the information is reflected in future decisions and policy initiatives, made or enacted by Minnesota state and local governments.

The GEIS consists of three phases during the period summer 1998 through summer 2001: scoping the study; studying and analyzing the 12 scoped topics; and drafting and finalizing the GEIS. The EQB has established a 24-member Advisory Committee to provide advise to EQB during all phases of the GEIS. The scoping phase of the GEIS was completed in December of 1998.

This literature summary is the first step in the second phase aimed at study and analysis of the 12 key topics. This summary is intended to inform the Environmental Quality Board (EQB) members, EQB staff, and the Advisory Committee on the "Feedlot GEIS" scoping questions and research needed for adequate completion of the GEIS. The EQB would like to acknowledge the time and effort of the Advisory Committee members who provided invaluable input in the development of this "tool" for use throughout the GEIS process.

The literature summary is formatted to address the 12 topics of concern and 56 study questions outlined in the Feedlot GEIS Scoping Document (www.mnplan.state.mn.us). Any conclusions or inferences contained in this report are those of the authors and do not necessarily reflect the positions of the EQB or the Feedlot GEIS Advisory Committee.

The EQB would like to make this literature summary available to others interested in the effects of animal agriculture. Copies of this literature summary will be available for use in the Minnesota Planning/EQB Library: 300 Centennial Building, 658 Cedar Street, St. Paul. The Library will also house copies of the key literature review articles and the searchable database compiled as part of this literature review. A limited number of copies of this literature summary will be printed for distribution at cost.

For further information on the GEIS or this literature summary please contact the EQB at 651-296-9535.

Sincerely,

Gene Hugoson, Commissioner, Minnesota Department of Agriculture and
Chair, Minnesota Environmental Quality Board

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EXECUTIVE SUMMARY

Animal agriculture can be a source of numerous airborne contaminants including gases, odor, dust, microbes, and insects that are produced or emitted inside and near animal production facilities and when waste products are land-applied. Numerous gaseous compounds and living organisms are generated from livestock and poultry manure decomposition shortly after it is produced or during storage prior to use as a fertilizer on cropland. Particulate matter and dust come primarily from the feed and the animals. The rate of generation of these gases, organisms, and particulates varies with time, species, housing, manure handling system, feed type, and management system used, thus making prediction of contaminant presence and concentrations extremely difficult.

Research has shown some animal production systems have reduced contaminant generation rates compared to other production systems. Numerous control strategies are being investigated to reduce contaminant generation. These strategies include the use of vegetable oil (in the feed or directly sprinkled in the barn) to lower airborne dust and other particulate emissions or the use of a biomass cover on a manure storage basin to reduce odor and gases emissions from stored manure. Even when using best management systems and/or mitigation techniques, some airborne contaminants may be generated. The contaminants may build up concentrations inside livestock and poultry buildings that result in animal and human health concerns. Most of these concerns are associated with chronic or long-term exposure. Some human and animal health concerns or safety hazards can result from acute or short-term exposures, like those expected during the pumping of liquid manure from a pit inside a slatted floor livestock building.

Once these contaminants are generated they can be emitted from the sources (building, manure storage unit, or cropland) through the barn's ventilation system or by natural (weather) forces. Again emission rates are dependent on many factors—time of year and day, temperature, humidity, and other weather conditions, ventilation rates or wind forces, housing type, manure properties or characteristics, and animal species.

Determination of emission rates for gases and odor, dust, microorganisms, and insects is an active area of research in the US and Europe. Emission rates from point sources (buildings) and area sources (manure storage units and manure applied on cropland) are difficult to accurately determine because collection techniques have not been standardized, the large number of contaminants to measure, and the many factors and conditions at sites that affect them. Emission rates of only a few of the many gas compounds identified have been investigated. Ammonia is the most common gas studied and measured because of the negative environmental impact it can have on ecological systems. There is very little emission data for other contaminants such as odor, dust and microorganisms. The environmental and health effects of these ambient air contaminants on people, animals, and the environment surrounding animal production sites is only beginning to be investigated. In some areas some or all of the emission contaminants have created environmental or health concerns, but long term impacts on ecological systems and people are not known.

There are management systems and control technologies that can reduce the contaminant emission rates. These systems can reduce generation or they can collect or capture the contaminants as they leave a source. An example would be the use of a biofilter, which reduces odor and gas emissions in the ventilating exhaust air from a livestock building. Windbreak walls are another example. They can capture dust released from animal buildings, which can also carry odors and microorganisms. Successful technologies that find widespread application must be both effective in reducing contaminant emission rates and economical for use in the animal industry.

Finally, after these materials are emitted and become airborne they are transported downwind. Travel distance can vary greatly due to size of particles, weather conditions, and surrounding topography and vegetation. Odor is the most common contaminant of concern downwind of some animal sites, although certain gases like hydrogen sulfide and even flies can be of concern to neighbors living and working near these production units.

Computer prediction models are being used to estimate the movement and concentration of these contaminants downwind for animal production sites. The models being adopted were used to model emissions from other smokestack industries, which generally have a more constant and standard (one or two specific compounds) emission rate. Evaluation of these models is needed to verify that they accurately predict contaminant levels around animal facilities. It is anticipated that these models will be used to assist in local decision making on setback requirements and other land use issues.

Contaminant emissions rates from animal production systems are beginning to be categorized, even though their measurement and identification are difficult and highly variable. The impact of the contaminants on the environment and their health effects on humans and animals are not fully known. Research continues to find mitigation and control strategies that not only reduce the generation and emission rates of these contaminants into the buildings and to the ambient air but also does it in an economical and manageable way that will be compatible with animal production systems.

OVERVIEW/CRITIQUE OF STUDY QUESTIONS

The University of Minnesota team that was assembled to address the GEIS scoping document questions under topic III. H.—air quality and odor—decided to regroup the questions from five to a total of four. The original question 3, which asked how the impacts discussed in questions 1 and 2 were affected by animal species, size, management and systems types, was incorporated into the first two questions. Contributors to this topic were assigned to one or more of these four questions. The questions and a list of contributors for this section of the GEIS are listed below:

Questions 1 & 3—Quantify emissions and environmental impacts as function of species, size, and management, etc?

Contributors—Charles Clanton, Richard Nicolai, Jun Zhu, Sally Noll, Kevin Janni, and Roger Moon

Questions 2 & 3—Health risks/impacts as function of species, size, & management, etc.

Contributors—Philip Goodrich, Carlos Pijoan, Jill Bruns, Thomas Blaha, Larry Jacobson, Sally Noll

Question 4—Mitigation and emission control technologies

Contributors—Jose Bicudo, Richard Nicolai, Jerry Shurson, Lisa Brosseau, Sally Noll, Larry Jacobson

Question 5— Monitoring, measuring, and modeling emissions

Contributors—David Schmidt, Richard Nicolai, Kevin Janni, Chuck McGinley

This is the final draft of the document that is being forwarded to the Environmental Quality Board (EQB). Changes have been made since the first and second drafts as a result of comments from Citizens Advisory Committee (CAC)/EQB members and designated reviewers as well as additions made by the authors during the final draft preparation. The document is a review of the information sources (literature summary) found addressing the above four questions.

The reader will see from the table of contents that the above four groupings of questions are not listed in numerical order. The authors decided to begin with question 5, Monitoring, measuring, and modeling emissions, followed by the questions as listed above (1 & 3, 2 & 3, and 4). The reason for this change was the belief of the authors that it was more logical to first describe how emissions are measured, then list specific contaminate concentrations and emission rates, followed by their environment and health impacts, and finally procedures for their mitigation and control.

The authors believe this is a comprehensive review of the air quality and odor topic concerning animal production in Minnesota. It is longer than most originally envisioned because we found more material than anticipated, and also as a response to comments received from the CAC and other reviewers. We have attempted to avoid duplication of materials both within this document and between other GEIS topic reports. There are references to other reports listed in the document. Some materials are repeated intentionally where appropriate to certain sections or reports. Some materials will probably be duplicated, especially between different topic reports, since there simply was not time to coordinate fully with the other topic report authors.

MONITORING, MEASURING, AND MODELING EMMISSIONS (QUESTION 5)

INTRODUCTION

Quantifying air emissions from animal agriculture is a complex process. The complexity arises from the multitude and variety of individual sources responsible for these emissions, the extreme variability of these emissions, and the variety of components being emitted. Emission sources include barns, manure storages, silage piles, dead animal compost structures and a variety of other smaller emissions sources. Each of these sources will have a different emission profile, i.e., different gases, dusts, and microbes emitted, and these emissions will fluctuate throughout the day and throughout the year. Therefore, quantifying these emissions and their impact on the surrounding environment is extremely difficult. The following information documents various measurement, monitoring, and modeling techniques and standards that could be used to detect and regulate these air emissions.

The American Society for Testing and Materials and the United States Environmental Protection Agency have led the way in defining standards and methods for measuring both emissions and ambient concentrations of specific gases and particulates from industrial sources. These EPA standards were developed as a result of rules promulgated from the Federal Clean Air Act. Therefore, methods to measure those pollutants listed as a “Criteria Air Pollutant” or a “Hazardous Air Pollutant” in the Clean Air Act are fairly well defined. Unfortunately, the majority of emissions from animal agriculture do not appear on these EPA priority pollutant lists. Because of this, very few standard methods and monitoring techniques are available to measure the emissions from agricultural sources. However, these methods and protocols are useful in the development of new standards and protocols for the measurement of air pollutants of interest emitted from animal agriculture.

Part 50 of Title 40 in the Code of Federal Regulations—National Primary and Secondary Ambient Air Quality Standards (EPA 1998c)defines ambient concentrations for the six Criteria Pollutants: sulfur dioxide, suspended particulate matter, carbon monoxide, ozone, lead, and nitrogen dioxide. Measurement and monitoring methods for these pollutants are defined by 40CFR53—Ambient Air Monitoring Reference and Equivalent Methods (EPA 1998a) and 40CFR58—Ambient Air Quality Surveillance (EPA 1998b). Other Parts of Title 40 may also be a source of information when developing standard measurement methods.

The American Society for Testing and Materials has standard methods available for measuring ambient concentrations of some of the USEPA "Criteria pollutants" and some general standards for sampling and analysis of ambient air and source emissions (ASTM 1997; ASTM 1998).

This review will focus on measurement and modeling of some of the most common aerial pollutants from agriculture, typically dust, ammonia, methane, volatile organic compounds, hydrogen sulfide, and odors. This document is broken into three distinct sections—the first dealing with measurement techniques and standards, the second addressing computer modeling approaches to predict ambient concentrations of these emissions and the third, a summary of state ambient standards for hydrogen sulfide and odor.

MEASUREMENT AND MONITORING TECHNIQUES

Measurement and Monitoring of Particulate and Gas Emissions

Emission is the amount of a particular compound of concern released per time. This emission rate is most often calculated by measuring the concentration of the gas or particulate in the exhaust air stream and multiplying by the ventilating rates of the same exhaust streams. As such, both concentrations and ventilation rates must be known for each emitting source. Concentrations are measured in terms of mass of compound per volume of air or volume of compound per volume of air. Unfortunately, most of the research in agriculture has focused on the concentration of specific gasses and particulates inside buildings or ventilation rates of buildings and has not combined the two. This combined measurement is critical because ventilating rate could affects concentration measurements.

Methods for measuring and monitoring either emissions or ambient air quality must be designed and developed to meet the demands of the research or regulatory program. This criteria most likely includes accuracy and precision of the method, but may also consider a variety of other criteria such as economics, data acquisition parameters, automatic operation, maintenance, calibration, average concentrations versus continuous measurement and a variety of other factors. Therefore, in order to define or develop standard measurement techniques the goals of the measurement must be well established.

The measurement technique or standard must also include protocols for sampling methods. Sampling methods, especially from sources where emissions are extremely variable, can drastically affect the outcome of any measurement or monitoring outcome. Sampling methods are defined by the type of emitting source, e.g., area source or point source, the variability of the emissions, and the goal of the measurement, e.g., average or maximum.

Most of the emission research from animal agriculture has focused on laboratory scale emission measurement. For purposes of regulation and field monitoring of full scale facilities, laboratory methods are not typically applicable. Some field research has been conducted to measure emissions in the field. These research projects have employed several different techniques. These techniques are specific to the type of air pollutant monitored and the goal of the project.

A recent European project was designed to measure emission rates of ammonia, inhalable and respirable dust, and endotoxins from livestock and poultry buildings (Phillips and others 1998). The goal of the study was to standardize instrumentation and methods for physical, chemical, and microbiological characterization of aerial pollutants; quantify emissions as a function of animal species, management system and external climate; and verify mathematical models for predicting emissions. This study represents one of the largest air pollutant emissions studies from animal agriculture. Table 1 indicates the methods used to measure these aerial emissions (Wathes and others 1998). The measurement methods used in this research have not been designated as standard methods, however, most of the research currently being conducted in Europe uses these methods (van't Klooster and others 1996).

One of the most rigorous ammonia emissions research programs is taking place in The Netherlands. In response to concerns of soil acidification, regulators have implemented a program to reduce ammonia emissions from animal agricultural production. These regulations have encouraged the development of low ammonia emission systems. In order to qualify as a low emission system, the facilities are monitored for ammonia emissions according to a strict measurement protocol (Verdoes and others 1996). Ammonia measurements for this work, and for most other ammonia research in Europe, use Chemiluminescence NO_x analyzer and an upstream thermal ammonia converter as described by Scholtens (Scholtens 1993).

Table 1. Measurement techniques for aerial pollutants in livestock buildings (Wathes, Phillips and others 1998)

Variable	Technique	Location	Frequency
Ammonia concentration	Chemiluminescence NOx analyzer	3 @ animal height 3 @ human height 1 @ outlet 1 @ ambient	Hourly
Carbon dioxide concentration	Infra-red analyzer	As above	Hourly
Ventilation rate	Indirect mass balance of CO2	As above	12 h
Airborne dust concentration	gravimetric filtration mass oscillator	As above but not ambient	12 h
Airborne endotoxin concentration	Gravimetric filtration	As above but sample pooled	12 h
Air temperature	Platinum resistance	As above	6 min
Relative humidity	Capacitance sensor	As above	6 min
Airborne microorganisms concentration	Impaction	Single	12 hr
Wind speed	Cup anemometer	1 @ ambient	6 min
Wind direction	Wind vane	1 @ ambient	6 min

Unfortunately, measurement of building emissions has received more attention than measuring emissions from area sources, e.g., open manure storages or outdoor feedlots. Harper (Harper and Sharpe 1998) measured ammonia emission from manure lagoons in North Carolina using micrometeorological techniques. Air samples were collected at several locations above the surface of the lagoon and drawn through gas washing bottles. Sampling time of four hours corresponded to micrometeorological data collection. A total of twenty measurements were made throughout three measurement seasons (winter, spring and summer) to determine annual emission rates. Similar micrometeorological techniques to measure gas and odor emissions have been used by other researchers (Phillips and others 1997; Smith and Kelly 1996).

Fourier-Transform Infrared (FTIR) measurement methods have been used recently to measure gas emission rates from livestock facilities. This method has the capability of simultaneously measuring the concentrations of a variety of gases including ammonia, nitrous oxide, carbon dioxide, and methane. These concentrations are combined with micrometeorological data to determine emissions of these gases from both point and area sources (Schafer and others 1997).(Depta and others 1997)

Zahn et. al. (Zahn and others 1997) attempted to develop a method to measured emissions of volatile organic compounds in the exhaust air from swine facilities. This study was designed to develop methods to quantify specific chemical compounds thought to be responsible for odor emissions from swine facilities. In this methodology, gas samples were collected with thermal desorption tubes and analyzed using a gas chromatograph and mass spectrometer. Unfortunately, this research did not measure emission rates but was limited to concentrations. ASTM D-5466-95 is a standard method that has been developed for measuring volatile organic compounds. However, this method is only applicable to volatile organic chemicals that remain stable in pressurized or sub-atmospheric pressure canisters.

Very few research institutes are engaged in measuring emissions of hydrogen sulfide from livestock facilities. The University of Minnesota currently is measuring concentrations of hydrogen sulfide using a Jerome® Meter (Jacobson and others 1997) and will soon be combining this data with ventilation rate measurements using the carbon balance method and fan ventilation rates to determine hydrogen sulfide emission rates. The Jerome® meter measures concentrations of total reduced sulfur in the ppb range comparable to the an EPA approved total reduced sulfur measurement (EPA) and a reflectance measurement technique (ASTM 1984) using an MDA Scientific Chemcassette® Model 7100 (Minnesota Pollution Control Agency 1999). The EPA does have a measurement method defined for continuos emissions of hydrogen sulfide (Test Method 15 (EPA)). This method uses the GC/MS and is limited to concentrations between 0.5 and 10 ppm.

Measurement and Monitoring of Particulates, Gasses, and Odors in Ambient Air

Health and environmental consequences of ambient air quality are not only a function of emissions but of the combined factors of emission and the dispersion, deposition, and degradation of these compounds in the downwind plume. For example, larger dust particles that settle quickly after leaving a barn have little impact on the ambient air quality at any substantial distance downwind from the emitting source. More information on predicting the movement of these compounds downwind will be discussed in the following section on air emission modeling. Ambient air quality monitoring and measurement reflect both source emissions and these other processes taking place downstream of the emitting source.

Ambient air is defined as that portion of the atmosphere, external to buildings, to which the general public has access (EPA 1998c). Ambient monitoring typically reflects an average concentration of a particular compound over some period of time. Once again, standard ambient measurement protocols have been developed for EPA Criteria Air Pollutants and some Hazardous Air Pollutants but methods for measuring other compounds are limited. Ambient air quality measurements are much more difficult than emission measurements because often concentrations of the compounds being measured are very low and below the detection threshold of most equipment.

Ammonia

Several methods and equipment are available to measure ambient concentrations of ammonia. A few studies have compared these methods and equipment. One such study has been conducted by Mennen et. al, (Mennen and others 1996). This research evaluated six automated ammonia analyzers in the field for their suitability for the Netherlands National Air Quality Monitoring Network. The instruments studied were a continuous flow denuder, a WO_3–coated thermodenuder, a V_2O_5-coated thermodenuder, a commercial Differential Optical Absorption Spectroscopy system, a photoacoustic monitor, and a chemiluminescence NO_x monitor with an upstream NH_3 thermal converter. Results from this study indicate that several of the devices might be suitable for ambient monitoring with the continuous flow denuder meeting all of the criteria set out in this study. Other more economical ambient ammonia monitors include a variety of passive diffusion samplers (van't Klooster and others 1996).

Hydrogen Sulfide

The Minnesota Pollution Control Agency currently has an extensive program documenting ambient hydrogen sulfide concentrations around livestock facilities (Minnesota Pollution Control Agency 1999). Ambient monitoring employs use of a Jerome® meter for prescreening, an MDA Scientific Chemcassette® Model 7100 and a TRS monitor (EPA Test Method 15A (EPA)) for compliance monitoring.

Dust and Particulates

Suspended dust is a designated EPA Criteria Air Pollutants. As such, EPA standard methods have been developed to measure concentrations in ambient air. These standards are outlined in EPA National National Primary and Secondary Ambient Air Quality Standards Appendix L (EPA 1998c) and elsewhere in EPA documents citing promulgated test methods.

Odor Measurement Technologies and Methods

Many of the gases released from animal production are odorous, meaning they can be detected by the human olfactory system. As such, odors can be measured in one of two ways. Measurements can be made by measuring the concentration of odorous gases and correlating these concentrations to human olfactory sensations, or the human nose can be “calibrated” to measure odors. Both of these measurement methods have significant drawbacks. The techniques and methods to measure odor using gas concentrations or the human olfactory system will be explained in the following sections.

Gas Measurement as a Method of Odor Quantification

An odor consists of a complex mixture of many odorous compounds. There are at least 168 different gases that contribute to swine odor (O'Neill and Phillips 1992). As such, analytical monitoring of individual chemical compounds present in such odors is typically not practical (ASCE 1995). However, it has been proposed that some of the gases found in livestock odors could be used as a “indicator gases.” (A good indicator gas would be one whose concentration would correlate well with the human olfactory system, e.g., a high concentration of an indicator gas would result in a high concentration of odor.) The advantage of using an indicator gas is that it would be easier to measure than odor.

Spoelstra (Spoelstra 1980) concluded that hydrogen sulfide, ammonia, and phenols would not be good indicators of odor but rather p-cresol and volatile fatty acids may be suitable. Jacobson (Jacobson and others 1997) documented the lack of correlation between hydrogen sulfide and livestock odor. Pain (Pain and Misselbrook 1990) showed little correlation between ammonia concentrations and odor. Zahn (Zahn and others 1997; Zahn 1999) attempted to correlate a suite of volatile organic compounds to odor.

The “electronic nose” is an attempt to correlate an odorous air sample to odor by evaluating the concentrations of several gases in the sample air. Gas sensing methods include metal oxide semi-conductor capacitors; chemically modified field-effect transistors; optical devices, and peizo-electronic quartz crystal devices (Mackay-Sim 1992). Misselbrook (Misselbrook and others 1997b) did one of the most recent studies that evaluated this equipment. This research developed a relationship between the output pattern of the electronic noses tested and the human sensory system using olfactometry for land application of cattle slurry to cropland. The research indicates that there may be some possibility for this type of technology to be used in the future to evaluate agricultural odors.

Ostojic (Ostojic and O'Brien 1996) reviewed attempts to correlate odor to gas. His review indicates that measurements of specific gases to correlate to odors are limited by the odor threshold information, the complex interactions between odor sensation and multiple gas composition, and the detection limits of the olfactory system, far exceeding the detection limits of gas sensing equipment.

Sensory Methods to Quantify Odors

There are five parameters that provide a fairly complete description of an odor. Quantification of these parameters provides a sensory measurement tool for odor quantification.

Concentration of odors are measured as the amount of clean air needed to dilute a sample of odorous air to the point where it can be either detected or recognized. The detection threshold is the minimum amount of an odorous air that can be mixed with clean air and still be detected by a human nose. Recognition threshold is the minimum amount of odorous air that can be mixed with clean air and that people are able to describe the odor by applying a character descriptor to. The odor concentration is expressed as a volume ratio of clean air to odorous air. The two most used methods to quantify this ratio are discussed below.

Intensity describes the strength of an odor and is measured at concentrations above the detection threshold (ASCE 1995). Intensity changes with concentration and can be measured at full strength or after dilution with clean air. Intensity measurements are most often based on the intensity of a reference gas. This gas is most often n-butanol.

Persistence is a parameter that describes the relationship between odor concentration and perceived intensity. It is a calculated value based on the intensity at full and the intensity of diluted samples. Odors with high persistence include livestock manure and smoke.

Character descriptors are used to describe what an odor “smells like.” Some terms used are sweet, sour, pungent, mint, citrus, and earthy. Character descriptors are used at or above the threshold.

Hedonic Tone measures the pleasantness or unpleasantness of an odor (ASCE 1995). This is typically recorded in a scale of -10 to +10 with neutral odors being recorded as zero. Unpleasantness usually increases with odor intensity. Pleasant odors may increase in pleasantness with odor intensity when the intensity is low, but become less pleasant and eventually unpleasant at relatively high intensities.

Odor concentration and odor intensity are the two most common parameters used for odor quantification. The other three odor parameters—persistence, character descriptors, and hedonic tone—are commonly viewed as more subjective parameters not lending themselves to science or regulatory purposes.

Olfactometry

Two techniques are used most commonly to measure odor concentration or dilution threshold. Dynamic forced-choice olfactometry is a method where the odor samples are captured in bags and evaluated by trained human panelists. The scentometer is a dilution device used in the field.

Dynamic forced-choice olfactometry is the most common method for determining odor concentration (dilution threshold). Dynamic forced-choice olfactometry is widely used to evaluate livestock odors (Hobbs and others 1999; Watts and others 1994; Ogink and others 1997). The American Society for Testing and Materials has developed a standard practice for olfactometry (ASTM 1991) which is the method most commonly used in the United States. In this method odorous air samples are diluted with clean air. Panelists are asked to smell three samples, two clean air samples and one odorous sample mixed with clean air, and determine which of the samples is different from the other two. The detection threshold is determined when the panelist correctly identifies the odorous air sample. The ratio of clean air to odorous air in that sample is then determined to be the detection threshold for that sample. The ratio of clean air to odor sample of the mixture is reported as odor units (ou). An olfactometer is the equipment used to dilute the odorous sample and deliver the diluted odorous sample, and the two clean samples, to the panelist. Several styles of olfactometers are available. Olfactometers differ primarily in how they achieve dilution ratios, how samples are presented to the panelists, and the airflow rate at which the samples are delivered.

Dynamic forced-choice olfactometry is reproducible, statistically reliable and is widely used in Europe to evaluate livestock odors (Dravnieks and Jarke 1980). A standard method for this type of olfactometry has been standardized for use in European odor laboratories (Thomas and Skoda). This method is an excellent tool for research in a laboratory setting; however, it is not a good tool for regulatory purposes since it is not very portable, requires a number of trained panelist, and is expensive.

The Scentometer is another piece of equipment designed to determine odor concentration or dilution threshold. The Barnebey and Sutcliffe Corporation developed the Scentometer in the late 1950s, specifically for field evaluation of ambient odors (Barnebey-Cheney 1973). It is a rectangular, clear plastic box with two nasal ports, and two chambers of activated carbon with four to six air inlets. By covering some of the inlets, various odorous air concentrations can be sniffed through the nasal ports to determine the detection threshold. Each inlet has a known threshold (odor unit) number. Portability to the field and relative low cost are some advantages of the instrument (Barnebey-Cheney 1987). The Scentometer is not known for high accuracy (Jones 1992), requires a sufficient number of panelists, and subjects the panelist to odor fatigue by not isolating them from the ambient odorous air.

Sweeten (Sweeten 1995) provides a detailed review of the use of dynamic olfactometers scentometers.

Intensity Measurements

An intensity measurement involves ranking an odor to a known scale. The scales are either descriptive (e.g., no odor, faint odor, strong odor, etc.), or numerical (e.g., zero to ten scale). Although these scales can be somewhat subjective, a standard scale can be developed using specific gas concentrations. ASTM standard E 544-88, Referencing Suprathreshold Odor Intensity (ASTM 1988), defines concentrations of n-butanol to correlate with an odor intensity measurement. This intensity measurement can be used in the laboratory with odor samples collected in bags directly from the odor source or in the field in the odor plume.

Field measurements of odor using intensity measurements have been used by several researchers and communities to monitor odor emissions and odor plume transmission (Nicell and St. Pierre 1996; MacKenzie and Mann 1996; McGinley 1996; Hartung and Jungbluth 1997; Zhu and others 1998). In all cases, community members or trained field monitors determined odor intensity on some predetermined scale. These results were then used to evaluate odor control technologies, odor dispersion models, or quantify odor emissions.

Fly Monitoring and Measurement

Methods for monitoring breeding of house flies and stable flies have been developed for use in integrated pest management (IPM) programs on livestock and poultry premises (Lysyk and Moon 1994). Some of the methods are used routinely at progressive livestock and poultry operations in Minnesota or elsewhere, to improve on-site fly management and thereby prevent annoyance and health problems for animals, workers and neighbors. Scouting is used routinely to monitor fly breeding at some beef and dairy feedlots in Nebraska. Premises are inspected at weekly intervals to detect, map and eliminate fly breeding sites before they turn into problems.

In a similar manner, adult insects can be monitored with spot cards and sticky tapes inside egg layer barns and dairies. The resulting counts are being used at some facilities in California, North Carolina and California to evaluate need for additional fly suppression measures. Sticky fiberglass traps have been used to monitor outdoor abundance of stable flies and house flies in the context of field research in Florida, Nebraska, Kansas and elsewhere. Despite existence of these monitoring methods, procedures for scouting and trapping indoors and outdoors are not standardized, and are not used widely to monitor insect abundance—either on animal premises or in surrounding residential environments.

At present, insect abundance in residential neighborhoods is monitored passively, through logging of complaints about excessive numbers of insects from citizens to public health and environmental quality authorities in Minnesota and other states. These complaints are recorded, and some have prompted action from authorities, but no active monitoring system is in use anywhere. It is not clear that all complaints are directly related to actual insect abundance. Research projects in Ohio (Winpisinger-Slay and Berry unpubl.) and Minnesota (Moon R. 1999) have been initiated to calibrate catch rates on traps with matching levels of human annoyance at residences in rural settings. The results may provide public health authorities with a tool for setting and enforcing community fly nuisance standards.

It should be generally understood that house flies and other animal-related insects have always been a common part of rural life in the Upper Midwest. These insects winter in freeze-protected environments, and then disperse and reproduce in ephemeral deposits of organic media that are scattered on the landscape during the summer months. Fly populations grow exponentially until cold weather freezes out the outdoor populations.

A critical question that cannot be answered with available knowledge is whether an industry with large concentrations of animals at few premises would contribute more or fewer flies to the overall landscape than an industry with fewer animals at a greater number of premises. One approach to studying this question might be through simulation modeling, where biologically based models of on-farm fly populations were coupled with difusion models to evaluate patterns of abundance on landscapes surrounding modeled premises of different sizes. On-farm population models have been developed for house fly (Wilhoit and others 1991), stable fly (Lysyk 1999), and face fly (Moon 1986), but those models remain to be evaluated through comparison with empirical field data. Furthermore, knowledge about dispersal by adults of both species is insufficient to develop realistic models of diffusion by adults in different kinds of landscapes.

Table 2 Elements of Dispersion Modeling.

INPUT	Source	What is generating the pollution?
	Chemical	What type of pollution?
	Emission Rate	How much pollution?
	Location	Where is the Source?
	Meteorology	What are the atmospheric conditions?
MODEL	Selection	Which model fits the “needs” ?
OUTPUT	Receptors	Who and what will be affected?
	Distances	Where are the receptors?
	Time	What are the temporal considerations? … when and how often?
EVALUATION	Critiques	Is the model valid? … accuracy and precision

AIR DISPERSION MODELING

Efforts to model air pollution began after 1917. However, the science of “atmospheric dispersion modeling” is recognized to have started in the 1950s. The Clean Air Act Amendments (CAAA) of 1977 first required the Environmental Protection Agency (EPA) to use air quality simulation models. The EPA held its first conference on air quality modeling in December, 1977. The Air Pollution Control Association (APCA) presented a Critical Review on “Atmospheric Dispersion Modeling” at the 1979 Annual Meeting and subsequently published a critical review as an APCA Reprint Series (Volume 10) in March, 1980. The APCA Reprint Series contains “A Critical Review” by D. Bruce Turner—with critical review comments and thirteen papers published between March, 1977, and September, 1979. This APCA Reprint Series, “Atmospheric Dispersion Modeling,” is a good starting point for the body of literature encompassing “air quality simulation models.”

Turner (1979) defines a *dispersion model* as “a mathematical expression of the effects of the atmosphere upon air pollution. This includes the effects of advection (transport) and dispersion (including dilution by the wind and dispersal due to turbulence) and may also include considerations of plume rise, wind shear, and chemical and physical transformations (including removal mechanisms).”

Air dispersion modeling consists of four major elements: (1) Input, (2) The Model, (3) Output, and (4) Evaluation; as outlined in Table 2 (Turner 1979).

A failure to properly research the Input elements for modeling is the equivalent to the popular adage for computers: “Garbage In–Garbage Out.” Further, the selection and usage of an inappropriate model will yield erroneous output results. If the Evaluation element can be implemented, the modeling process may be validated or corrected. However, without the Evaluation element, the modeling process can simply yield misleading results and the ramifications of subsequent decision making.

What is, therefore, an “ideal” model? (Lamb 1984; Benarie MM 1987; Zannetti 1990). Zannetti (Zannetti 1990) cautions that complex models do not necessarily perform better than simpler models. The model selection must be based not on its complexity but rather on its applicability.

The application of air dispersion models (air quality simulations) to “Animal Agriculture” includes the following pollutant types:

- “Air Toxics” (non-regulated and regulated gases)
- Odor (common nuisance and health impacting)
- Particulate (non-pathogen and pathogen)

Further, the application of air dispersion models (air quality simulations) to “Animal Agriculture” addresses the following air pollution phenomena:

- Near-field phenomena (<1 km from the source, < ½ mile)
- Short-term transport (<10 km from the source, < 6 miles)

“Animal Agriculture” encompasses a unique set of air pollution cases that differ in many respects from industrial and urban air pollution cases. The modeling parameters that require special treatment for “Animal Agriculture” cases include:

- Rural meteorology (throughout the day and night).
- Facility design and features (i.e. natural and forced ventilated structures and open manure storage basins).
- Pollutants generation from animals (compared to processes in industry).
- Pollutants generation from biological activity in manure storage basins.
- Pollutant release from manure storage basins (large area sources).
- Receptor (population) density surrounding facilities.
- Receptor “sensitivity” and “tolerance” to selected pollutants (i.e. air toxics, odor, and pathogens).

Given the uniqueness of emissions from animal agriculture, what then is the appropriate air dispersion model to apply? The mathematics of air dispersion modeling includes three categories (Zannetti 1990):

- Eulerian Dispersion Models,
- Gaussian Models, and
- Lagrangian Dispersion Models

One model type and method will not be necessarily suitable for all livestock facilities and manure storages or combinations of facilities and storages. Gases, odor, and particulate behave differently and are generated differently from buildings and from basins.

Models recognized and approved by the EPA and the Minnesota Pollution Control Agency (MPCA) are called “Regulatory Models.” Regulatory Models have been formalized for the purpose of meeting specific federal requirements of the Clean Air Act (Stern 1976; Zannetti 1990), i.e. New Source Review (NSR) and Prevention of Significant Deterioration (PSD).

The most widely recognized and used regulatory model is the Industrial Source Complex (ISC) Model. The ISC model is a steady-state Gaussian plume model suitable for a wide range of "industrial" applications and special cases. Variations of the standard ISC model include the Industrial Source Complex Short Term (ISCST) and the SCREEN[3] model. However, there are many other "non-regulatory" models available commercially and as public domain software that have specific applicability to animal agriculture. One important consideration for these regulatory models is the fact that they do not include provisions for the degradation and deposition of gases in transport downwind from the source.

Table 3 Comparison of the various state standards for hydrogen sulfide (State of Minnesota R. 7009-0080)

State	Concentration (ppm)	Averaging Time
Alabama	20	30 minute
Alaska	0.035	30 minute
Arizona	0.08	24 hour
	0.13	60 minute
California	0.03	60 minute
Colorado	0.10	60 minute
Delaware	0.06	3 minute
	0.03	60 minute
Georgia	15	OSHA PEL guidance only
Hawaii	0.025	60 minute
Idaho	0.05	
Illinois	0.01	8 hour
Michigan	0.0045	10 minutes
	0.0007	24 hour
Minnesota	0.05	30 minutes, twice per year
	0.03	30 minutes, twice per 5 day
Montana	0.05	60 minute
Nebraska	10.0 (TRS)	1 minute
	0.1 (TRS)	30 minute
	0.01 (TRS)	30 day
	0.005 (TRS)	30 day
Nevada	0.08	60 minute
New Hampshire	0.03	24 hour
New Mexico	0.01	60 minute
New York	0.01	60 minute
	0.0007	1 year
North Carolina	1.5	15 minutes
North Dakota	10	instantaneous
	0.2	60 minute
	0.1	24 hour
	0.02	90 day
Oklahoma	0.1	30 minute
Pennsylvania	0.1	60 minute
	0.005	24 hour
South Carolina	0.1	24 hour
Tennessee	20	12 hour
Texas	0.08	screening level
Vermont	0.02	24 hour
Wyoming	0.05	30 minute
	0.03	30 minute

The Minnesota Pollution Control Agency recently used the ISCST model to evaluate ambient concentrations of ammonia and hydrogen sulfide resulting from the cumulative effect of 60 feedlots located in a region in West-Central Minnesota (Pratt 1998). The model predicted exceedences of the state's 30 ppb half hour average up to 4.9 kilometers from the source with the highest emissions. Predicted ammonia concentrations exceeded the states proposed Health Risk Values of 1000 $\mu g/m^3$ at distances up to 1.6 miles from the highest emitting source. The author reported several problems with the modeling results including: 1) no provisions for chemical transformations; 2) no provisions for wet or dry deposition; 3) hourly ammonia emission were estimated from annual ammonia emissions data; 4) emission data for hydrogen sulfide were based on unvalidated prediction model; 5) one hour steady state conditions were used; 6) the model ignored calm conditions.

Atmospheric (Air) dispersion modeling is an evolving science as practiced for regulatory purposes and general land use planning purposes. EPA began such a process when the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) met in 1999 to introduce state-of-the art modeling concepts into EPA's air quality models. The new AERMIC Dispersion Model, known as AERMOD, will be phased in during the year 2000 as a replacement for the ISC standard regulator model. One special feature of AERMOD that may have particular applicability to modeling emissions from animal agriculture is its ability to include the air boundary layer above surface releases, ie., manure storage basins.

Odor Modeling

Odor is a significant issue for animal agriculture (Heber 1998). Land use planning and determination of setback distances is a difficult and complex issue. Air dispersion modeling is a tool which will assist in setting setbacks and siting facilities (Heber 1998; Smith 1993).

Regulatory models (i.e. ISCST and SCREEN3) are unsuitable and not recommended for modeling odors (Duffee 1992). Several odor-specific models have been developed and tested by researchers (Hogstom 1972; Murray and others 1978; Smith and Hancock 1992; Duffee 1992). These "odor-specific" models predict odor dispersion and dilution using modified "fluctuating plume, puff" modeling methods and claim to predict odor impacts 30 times greater than "standard regulatory models" (Duffee 1992). Field evaluation methods have been used to validate air dispersion models for odor (McFarland 1996; Smith 1993; Li and others 1994; Zhu and others 1998) with little success to date. The most significant problem with validation of any odor model is the ability to quantify odors in ambient air.

Specific new research is needed to evaluate and judge the validity of current air dispersion models for gas, odor, and particulate emissions from agricultural sources. New additional research is needed to address the unique set of air pollution cases of animal agriculture, ie., natural ventilated structures, manure storage basins, calm/near calm meteorology, and cumulative effects of multiple sources and activities in the rural community.

ODOR AND HYDROGEN SULFIDE STATE STANDARDS

Federal, state and some local governments regulate ambient concentrations of specific gases and dust. Although the USEPA has set ambient standards for Criteria Pollutants, several states have implemented standards for hydrogen sulfide and odor. Table 3 is a summary of the various state hydrogen sulfide standards (State of Minnesota). Table 4 is a summary of odor regulations compiled by the North Dakota Office of Attorney General (Attorney General of the State of North Dakota 1999).

Table 4. A summary of odor regulations (Attorney General of the State of North Dakota 1999).

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
Arizona	Yes (Water)	Arizona has a rule that restricts "odor in drinking water." Arizona does not have a specific rule or statute restricting odor in the air other than their general pollution and nuisance laws. AZAC § R18-11-108(A)(3)		http://www.adeq.state.az.us/air/assess/index.htm
Colorado	Yes	AQCC Reg. 2 - Residential or commercial - viol. If odors are detected after the air has been diluted with 7 or more volumes of odor free air. All other land use areas - 15 or more vols. EXCEPT- if source is mfg. or agricultural operation, no viol. if "best practical control methods" are used. Exception doesn't apply if, after air has been diluted with 127 or more vols. of odor free air and odors are detected.	Barnebey-Cheney Scentometer or any other instrument, device or technique.	http://www.state.co.us/gov_dir/cdphe_dir/ap/aphom.html
Connecticut	Yes	No person shall cause or permit the emission of any substance or combination of substances which creates or contributes to an odor, in the ambient air, that constitutes a nuisance. § 22a-174-23(a). It constitutes a nuisance if a rep. of the comm. or at least 50% of any group of reps. of the comm. determines, based upon at least 3 samples or observations in a 1 hour period, that after a dilution of 7 parts clean air to 1 part sampled air, the odor is equal to or greater than the odor detection threshold. The owner or operator of the source of the burden to rebut the presumption of a nuisance. § 22a-174-23(b). A table sets out the concentration levels. § 22a-173-23(c). The comm. may reasonable suspect that a source has caused or contributed to a violation based upon 1 or more of the following: 1) citizen complaints; 2) comparisons of odors upwind and downwind of the source; 3) material handling and storage practices; 4) methods of operation; 5) site inspections; 6) surveys; 7) info. gathered from any other source; or 8) actual or estimated stack emissions, fugitive emissions or ambient pollutant concentrations. § 22a-174-23(e). An agr. or farming operation shall be exempt to the extent provided by §19a-341. § 22a-174-23(j). The provisions of this section shall not apply to mobile sources or structures which are occupied solely as a dwelling and contain six or fewer dwelling units. § 22a-174-23(k).	Comm. may use air quality modeling tech. To calculate ambient pollutant concentrations. It cannot be the sole basis for finding a violation unless the comm. has received 10 or more written complaints. §22a-174-23(f).	http://dep.state.ct.us/lawreg/lawhome.htm
Delaware	Yes	Reg. 19 - No limit, just "significantly effect the citizens...outside the boundaries of the air contaminant source."	Scentometer, air quality monitoring and affidavits	http://www.dnrec.state.de.us/
Florida	Yes	62-296.320(2) - No person shall cause, suffer, allow or permit the discharge of air pollutants which cause or contribute to an objectionable odor.		http://www.dep.state.fl.us/ogc/documents/rules/air/62-296.doc
Kentucky	Yes	Secondary standard for odor shall be applicable only when the cabinet receives a complaint with respect to odors from a source. 401 KAR 53:005 § 2(2). Odor means the property of an air contaminant that can be detered by the sense of smell. § 3(12). The ambient air quality standards are listed on Appendix A to 401 KAR 53:010.		http//www.state.ky.us/directory/agencyn.htm
Louisiana	Yes	Title 33, Part III, Ch. 29 § 2901(A) establishes ambient air standards for odors. There	Odor test methods: 1)	http://www.deq.state.la.

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
		is an "odor dilution ratio" and "perceived odor intensity" is the intensity of an odor sensation that is independent of the knowledge of the odorant concentration. § 2901(c). Exemptions are provided for 1) single family dwellings; 2) restaurants; 3) other establishments for the purpose of preparing food for human consumption; 4) materials odorized for safety purposes; 5) materials possessing strong odors for reasons of public health and welfare where not suitable substitute is available and where best modern practices are employed; 6) agricultural, fiber, timber, poultry, seafood or fisheries production, unless such odors are detected in concentrations or intensities above that normally detected from these processes or by products when using applicable air pollution control devices; and 7) emission points regulated under the Total Reduced Sulfur (TRS) emission standard. § 2901(E).	Butanol odor evaluation procedure; 2) Butanol referencing techniques for quantifying odors in terms of intensity; 3) Problems/Backflows. (All of the above are described in technical detail at § 2901(G))	us/olae/irdd/title33/p03c2901.pdf
Maine	Yes	06-096(4) provides for adequate provisions for the control of odors under the solid waste laws. The board may establish terms or conditions of approval, reasonable requirements to control odors.		http//www.state.me.us/dep/mdep_reg.htm
Maryland	Yes	A person may not cause or permit the discharge into the atmosphere of gases, vapors, or odors beyond the property line in such a manner that a nuisance or air pollution is created. § 26.11.06.09. Also use nuisance section at 26.11.06.08		http://www.dnr.state.md.us/
Massachusetts	Yes	No person having control of any dust or odor generating operations...shall permit emissions therefrom which cause or contribute to a condition of air pollution. 310 CMR § 7.09. Air pollution means the presence in the ambient air space of one or more air contaminants or combinations thereof in such concentrations and of such duration as to: a) cause a nuisance; b) be injurious, or be on the basis of current information, potentially injurious to human or animal life, to vegetation, or to property; or c) unreasonably interfere with the comfortable enjoyment of life and property or the conduct of business. 310 CMR § 7.00.		http://www.magnet.state.ma.us/dep/dephome.htm
Michigan	Yes	Odor is included in the definition of "air contaminant." Emissions of air contaminants are prohibited if the cause either of the following: a) Injurious effect to human health or safety, animal life, plant life of significant economic value, or property. b) Unreasonable interference with the comfortable enjoyment of life and property. Pt.9, R.336.1901. Rule 901.	No rule concerning the method and just use general reasonableness, frequency, duration, intensity etc.An old court case lists some of these.	http://www.deq.state.mi.us/aqd/
Minnesota	Yes	While they do not have a general restriction on odors (this is left up to the locals), Minnesota does have a state statute, § 116.061(1)(a)(3), which requires notification of excessive emissions that cause obnoxious odors constituting a public nuisance. Also, in their ambient air quality standards, they limit Hydrogen Sulfide to 0.05 ppm by volume (70.0 micrograms per cubic meter); 1/2 hour average not to be exceeded over 2 times per year. See Rule 7009.0080.		http://www.dnr.state.mn.us/
Mississippi	Yes	Rendering plants or other similar operations which may cause odors must be at least 1500 feet from the nearest residential, recreational, or light commercial area and be	Factors to consider include: 1) the number of	http://www.deq.state.ms.us/domino/deqweb.ns

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
		located in compliance with Miss. Code Ann. §41-51-19. APC-S-2(15). There shall be no odorous substances in the ambient air in concentrations sufficient to adversely and unreasonable: 1) affect human health and well being; 2) interfere with the use or enjoyment of property; or 3) affect plant or animal life. APC-S-4.	complaints or petitioners; 2) the frequency of occurrence; and 3) the land use of the affected area.	f
Missouri	Yes	10CSR 10-2.070 restricts emissions of odors when the odor can be perceived when 1 volume of odorous air is diluted with 7 volumes of odor-free air for 2 separate trials not less than 15 minutes apart within the period of 1 hour. Missouri actually has four separate standards which are closely related to the above. See attached. One for Kansas City metro area, Springfield, Greene County and St. Louis metro area. 10-5.160 provides a separate standard for objectionable odors when 30% or more of a sample of the people exposed to it believe it to be objectionable in usual places of occupancy, the sample size to be at least 20 people or 75% of those exposed if fewer than 20 people are exposed. The agricultural exemption still applies to this section. See 10.5-160(2). 10 CSR 10-2.070(3) provides an exception for odors from the raising and harvesting of crops or feeding, breeding and management of livestock or domestic animals or fowl (Class 1A CAFOs). However, the commission will vote next month on whether to take out the agriculture exemption. See the attached proposed amendment (which may be subject to change prior to the vote).	Barnebey-Cheney Scentometer or by similar technique that will give equivalent results. as agreed to at the source operator and the staff director.	
Montana	Yes	No person shall cause, suffer, or allow any emissions of gases, vapors, or odors beyond his property line in such a manner as to create a public nuisance. § 17.8.315. Also limits business and equipment operation, storage, gases, dust and incineration among others as to odors. Id. Waste generating noxious odors may not be open burned. § 17.8.604.		http://www.deq.state.mt.us/
Nebraska	Yes	No specific odor reg. as such, but have total reduced sulfur (TRS) regs. and H_2S like MN. TRS 10.0 parts per million (10.0 ppm) maximum 1 minute average concentration. 0.10 parts per million (0.10 ppm) maximum 30-minute rolling average. See Title 129, Ch. 4 §§ 007 et seq. Neb. said they did have an agr. exemption, got sued (because Iowa Beef said they were discriminated against). The Iowa case was decided and Neb. then took out the ag. exemption and the suit was dropped about 2 weeks ago.	TRS thermal converter in conjunction with an SO2 monitor.	http://www.deq.state.ne.us/
Nevada	Yes	No person may discharge or cause to be discharged from any stationary source, any material or regulated air pollutant which is or tends to be offensive to the senses, injurious or detrimental to health and safety, or which in any way interferes with or prevents the comfortable enjoyment of life or property. NAC 445B.393(1). Investigation shall occur when 30% or more of a sample of the people exposed to it believe it to be objectionable in usual places of occupancy. The sample must be at least 20 people or 75% of those exposed if fewer than 20 people are exposed. NAC 445B.393(2).	The director shall deem the odor to be a violation if he is able to make two odor measurements within a 1-hour period. These measurements must be separated by at least 15 minutes. An odor	http://www.state.nv.us/cnr_menu.htm

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
			measurement consists of a detectable odor after the odorous air has been diluted with eight or more volumes of odor free air. NAC 445B.393(3)	
New Jersey	Yes	When I spoke with New Jersey, they said they had odor provisions. However, when I received their fax of the regs. it appears that they limit "air pollution" and include odors within that although odors are not specifically mentioned in the definition. They also sent copy of their penalties for emissions. See attached NJCA § 7:2705.1 and NJSA § 26:2C-19		http://www.state.nj.us/dep/
New York	Yes	No person shall cause or allow emissions of air contaminants to the outdoor atmosphere of such quantity, characteristic or duration which are injurious to human, plant or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life or property. Notwithstanding the existence of specific air quality standards or emission limits, this prohibition applies, but is not limited to any particulate, fume, gas, mist, odor, smoke vapor, pollen, toxic or deleterious emission, either alone or in combination with others. §211.2 Notwithstanding the existence of specific standards, emissions of odorous, toxic, or deleterious substance in concentrations or of such duration that will affect human health or well-being, or unreasonably interfere with the enjoyment of property, or unreasonably and adversely affect plant or animal life shall not be permitted. §257-1.4(b)		http://unix2.nysed.gov/ils/executive/encon/encon.htm
North Carolina	Yes	15A NCAC §2D.0522. A person shall not cause, allow, or permit any plant to be operated without employing suitable measures for the control of odorous emissions including wet scrubbers, incinerators, or other devices approved by the commission. NC also adopted temporary odor rules for animal operations. Public hearing will be summer or 1999 and effective July 1, 2000. Temp. rule specifies "applicable management practices for the control of odors" 15A NCAC 2D.1802(c) and requires a "best management plan for animal operations" 15A NCAC 2D.1803. Exemptions are provided for at 2D.0102.	May consider: 1) nature, intensity, frequency, pervasiveness..., and duration; 2) potential to emit known odor causing compounds... 3) any epidemiological studies... 4) any other evidence, including complaints...	http://www.ehnr.state.nc.us/EHNR
North Dakota	Yes	No person may discharge into the ambient air any objectionable odorous air contaminant which is in excess of 2 odor concentration units. N.D. Admin. Code §33-15-16-02. H2S is restricted re: objectionable odors. Two samples with concentrations greater than 0.05 part per million (50 parts per billion)sampled at least fifteen minutes apart within a sixty minute period the measured in accordance with section 33-15-16-04 constitute a violation. § 33-15-15-02.1.	Barnebey-Cheney Scentometer or other instrumental method as approve by the Dept. An odor is objectionable when a Dept. certified inspector	http://www.health.state.nd.us/ndhd/environ/ee/index.htm

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
			or at least 30% of a random group of people, or an odor panel deem it objectionable if the odor were present in their place of residence.	
Oregon	Yes	They have several sections concerning odor regs. Wastes req. special management/agric. waste--must be disposed of so as not to create odors...§ 340-093-0190(1)(a). Incidental control practices for CAFO's--app. of manure...should be done when air movements is least likely to carry objectionable odors to residential or recreational areas § 340-051-0075. Solid waste, storage and collection §340-093-0210(5)(b). Several others sections define "air contaminant" as including "odor," §§304-028-0110- Stationary source air poll. and 340-021-0005--gen. emission standards for particulate matter.		http://www.deq.state.or.us/od/rules/statrule.htm
Pennsylvania	Yes	25 §123.31 - Malodorous air contaminants cannot be detectable outside the property... Emissions shall be incinerated at a minimum of 1200°F for at least 0.3 second prior to their emission into the outdoor atmosphere. Techniques other than incineration may be used if they are equivalent or better and are approved in writing by the Dept. § 123.31(c) provides an ag. exemption: The prohibition in subsection (b) does not apply to odor emissions arising from the production of agricultural commodities in their unmanufactured state on the premises of the farm operation. § 123.41 - A person may not permit the emission ... in such a manner that the opacity of the emission is either of the following: 1) Equal to or greater than 20% for a period or period aggregating more than 3 minutes in any 1 hour. 2) Equal to or greater than 60% at any time. The proposed amendments have received public comment and changes are being made to the draft. However, revised draft is still an internal documents and not available to the public yet.	Olfactory sense of dept. personnel. They have proposed amendments to change certain things such as not having to prove public nuisance, changing some definitions, make it more tech. based, i.e. if a co. has implemented current tech. to control odor they have a 5-year grace period before being review/asked to do more.	http://www.dep.state.pa.us/
Rhode Island	Yes	No person shall emit or cause to be emitted into the atmosphere any air contaminant or combination of air contaminants which creates an objectionable odor beyond the property line of said person. Rule 17.	A staff member of Div. of Air Res. shall determine by personnel observation if an odor is objectionable, taking into account its nature, concentration, location, duration and source.	http://www.health.state.ri.us/yhd08.htm
Texas	Yes	Texas said they do have an odor reg. but what they faxed was a nuisance reg. which provides: No person shall discharge from any source whatsoever one or more air contaminants or combinations thereof, in such concentration and of such duration as are or may tend to be injurious to or to adversely affect human health or welfare, animal life, vegetation or property, or as to interfere with the normal use and enjoyment of		http://www.sos.state.tx.us/tac/30/1/index.html

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
		animal life, vegetation, or property. § 101.4. Under their location standards for domestic wastewater treatment facilities they define "nuisance odor prevention" as: the reduction, treatment, and disposal of potential odor conditions that interfere with another's use and enjoyment of property that are caused by or generated from a wastewater treatment plant unit, which conditions cannot be prevented by normal operation and maintenance procedures of the wastewater treatment unit. § 309.11(6). Texas also adopted new "CAFO" rules in Aug. 1998. The buffer zone was increased to at least one-half mile from any occupied residence, business, school, public park, or church, unless the intervening landowner gives approval. In the alternative, new operations can be sited with at least a quarter-mile buffer if the owner develops and implements an odor control plan to minimize air contaminants. See 8-19-98 press release.		
Vermont	Yes	A person shall not discharge, cause, suffer, allow, or permit any emissions of objectionable odors beyond the property line of a premises. Subchapter II § 5-241(3). Vermont also has regs. for control of odor from industrial processes at Subchapter II § 5-241(3).	Vermont does not have rules concerning method. After a complaint, they go out and if there is an odor, they will try to determine the source and work it out.	http://www.anr.state.vt.us/dec/air/
Virginia	Yes	The rule applies to each facility that emits odor but does not apply to accidental or other infrequent emissions of odors. Pt. IV, Rule 4-2, § 120-04-0201. The board directs an investigation and the board may, at its discretion, hold a public hearing to hear complaints. Upon violation, the board approves measures for the economically and technologically feasible control of odorous emissions. § 120-04-0204	The investigation may include the use of an odor panel survey and/or other methods approved by the board.	http://legis.state.va.us/codecomm/codhome.htm
Washington	Yes	Under Washington's General Standards for Maximum Emissions there is an Odor section: Any person who shall cause or allow the generation of any odor from any source which may unreasonably interfere with any other property owner's use and enjoyment of his property must use recognized good practice and procedures to reduce these odors to a reasonable minimum. WAC § 173-400-040(4).		http://www.wa.gov/dnr/
West Virginia	Yes	No person shall cause, suffer, allow or permit the discharge of air pollutants that cause or contribute to an objectionable odor at any location occupied by the public. § 45-4-3(3.1). "Odor" means a sensation resulting from stimulation of the human sense of smell, § 45-4-2(2.5). Variance--An acceptable control program shall be developed and presented to the Director... After approval, but the issuance of a variance, the person responsible... shall not be considered to be in violation of this rule. § 45-4-6(6.1). There is also a section on emergency circumstances - § 45-4-6(6.2) and exemptions for "internal combustion engines" and ag. operations - §45-4-7. West Virginia also has a draft of proposed amendments that they won't release just yet. It has a little more teeth, more options re: monitoring and enforcement but industry had input into it so not as tough as they would have liked to seen.	Barnebey-Cheney Scentomoeter or any other instrument, device, or technique designated by the Director.	http://www.wvweb.com/www/travel recreation/fishing/fishing.html

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
Wisconsin	Yes	No person may cause, allow or permit emission into the ambient air of any substance or combination of substances in such quantities that an objectionable odor is determined to result unless preventative measures satisfactory to the department are taken to abate or control such emission. NR 429.03(1). Tests: Decision resulting from investigation by the department, based upon the nature, intensity, frequency, and duration of the odor as well as the type of area involved and other pertinent factors OR when 60% of a random sample of persons exposed to the odor in their place of residence or employment, other than employment at the odor source, claim it to be objectionable and the nature, intensity, frequency and duration of the odor are considered. Wisconsin also sent a copy of a survey they use entitled: "Odors in Your Community."	An odor shall be deemed objectionable when either or both of two tests are met. (See description to the left.)	http://www.dnr.state.wi.us/
Wyoming	Yes	Odor emission at the property line is limited being undetectable at 7 dilutions with odor free air. Two measurements shall be taken within a 1 hour period, separated by at least 15 minutes. Reduction of animal matter gases etc. shall be incinerated at a temp. of not less than 1200°F for a period not less than 0.3 second, or processed by condensation or such manner as determined by the Division. Also regulates how odor producing materials are stored, transported, and handled. Section 16.	Barnebey-Cheney Scentometer or any other instrument, device, or technique designated by the Division as producing equivalent results.	http://www.dnr.state.wi.us/

QUANTIFY EMISSIONS AND ENVIRONMENTAL IMPACTS AS FUNCTION OF SPECIES, SIZE, AND MANAGEMENT (QUESTIONS 1 AND 3)

INTRODUCTION

Airborne emissions from animal production sytems can be defined as gases, dust, and microbes, which are released into the ambient air surrounding the facility over some period of time. The quantity and mix of compounds emitted is a function of several factors but primarily animal species and facility design. Emission values are reported in terms of the amount of compound emitted per time on a per animal or per area basis. Unfortunately, most of the research to date has focused on the concentrations of compounds within buildings due to health concerns for both animals and those working in the barns. Considerably less effort has been devoted to quantifying these emissions and measuring concentrations of these same compounds in ambient air. The following section will present information in the following areas:

- management factors that affect gas, odor, and dust emissions
- detection and emission of gases from livestock buildings or manure storages
- dust and bioaerosol emissions
- fly and insect populations

EFFECT OF FACILITIES DESIGN AND MANAGEMENT ON EMISSIONS

Animal production and waste handling and treatment facilities should be planned as an integral system that reduces environmental impacts while promoting animal health and performance and worker safety. It is well known that direction of prevailing winds, the number and species of animals, the type and size of manure storage, the type of feed used, the distance to neighbors and farm residence, topography and presence of natural windbreaks, affect what is emitted or how these emissions impact the surrounding area.

It has been shown that odor and gaseous emissions from buildings are increased if the walls and floors are constantly covered with layers of feces and urine (e.g. (Voermans and others 1995; Aarnink and others 1997)). Voermans et al. (Voermans and others 1995) described the effect of pen design and climate control on the emissions of ammonia from pig houses. Design modifications are based on lowering the emitting surfaces, frequent removal of slurry from the houses, movement of slurry through slats, temperature control and ventilation rates. Emitting surfaces under the slats are reduced by sloped plates, gutters and narrow channels. Reductions in ammonia emission from new buildings varied from 30 to 70% as compared to conventional buildings. As stated by Verdoes and Ogink (Verdoes and Ogink 1997), more research is needed in order to identify how different factors (environmental conditions, feed, pen design, manure handling and management) influence both odor and gaseous emissions from barns.

In the United States, hoop structures with straw bedding are being considered as an alternative to large-scale confinement structures for swine production (Brumm and others 1997). On deep litter systems (15 lb straw/pig-day), ammonia emission is comparable with emission from a fully slatted floor barn (Valli and others 1994). Emissions can be kept at low levels by increasing the amount of straw or by allowing partial urine drainage. However, emissions of air polluting nitrogen gases in deep litter systems tend to be higher due to the formation of N_2O which contributes to the greenhouse effect and affects the ozone layer (Voorburg 1994; Groenestein and Faassen 1996).

The first measurements of odor and ammonia emissions in housing systems for layers were carried out by Dutch researchers in 1985 (Klarenbeek 1985). They concluded that odor emission from systems with dried manure was between 20 and 35% of the odor emission when manure was stored as slurry.

Ammonia emissions from housing systems for laying hens with litter were four times higher than with battery cages

Flooring design has been shown to significantly affect the airborne dust levels; solid floors have much higher levels than open-mesh floors (Carpenter and Fryer 1990; Dawson 1990). The latter allow feces and soiled bedding to fall below the floor level and minimize dust generated by animal activities.

Summary

The effect of animal facility design and management can have a major impact on all types of emissions. Specific research that has investigated these factors has generally determined large variations in airborne emissions of contaminants like ammonia or dust. Unfortunately, all of the management factors contributing to these changes in emissions are not well understood or documented.

GASEOUS EMISSIONS

Animal housing and manure handling systems generate a variety of gases. Most of the research conducted to date has not quantified these emission but rather documented the generation of these gases. Kreis (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 (O'Neill and Phillips 1992) compiled a list of 168 different compounds identified in swine and poultry wastes (Table 5). Unfortunately, without emission data it is difficult to determine the real impact these gases have on human health or the environment since it is both the dose and duration of these chemicals that can cause the problems.

Only three of these gases have been studied in detail, quantifying emissions and documenting environmental concerns or human health problems. These include hydrogen sulfide, ammonia, and methane. Other gases, such as oxides of nitrogen and volatile fatty acids, are currently being studied in greater detail because of their potential impact on global warming or their contribution to odor.

Table 5. Listing of volatile organic compounds and gases identified in livestock wastes. Adapted from (O'Neill and Phillips 1992).

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	Carboxylic Acids					
1	formic acid methanoic acid	2-640	2	1	0	0
2	acetic acid ethanoic acid	0.025-10	13	4	0	0
3	propionic acid propanoic acid	0.003-0.89	13	4	0	0
4	n-butyric acid butanoic acid	0.0004-42	12	3	0	0
5	i-butyric acid 2-methylpropanoic acid	0.005-0.33	12	3	0	0
6	n-valeric acid pentanoic acid	0.0008-0.12	9	3	0	0
7	i-valeric acid 3-methylbutanoic acid	0.0002-0.0069	8	0	0	0
8	2-methylbutanoic acid	0.02	1	0	0	0
9	2-methyl-2-butenoic acid (angelic acid)	-	1	0	0	0
10	n-caproic acid hexanoic acid	0.02-0.52	5	0	0	0
11	i-caproic acid 4-methylpentanoic acid	0.037	5	0	0	0
12	2-methylpentanoic acid	-	1	0	0	0
13	oenanthic acid heptanoic acid	0.022-0.033	5	0	0	0
14	caprylic acid octanoic acid	0.0003[r]-0.6	4	0	0	0
15	pelargonic acid nonanoic acid	0.0016[r]-0.12	4	0	0	0
16	capric acid decanoic acid	0.05	1	0	0	0
17	hendecanoic acid undecanoic acid	-	1	0	0	0
18	lauric acid dodecanoic acid	0.004[r]-0.005[r]	2	0	0	0
19	tredecanoic acid	-	1	0	0	0
20	myristic acid tetradecanoic acid	-	1	0	0	0
21	benzoic acid benzenecarboxylic acid	-	5	0	0	0
22	penylacetic acid phenylethanoic acid α-toluic acid	0.00003	4	0	0	0
23	3-phenylpropionic acid 3-phenylpropanoic acid hydrocinnamic acid	-	4	0	0	0
	Alcohols					
24	methanol methylalcohol	4-7,800	3	0	0	0
25	ethanol	0.64-1,350	4	0	0	0

	Compound (names)	Odour detection threshold (mg/m³) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	ethyl alcohol					
26	n-propyl alcohol 1-propanol	0.075-140	4	0	0	0
27	i-propyl alcohol 2-propanol	3.9-5,400	4	0	0	0
28	n-butyl alcohol 1-butanol	0.158-42	5	0	0	0
29	sec-butyl alcohol 2-butanol	0.4-80	1	0	0	0
30	isobutyl alcohol 2-methyl-1-propanol	0.036-500	4	0	0	0
31	pentanol n-amyl alcohol	0.4-35	2	0	0	0
32	i-pentanol 3-methylbutanol iso-amyl alcohol	0.08-0.1	4	0	0	0
33	1-hexanol n-hexyl alcohol	0.04-1.93	1	1	0	0
34	hex-3-ene-1-ol	-	0	1	0	0
35	2-methyl-2-pentanol, demethyl-n-propyl-carbinol	-	1	0	0	0
36	1-heptanol	0.05-2.4	1	1	0	0
37	iso-heptanol	-	1	0	0	0
38	3-octanol amylethyl alcohol	-	1	0	0	0
39	2-ethylhexanol	0.4	1	0	0	0
40	2-methoxyethanol methyl cellosolve methyl glycol	0.3-190	1	0	0	0
41	2-ethoxy-1-propanol	-	3	0	0	0
42	2,3-butanediol	-	2	0	0	0
43	benzyl alcohol α-hydroxytoluene	-	0	1	0	0
44	α-methylbenzyl alcohol	-	0	1	0	0
45	4-methylcyclohexanol	-	1	0	0	0
46	2-penylethanol	0.00035	1	0	0	0
	Phenolics					
47	penol carbolic acid benzenol hydroxybenzene	0.022-4	14	3	0	0
48	p-cresol 4-hydroxytoluene 4-methylphenol	0.00005-0.024	16	4	0	0
49	m-cresol 3-hydroxytoluene 3-methylphenol	0.00022-0.035[a]	2	1	0	0
50	o-cresol 2-hydroxytoluene 2-mthylphenol	0.0004	1	0	0	0
51	p-methoxyphenol 4-methoxyphenol hydroquinone mono-	-	1	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	methylether					
52	o-methoxyphenol 2-methoxyphenol guaiacol	0.0037-0.64	1	0	0	0
53	p-ethylphenol 4-ethylphenol 1-ethyl-4-hydroxybenzene	-	9	1	0	0
54	m-ethylphenol 3-ethylphenol 1-ethyl-3-hydroxybenzene	-	1	0	0	0
55	o-ethylphenol 2-ethylphenol 1-ethyl-2-hydroxybenzene phlorol	-	1	0	0	0
56	2,6-dimethyl phenol 1,3-diethyl- 2-hydroxybenzene	0.0002	0	1	0	0
57	3,4-dimethylphenol 1,3-dimethyl- 5-hydroxybenzene	0.003	0	1	0	0
58	3-hydroxy-2-methyl- 4-pyrone lanxinic acid maltol	-	0	1	0	0
	Aldehydes					
59	formaldehyde methanal	0.033[r]-12,000	3	0	0	0
60	acetaldehyde ethanal	0.0027-1	4	1	0	0
61	propionaldehyde propanal	0.0036-0.69	4	0	0	0
62	acrolein 2-propenal acrylaldehyde	0.069	2	1	0	0
63	butyraldehyde butanal	0.00084-0.2	2	1	0	0
64	iso-butyraldehyde 2-methyl propanal	0.015-0.14	5	1	0	0
65	crotonaldehyde 2-butenal	1.7	1	1	0	0
66	valeraldehyde pentanal	0.0025-0.034	4	1	0	0
67	iso-valeraldehyde 3-methylbutanal	0.0016	0	1	0	0
68	2-pentenal	-	1	0	0	0
69	caproaldehyde hexanal	0.028-0.067	7	0	0	0
70	2-hexenal	0.034[a]-0.63	1	0	0	0
71	oenanthaldehyde heptanal	0.006-0.26	5	0	0	0
72	2-heptenal	0.034[a]-0.25	2	0	0	0
73	2,3-heptadienal	-	2	0	0	0
74	caprylaldehyde octanal	0.0078	3	0	0	0
75	pelargonaldehyde	0.0003[a]-0.045	2	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	nonanal					
76	2-nonenal	0.0005[a]-0.0036	1	0	0	0
77	2,4-nonadienal	0.00025[a]-0.0004	2	0	0	0
78	capraldehyde decanal decylaldehyde	0.00025[a]	3	0	0	0
79	2,4-decadienal	0.00018[a]	2	0	0	0
80	benzaldehyde benzenecarbonal	0.18-3,400	5	0	0	0
81	acetone dimethylketone (2-)propanone	0.94[a]-1,550	4	0	0	0
82	diacetyl dimethylglyoxal 2,3-butanedione	0.000007-0.005	4	1	0	0
83	(2-)butanone methylethylketone	0.75[a]-250	4	0	1	0
84	acetoin 3-hydroxy-2-butanone	-	4	1	0	0
85	3-pentanone diethylketone propione	3-33	4	0	0	0
86	cyclopentanone adipic ketone	31-1120	1	0	0	0
87	2-methyl cyclopentanone	-	0	1	0	0
88	2-octanone hexylmethylketone	0.06[r]-0.78	4	1	0	0
89	amylvinylketone 1-octene-3-one	0.0001[a]	3	0	0	0
90	acetophenone acetylbenzene methylphenylketone	0.01[a]-1.5	4	0	0	0
	Esters					
91	methylformate formic acid methyl ester	165[r]-5,000	1	0	0	0
92	methylacetate acetic acid methyl ester	0.5[a]-550	2	0	0	0
93	elthylformate formic acid ethyl ester	54[r]-61[r]	1	0	0	0
94	ethyl acetate acetic acid ethyl ester	0.6[a]-180	1	0	0	0
95	propylacetate acetic acid propyl ester	0.2-70	2	0	0	0
96	i-propylacetate acetic acid isopropyl ester	1.9-140	1	0	0	0
97	butylacetate acetic acid butyl ester	0.03-1750	2	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
98	i-butylacetate acetic acid isobutyl ester	1.7-17	1	0	0	0
99	i-propylpropionate propanoic acid iso-propyl ester	-	1	0	0	0
	Nitrogen heterocycles					
100	indole 1-benzopyrrole	0.0006-0.0071	11	4	0	0
101	skatole 3-methylindole	0.00035-0.00078	13	4	0	0
102	pyridine azine	0.04-40	1	0	0	0
103	3-aminopyridine	-	2	0	0	0
104	(2)-methylpyrazine	-	1	0	0	0
105	methylpyrazine	-	1	0	0	0
106	trimethylpyrazine	-	1	0	0	0
107	tetramethylpyrazine	-	1	0	0	0
	Amines		1	1	0	0
108	methylamine aminomethane	0.0012-6.1	3	0	0	0
109	ethylamine aminoethane	0.05-0.5	3	0	0	0
110	n-propylamine aminopropane	0.022[a]	1	0	0	0
111	i-propylamine amino iso-propane	0.5	2	0	0	0
112	pentylamine 1-aminopentane amylamine	-	1	0	0	0
113	trimethylamine	0.00026-2.1	3	0	0	0
114	triethylamine	0.33[a]	4	0	0	0
	Sulphides		1	1	0	0
115	carbon disulphinde	0.05[a]-0.1	0	0	2	0
116	carbonylsulphide carbon oxysulphide	0.25[a]	2	0	2	0
117	dimethylsulphide methylthiomethane	0.0003-0.16	7	3	2	1
118	diethylsulphide ethylthioethane	0.0014-0.0045	2	0	1	0
119	dimethyldisulphide methyldithiomethane	0.0011-0.046	6	2	2	1
120	dimethltrisulphide methyldithiomethane 2,3,4-trithiapentane	0.0073[r]	4	1	1	0
121	diethyldisulphide ethyldithioethane	0.0003	1	0	0	0
122	dipropyldisulphide propyldithiopropane	0.13	1	0	0	0
123	methylpropyldisulphide methyldithiopropane	-	0	0	1	0
124	propylporop-1-enyl disulphide	-	1	0	0	0
125	diphenylsulphide	0.0026[a]	1	1	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	phenylthiobenzene					
126	3,5-dimethyl-1,2,4-trithiolane	-	0	1	0	0
127	3-methyl-5-propyl-1,2,4-trithiolane	-	0	1	0	0
128	3,6-dimethyltetra-thiane	-	0	1	0	0
129	2,6-dimethylthi-3-inc-carbonaldehyde	-	0	1	0	0
	Thiols (mercaptans)		2	0	0	0
130	methanethiol methyl mercaptan	0.0000003-0.038	7	2	2	1
131	ethanethiol ethylmercaptan	0.000043-0.00033	3	0	0	0
132	propanethiol n-propylmercaptan	0.0016[a]	1	1	1	0
133	2-propanethiol isopropylmercaptan	0.0000025-0.00002	0	1	0	0
134	2-propene-1-thiol allylmercaptan	0.000005-0.00004	1	0	0	0
135	butanethiol n-butylmercaptan	0.0015-0.003	1	0	0	0
136	2-butene-1-thiol crotylmercaptan	0.00043-0.0014	1	0	0	0
137	benzenethiol thiophenol	0.00014	1	0	0	0
138	α-toluenethiol benzylmercaptan	0.013[a]	1	0	0	0
	Unclassified					
139	carbon dioxide	odourless	5	1	0	0
140	hydrogen sulphide	0.0001-0.27	11	3	1	1
141	ammonia	0.03[a]-37.8	12	3	0	0
142	sulphur dioxide	0.87[a]-10	1	0	0	0
143	methane	odourless	3	0	0	0
144	pentane	350[a]	0	0	1	0
145	2-methylpentane	-	0	0	1	0
146	hexane	230[a]	1	0	1	0
147	hexene	-	0	0	1	0
148	heptane	750-930	0	0	1	0
149	octane	71[a]-710	0	0	1	0
150	octene	0.33[a]	1	0	0	0
151	undecene hendecene	-	0	0	1	0
152	dodecane	37[a]-50	0	1	1	0
153	benzene	1.5-380	1	0	1	0
154	toluene	0.08[a]-140	4	0	1	0
155	xylene dimethylbenzene (isomer not specified)	0.35-86	3	0	0	0
156	indane hydrindene	-	3	0	0	0
157	naphthalene	0.2	1	0	0	0
158	methylnaphthalene	-	3	0	0	0
159	chloroform trichloromethane	3-3,000	1	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
160	tetrachloroethane perchloroethylene	12-320	0	1	0	0
161	hydrazine	3.9-5.2[a]	1	0	0	0
162	2-methylfuran sylvan	-	1	0	0	0
163	2-pentylfuran	-	1	0	0	0
164	2-methylthiophene 2-methylthiofuran	-	1	0	0	0
165	2,4-dimethylthiophene 2,4-thioxene	-	1	0	0	0
166	diethylether ether ethoxyethane	0.75-35	1	0	0	0
167	limonene citrene carvene	0.01[a]	0	1	0	0
168	ocimene	-	0	0	1	0

Note r: value for recognition threshold is given when there is a published value of it lower than the published detection threshold.

Note a: tables do not specify whether the value is for detection or recognition.

Hydrogen Sulfide (H_2S)

H_2S gas is colorless, heavier than air, highly soluble in water and has the characteristic odor of rotten eggs. However, the odor of H_2S can be deceiving. The odor is first detected by most people at concentrations below 1 ppm by volume. Above 6 ppm, the odor will only increase slightly although the concentration of H_2S increases significantly; at 150 ppm, the gas can have a deadening effect on the sense of smell making detection difficult. Taiganides and White (Taiganides and White 1969) determined that H_2S was produced from the putrefaction of pig manure and found that the minimum concentration for identifiable H_2S odor was 0.7 ppm. High concentrations of H_2S are toxic to humans and animals (Hartung 1988). A concentration of 50 ppm can cause dizziness, irritation of the respiratory tract, nausea, and headache. Death from respiratory paralysis can occur with little or no warning in concentrations exceeding 1,000 ppm (Field 1980). No environmental problems associated with hydrogen sulfide emissions have been documented.

H_2S is usually very low in animal houses compared with NH_3 and CO_2. It was measured at 90 ppb in a normally ventilated confinement building and 280 ppb after the ventilation was shut off for six hours (Muehling 1970). Avery (Avery and others 1975) found that the H_2S production in swine confinement units was highly correlated with several factors, i.e., the average outside air temperature, the ratio of pit area to building volume, the air retention time for the building, and the daily sulfur intake. Shurson (Shurson and others 1998) showed a reduction in hydrogen sulfide emissions from nursery pigs fed a low sulfur diet as compared to a traditional diet. Donham (Donham 1985) documented a positive, but not significant, correlation between water sulfate levels (in the drinking and cleaning water) and the sulfide content in swine manure. Also noted was a slightly positive relationship between total sulfides in manure and the hydrogen sulfide concentration in the building exhaust air. Research by Jacobson (Jacobson and others 1997) could not determine a correlation between hydrogen sulfide concentrations in the air immediately above manure storages to total sulfur content of feed or water sulfate levels. Since the process of converting elemental sulfur or sulfate to sulfide is a biological process, hydrogen sulfide production will most likely be more dependent on manure slurry temperature, pH, and storage time.

Clark and McQuitty (Clark and McQuitty 1987) investigated air quality in six Alberta commercial free-stall dairy barns. They measured H_2S in four of the six barns and concluded that the concentrations of H_2S were low (the maximum recorded value was only 145 ppb), and the possibility of detecting more than trace concentration of H_2S was remote where manure was removed from free-stall dairy units with solid passageways. With respect to poultry layer facilities, McQuitty et al. (McQuitty and others 1985) conducted an air quality survey in three commercial poultry laying barns under winter conditions. They reported that there were no detectable traces of H_2S found in two of the three barns at any time during the study, while the maximum ambient concentration of H_2S in the third barn was 30 ppb.

Significant quantities of hydrogen sulfide can be released during agitation of stored liquid manure. The most extensive documentation of this well known phenomenon is presented by Patni et al. (Patni and Clarke 1991). This research measured peak hydrogen sulfide concentrations near the floor of a dairy barn during agitation at 70 ppm. Peak hydrogen sulfide concentrations in a deep pitted swine barn were 100 ppm and concentrations as high as 220 ppm were documented in the exhaust air from the pit fan.

Table 6. Variation in hydrogen sulfide emissions over a 12 hour measurement period

Time of day	Emissions µg/s/m2						
	dairy freestall N.V.	swine finishing M.V.	swine ges. M.V.	swine farrowing M.V.	swine finishing N.V.	swine nursery M.V.	poultry broiler M.V.
7am	0.4	5.6	0.4	8.8	5.1	20.7	0.1
9am	0.5	8.6	0.9	6.2	8.0	139.5	0.2
11am	0.3	4.9	0.7	7.1	6.2	41.4	0.2
1pm	0.2	8.0	0.8	5.8	9.8	27.6	0.2
3pm	0.9	7.1	0.7	3.9	13.0	27.5	0.1
5pm	0.3	8.9	0.9	3.6	5.9	34.4	0.1
7pm	0.6	6.4	0.7	3.1	5.6	29.0	0.3
Average	0.4	7.1	0.7	5.5	7.7	45.7	0.2

M.V. Mechanically ventilated
N.V. Naturally ventilated

The emission rate of H_2S from animal buildings has not been extensively studied by past researchers. Heber et al. (Heber and others 1997) reported that a mean emission rate of 0.00033 lb/day/pig place was observed from a 1000-head naturally ventilated swine-finishing house while Hobbs et al. (Hobbs and others 1999) showed documented H_2S emission rate from the open surface of liquid manure storage facilities was about 0.02 lb/ft^2/day (a deep pitted finishing barn has about 8 ft^2 per pig indicating H_2S emissions of 0.16 lb/day/pig place). Ni, et al. (1998) found that during 3 months (June to Sept.) a deep-pitted swine finishing barn emitted about 0.0015 lb/day/pig place. Zhu (Zhu and others 1998) reported hydrogen sulfide emissions from seven different facilities over a 12 hour period (Table 6). Emissions comparisons can be made for swine finishing buildings if a area per pig place is assumed. Using a value of 8 ft^2 per pig place for a finishing building, the average hydrogen sulfide emissions for the swine finishing facility is 0.00013 lb/day/pig place. This compares well to the field measurements made by Heber (Heber and others 1997).

In 1998, the Minnesota Pollution Control Agency measured ambient hydrogen sulfide concentrations at the property line of 138 different livestock facilities using a Jerome® Meter (Minnesota Pollution Control Agency 1999). Of the 500, 30-minute average, samples taken, 24 farms had at least one measurement exceeding the 30 ppb regulatory threshold. Four of these 24 farms were monitored continuously for several weeks using a Total Reduced Sulfur (TRS) monitor. During the period of continuous monitoring, only one of the facilities exceeded the 30 ppb standard.

Ammonia (NH_3)

Urine is the primary source of ammonia (NH_3) and is released during manure storage and decomposition. NH_3 gas is an irritant, colorless, lighter than air, and highly water soluble. It has a sharp pungent odor becoming detectable at levels as low as 5 ppm. Typical NH_3 levels in well ventilated confinement buildings are 5 to 10 ppm with liquid manure systems and 10 to 20 ppm where manure and urine are deposited on solid floors, especially poultry units. Levels can exceed 25 ppm with lower winter ventilation rates and reach 40 ppm in poorly ventilated buildings. Very high levels of NH_3 concentrations, such as 2500 ppm may even be fatal. In many countries, the threshold limit is 25 ppm (time weighted) for an eight hour working day for staff and for the living environment for livestock.

Large quantities of NH_3 emit from animal production facilities each year. Agricultural sources, and livestock farming in particular, are the largest contributors to NH_3 emissions (Groot Koerkamp and others 1998). For example, about 85% of the total NH_3 emission in The Netherlands originates from livestock farming. NH_3 from livestock husbandry emanates from buildings, slurry and manure stores, pastures (grazing), and during manure application, e.g., slurry spreading. Among these sources, livestock housing and manure storage tanks contributed about 40 to 60% of the total emissions.

Table 7. Influence of housing type on ammonia emissions.

Species	Management	Ammonia	Units	Author
Pig	not specified	1.5	kg/pig/yr	Clark and McQuitty (1987)
	Fully slatted	24.0	lb/1000 lbwt/yr	Hartung (1994)
	partly slatted	43.4	lb/1000 lbwt/yr	Hartung (1994)
	Liquid	15.0	lb/1000 lbwt/yr	Hartung (1994)
	Bedding	3.4	lb/1000 lbwt/yr	Hartung (1994)
	fully slatted	13	lb/1000 pigs/day	Heber (1997)
	lagoon	10.5, 6.2, 4.9	kg/ha/day	Harper (1998)
	sows, litter	744-3248	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	sows, slats	1049-1701	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	weaners, slats	649-1562	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	finish, litter	1429-3751	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	finish, litter	2076-2592	mg/500 kg/hr	Groot Koerkamp et al. (1998)
Layer	layer, deep litter	7392-10892	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	layer, battery	602-9316	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	Battery cages, basement storage	83	g/bird/yr	Hartung (1994)
	Battery cages, belts	34	g/bird/yr	Hartung (1994)
	Battery cages, belts and drying	31	g/bird/yr	Hartung (1994)
Broiler	broiler	2208-8294	mg/500 kg/hr	Groot Koerkamp et al. (1998)
Cattle	litter	371-900	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	slats	346-686	mg/500 kg/hr	Groot Koerkamp et al. (1998)
Dairy	Freestall	7-13	g/LU/day	Junbluth (1997)
	litter	260-890	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	cubicles	843-1769	mg/500 kg/hr	Groot Koerkamp et al. (1998)

Meyer and Bundy (1991) surveyed 200 swine-farrowing houses and found the average NH_3 concentration was 11.4 ppm from December to February and 6.9 ppm from March to May. Collins (1990) observed a 1000-sow swine complex to determine atmospheric NH_3 levels. He found the total annual discharge of the NH_3 was about 67,500 kg (144,400 lb), or about 0.40 lb/sow place/day. Ni et al. (1998) measured NH3 emissions from a 1000 pig finishing barn from June to September (3 months) and found an average rate of 0.028 lb/pig place/day. Clark and McQuitty (1987) studied the air quality in six Alberta commercial free-stall dairy barns and found that the NH_3 was present in all six barns and the overall mean values ranged from 7 to 20 ppm. The overall mean NH_3 production rates ranged from 1.7 to 4.4 L/(hour-cow (500 kg)). According to the research conducted by McQuitty et al. (1985) in three commercial poultry laying barns under winter conditions, the daily average of NH_3 in the exhaust air was 33 ppm.

Table 7 lists various ammonia emissions from several researchers. Unfortunately most of the research has been conducted in Europe where the facility design and management are different from that found in the United States.

NH_3 is attributed to the effects of acidification on the environment. NH_3 and chemical combinations (NH_x) are important components responsible for acidification in addition to sulfur compounds (SO_x), nitrogen oxides, and volatile organic components (Groot Koerkamp 1994).

NH_3 may cause several ecological problems in the environment. First, the inputs of nitrogen may lead to considerable changes in plant communities with the result that plants which prefer low nitrogen soils disappear and there is an increase in nitrogen indicator plants (Ellenberg 1988). Second, acidification of soil with low buffer capacity may occur after nitrification of the nitrogen added. A falling pH leads to the dissolution of toxic soil constituents such as aluminum ions, and to the leaching of nutrients and aluminum into the groundwater (Van Breemen and others 1982; Roelofs and others 1985; Speirs and Frost 1987). Third, the natural capability of forest soil to take up methane (CH_4) decreases by NH_3 deposition, thus increasing the concentration of the greenhouse gas in the atmosphere (Steudler and others 1989). Fourth, surface waters may be affected by eutrophication and acidification (Dillon and Molot 1989). Finally, NH_3 depositions on buildings will promote bacterial growth, which contributes substantially to weathering and corrosion damage of the buildings (Spiek and others 1990).

A European study shows the annual maximum amounts of nitrogen that can be taken up by natural habitats without any signs of adverse effects (called “critical loads”). These critical loads are 4.5 to 17.8 lb/acre for deciduous forest, 2.7 to 13.4 lb/acre for coniferous forest, 2.7 to 4.5 lb/acre for low vegetation, 2.7 to 8.9 lb/acre for grassland, and 2.7 to 4.5 lb/acre for moorland (Schneider and Bresser 1988). Therefore, the consequences of NH_3 emission are primarily of an ecological nature and must be considered on a long-term basis in terms of minimizing the environmental damage caused by NH_3 emission from agricultural production.

Methane (CH_4)

Methane is a nontoxic and odorless gas. Methane is very effective at absorbing infrared radiation, approximately 70 times as much as carbon dioxide. As such, methane’s contribution to global warming is believed to be second only to carbon dioxide (Safley and Casada 1992). Methane is emitted from both natural and man-made sources, including animal agriculture. Safley (Safley and Casada 1992) estimates a global emission rates of methane at 540×10^9 kilograms per year with 5% of the emissions resulting from the anaerobic decomposition of animal manure and another 15% coming from the gut of ruminant animals. Table 8 lists the estimated contribution per animal from cattle, pigs and poultry. These estimates were made on manure production and management practices on a global scale, and are therefore, only crude estimates of production per animal.

Limited research is available on the actual emission rates of methane. The methane emission estimates used by Safley were based on standard methane conversion factors (MCF). These MCF’s are based on manure handling method, temperature and the amount of volatile solids excreted by the animal. Steed and Hashimoto (Steed and Hashimoto 1994) conducted a laboratory experiment to verify the estimated MCF values used by Safley for dairy cows (Table 9). This research gives some indication of the effect of manure management on methane production. As was expected, the MCF was less for the dryer, more aerobic systems, e.g. feedlots and pasture, than for both solid and liquid manure storage systems.

Table 8. Estimated methane emissions from livestock and poultry waste (Safley and Casada 1992)

Animal Type	Methane Emissions (kg/year per animal)
Cattle in feedlots	23
Dairy	70
Swine	20
Caged Layer	0.3
Broiler	0.09
Turkey and ducks	0.16

Table 9. Measured methane emission factors (MCF) for dairy cows.

System Type	MCF estimates by Safley (1992)	MCF measured at 20°C Steed (1994)
Pasture/Feedlot	10	0.3
Liquid slurry	20-90	55.3
Solid	10	45.7

Summary

The emissions from animal production systems include an extensive list (168) of gaseous compounds. The three most researched gases are hydrogen sulfide, ammonia, and methane. H_2S poses the largest safety risk in confined spaces (indoor) and is of concern in the ambient air (outdoor) mainly because of the Minnesota state ambient air standard for this gas. It seems that swine facilities and manure storage units produce the largest concentrations and emissions of H_2S. Ammonia, also is produced by animal production systems, especially poultry facilities. Indoor concentrations of NH_3, poses some health concerns inside buildings but emissions may contribute to ecological damage to the environment. Finally, methane emissions, which are more of a problem with cattle than other animal species, contributes to global warming concerns.

DUST, ENDOTOXINS, AND AIRBORNE MICROORGANISMS

Dust—Composition and Sources

Dusts in and around animal facilities include bits of feed, dried skin, hair or feathers, dried feces, bacteria, fungi, and endotoxins (cell wall of gram-negative bacteria) (Koon and others 1963; Anderson and others 1966; Curtis and others 1975a; Heber and others 1988). Feed was found to be the primary component of the dust (Curtis and others 1975b; Heber and others 1988). Open unpaved feedlots can also be a dust source, which will include soil particles (Alegro and others 1972; Sweeten and others 1998; Sweeten and others 1988). Dust comes from the animals themselves, feed storage and processing sites, floors, manure storage and handling equipment, open lots, compost sites, and other elements of animal agriculture systems.

Table 10. Mean inhalable and respirable dust emission rates from English, Dutch, Danish, and German livestock buildings.

	Mean inhalable dust emission rate (mg/h 500 kg liveweight)	Mean respirable dust emission rate (mg/h 500 kg liveweight)
Cattle Buildings (dairy and beef)		
England	97	31
The Netherlands	143	35
Denmark	128	12
Germany	184	20
Overall mean	145	24
Pig Buildings		
England	633	93
The Netherlands	674	74
Denmark	1102	117
Germany	651	53
Overall mean	762	85
Poultry Buildings		
England	3138	373
The Netherlands	3640	721
Denmark	3509	618
Germany	2118	248
Overall mean	3186	504

Environmental Impact of Agricultural Dust Emissions

Little information is available on the environmental impact of animal agricultural dust emissions. Most dust research deals with human and animal health effects due to indoor dust exposure (Donham and Gustafson 1982; Donham and Leininger 1984; Mulhausen and others 1987; Donham 1990; Nicolai and Janni 1998a). The human and animal health impacts are discussed in the Animal Health and Human Health sections.

Dust emissions contribute to nutrient deposition. Accumulated dust may also affect cleanliness and aesthetics. Dust particles adsorb odorous gases, which can assist odor transport and dispersion (Day and others 1965; Hammond and others 1979). Research also indicates that indoor dust increases equipment deterioration (Gupta and others 1988).

Facility Dust Emissions

There is little research on dust emissions from animal agriculture facilities and their environmental impact in Minnesota or the upper Midwest. Most of the dust information available gives dust concentrations within swine and poultry facilities rather than emissions. The focus of these projects was indoor air quality, dust characterization, and its impact on both human and animal occupants inside the building. Little information is available on dust concentrations in dairy or horse facilities.

Takai et al. (Takai and others 1998) provides the first inhalable and respirable dust emission estimates from various cattle, swine, and poultry facilities in Europe. They reported on an extensive four-country study on aerial emissions from livestock housing facilities. Table 10 summarizes the estimated dust emissions. Emissions were estimated using mean daily dust concentrations near an air outlet and the daily mean ventilating rate (Takai and others 1998).

Inhalable dust was collected using an IOM (Institute of Occupational Medicine, Edinburgh) dust sampler, which represents the dust inhaled through a human's nose and mouth (Mark and Vincent 1986). Respirable dust was measured using a cyclone in series with a filter. The cyclone removes most of the particles with an aerodynamic diameter of 5 microns or more. The remaining respirable dust captured on the filter represents the dust that can penetrate deeply into the respiratory tract and the lungs of humans. Both samplers are commonly used in personal dust sampling.

Statistical analysis indicated that both country and housing type were significantly different for inhalable dust emissions. Inhalable dust emissions from cattle buildings were not affected by season. There were significant seasonal effects on inhalable dust emissions from both the pig and poultry buildings. Percheries (laying hen facilities with litter flooring and perches) in The Netherlands and Denmark and broiler houses in England and The Netherlands had the highest dust emission rates. Animal activity level, stocking density, spilled feed, bedding material selection, and humidity levels affect dust emissions (Takai and others 1998). The significance of country, season and other factors suggests that these results may not accurately describe dust emissions from animal buildings in Minnesota.

Published data on dust emissions from unpaved outdoor cattle feedlots is available from California (Alegro and others 1972) and Texas (Sweeten and others 1988). Emissions depend on soil texture, rainfall, feedlot surface moisture content, wind speed, season, and other factors. The climate and production practices in Minnesota differ from these regions, which means that their emission rates need to be modified for use in Minnesota.

Grain Handling and Processing Dust

There is little data on the everyday emissions of dust from grain handling and processing. Most of the testing is done during peak harvest times to develop worst case design criteria for dust collection devices (Muleski and Garman 1996) or to determine the potential to emit for Federal EPA regulations (Kenkel 1996). Research conducted in Oklahoma (Kenkel 1996) on country elevators determined that emissions were 15 to 35 times lower than EPA published material. Kenkel and Noyes determined an emission rate of 0.0191 lb/ton for the hopper bottom truck and 0.0388 lb/ton for the end-dump truck. They concluded that grain elevators were unlikely to be major sources of air pollution.

Dust from feed is also a concern at the producer level, ranging from a small tub grinder up to the larger feedmills. The dust emissions from these sites are constant throughout the year as the feed is handled and processed on a regular basis. Dust arises from grinding, flaking, mixing, and pelleting of the feed. No substantial research is available documenting emission from these sites.

Vehicle and Traffic Dust

Since the majority of the service and township roads are gravel, dust generated from vehicles traveling over these roads can be considerable. Currently, calcium chloride is spread on these roads in short strips where dust is considered a problem such as, in front of a residence or around animals that could continuously breath the dust.

Microbial and Endotoxin Emissions

Reported airborne concentrations of microbial and endotoxins can be somewhat misleading because of the wide ranges that are reported. For instance, three papers on egg layer housing reported the following airborne microbial concentrations for layers in cages: range of 360 to 3781 Colony Forming Units (CFU's) per liter of air (Hartung 1994); range of 17 to 5860 CFU's per liter of air (Muller 1987); and, range of total bacteria of 290 to 680 CFU's per liter (Clark and Rylander 1983). It is unclear at this time if the actual concentrations are varying that much or the variation is due to the sampling and measurement methods.

Table 11. Mean emission rates of inhalable and respirable endotoxins over 24 h from different animal housing.

Species	Mean inhalable endotoxin emission rate (µg/h per 500 kg liveweight)	Mean respirable endotoxin emission rate (µg/h per 500 kg liveweight)
Cows	2.9	0.3
Beef	3.7	0.6
Calves	21.4	2.7
Sows	37.4	3.7
Weaners (growing pigs)	66.6	8.9
Fattening pigs	49.8	5.2
Layers	538.3	38.7
Broilers	817.4	46.7

µg = micro grams

The most recent research estimated microbial (bacteria and fungi) and endotoxin emissions from cattle, swine and poultry barns in four countries in Europe (Seedorf and others 1998). The emission rates were estimated by using the ventilation rate and the indoor concentration.

In this study total airborne microorganism emissions rates were reported as the logarithm base 10 log of the number of colony forming units (cfu) per hour per 500 kg of live-weight animals housed in the building. The average total airborne microorganism emission rates were approximately 7 log cfu/h ∗ 500 kg live-weight, ranging from 9.5 log cfu/h ∗ 500 kg live-weight from broiler houses to approximately 6.5 log cfu/h ∗ 500 kg live-weight from beef and cow housing (Seedorf and others 1998).

The emission rates of Enterobacteriaceace were much lower. Layers had the highest emission rate at 7.1 log cfu/h ∗ 500 kg live-weight, sows had the lowest emission rate at 6.1 log cfu/h ∗ 500 kg live-weight. Fungi emissions ranged from 7.7 log cfu/h ∗ 500 kg live-weight for broilers to 5.8 log cfu/h ∗ 500 kg for weaners (i.e., grower pigs) (Seedorf and others 1998).

Seedorf et al. (Seedorf and others 1998) noted that data on the biological half-life period of viable microorganisms under varying environmental conditions was needed in order to predict their dispersion and estimate the risk of airborne disease transmission. Local topography, weather, and ventilation system design also affect potential contaminant transmission.

Estimated endotoxin emission rates in the inhalable and respirable dust fractions from different livestock are summarized in Table 11 (Seedorf and others 1998). The data indicates that poultry had the highest endotoxin emission rates while cattle had the lowest, with pigs in between. Seedorf et al. (Seedorf and others 1998) concluded that it was not known whether outdoor human exposure to such endotoxin emissions was hazardous to health.

Summary

Dust and other particulates, like microorganisms and endotoxins, are a real indoor air quality concern for both animals and humans. The emissions of these contaminants from animal production units are much less of a concern although only a limited amount of research has been done to document emissions levels and their impact on the environment and people near these areas. Particulates can transport odor and thus cause some nuisance concerns. It does seem from existing data that poultry units emit the highest levels of dust and endotoxins followed by swine units and cattle facilities in that order.

ODOR EMISSIONS

Odor emissions from an animal production site originate from three primary sources: manure storage units, animal housing, and land application of manure.

Most of the odorous gases that make up livestock odors 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 shavings), 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 the transformation is done aerobically (i.e., with oxygen) or anaerobically (i.e., without oxygen). Microbial transformations occurring under aerobic conditions generally produce fewer odorous by-products than those occurring under anaerobic conditions. Moisture content and temperature affect the rate of microbial decomposition.

After generation, the volatile compounds accumulate in the wastes. At exposed surfaces or when the wastes are agitated, the compounds can escape and be emitted into the air. Once in the air, they diffuse through and are transported along air currents and disperse into the atmosphere. Some compounds adsorb onto airborne particles and other surfaces.

There has been limited research on quantifying odor emissions from livestock facilities and manure storages. Most research on odors measures concentrations. It is important to understand the difference between emission and concentration. Odor concentration is measured as a dilution-to-threshold. Dilution to threshold is the ratio of the amount of clean air needed to dilute a sample of odorous air to the point where a human panelist cannot detect the odor. Odor emissions are calculated by multiplying the odor concentration by the air flow rate from which the sample is taken. For example, an air sample is taken from a 1000 cubic feet per minute exhaust ventilation fan on a livestock building. The odor concentration of the air sample was 350 odor units as measured with an olfactometer. Assuming the fan to be the only exhaust for a 100 pig finishing barn, the odor emission from that fan is calculated to be 3500 ou/min/pp (odor units per minute per pig). It is more meaningful sometimes to report emission based on area rather then the number of animals. In this case, odor emissions would be reported as ou/min/area.

Verdoes and Ogink (Verdoes and Ogink 1997) measured odor from "low ammonia emitting pig barns" in The Netherlands (Table 12). Research from Minnesota reports odor emission rates of 3.4 to 14.8 ou/s-m^2 for swine finishing barns (Zhu and others unpubl.; Heber and others 1998) determined an average odor emissions rate from four 1,000 head pig finishing barns to be 3.0 o.u./sec/pig place. The only attempt to quantify odor emissions from deep litter system was made by Schmidt (Schmidt 1999). An average emission rate of 2.6 o.u./s-m^2 was obtained from air samples taken in a single hoop barn. Although there does seem to be some reduction in odor emission with the deep bedded systems, there is clearly a need for more research in this area.

Table 12. Odor emissions for different pig categories (Verdoes and Ogink 1997)

Category	Period	Odor Concentration (ou./m^3)	Odor Emission (ou./s/pp*)
Dry Sows	Summer	434	12.18
	Winter	619	9.79
Farrowing Sows	Summer	836	39.56
	Winter	876	31.44
Weaned Piglets	Summer	2856	7.7
	Winter	1557	3.18
Fatteners - low pH ration	Summer	892	16.62
	Winter	1019	12.15
Fatteners - multiphase feeding	Summer	1245	18.57
	Winter	854	5.5

* pig place

Zhu (Zhu and others 1998) measured daily variations in odor emissions from a swine, dairy, and poultry systems (Figure 1). Dairy and broiler buildings showed the most consistent and lowest odor emission rates. Odor levels in all facilities increased slightly in the afternoons. The nursery building had the highest odor emissions for all the sampling times during the day. Peak emissions recorded at 9 am corresponded to the feeding time for the animals.

Watts et.al. (Watts and others 1994) found that emission rates from a cattle feedlot measured over the period of one week showed considerable variation with time of day, surface temperature, moisture content, and time since wetting. Mean daily emissions ranged from 20 to 300 ou/s/m^2. Measured odor emissions from the wet feedlot pad were up to 60 times more intense than the odors emitted from the dry pad, and the peak in odor emission occurred approximately 48 hours after wetting the pad. It is difficult to compare odor measurements because of the non standard methods used in odor measurement.

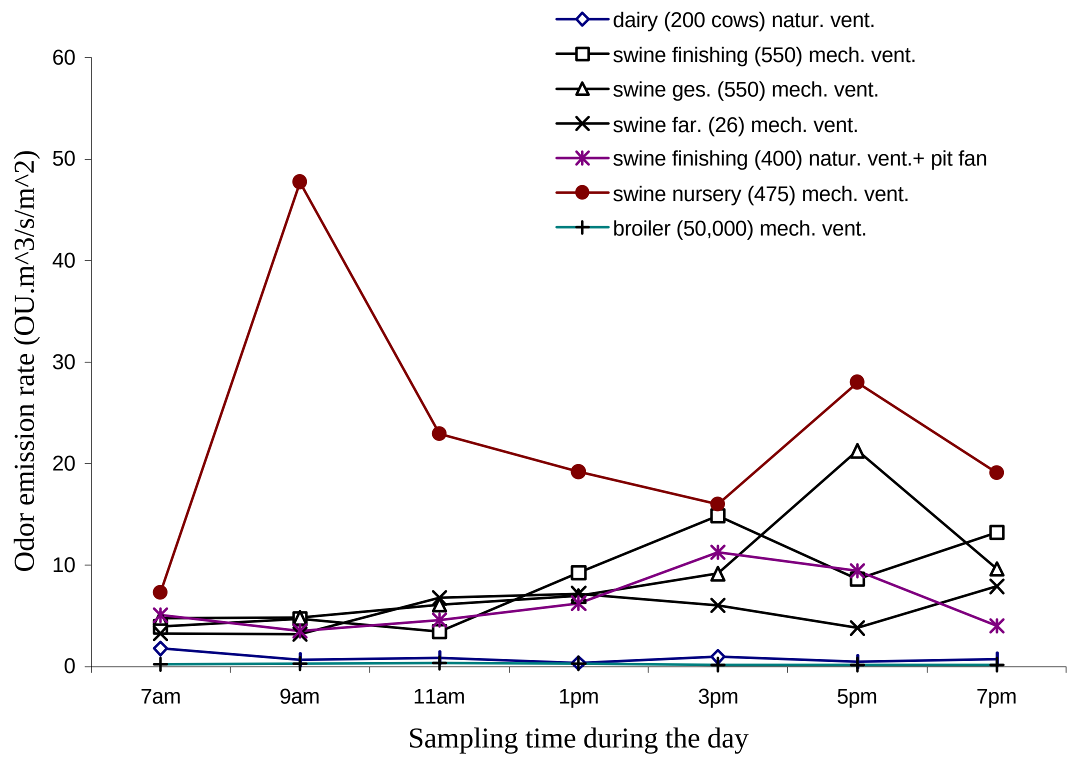

Figure 1. Daily variation in odor emissions for different animal buildings

Summary

Odor emissions from various animal production sites are beginning to be reported for animal production sites in the United States and Europe. Large ranges of values have been reported due to diurnal (24 hour) variations and difficulty in collecting and analyzing odor samples. Certain housing and manure handling systems seem to produce more odors than others systems for pigs, poultry and cattle. Pigs may have more concerns but dairy and poultry units also are capable of producing odors which can have a negative impact on neighbors.

CUMULATIVE IMPACT OF EMISSIONS

The cumulative impact of airborne emissions from animal agriculture is largely undocumented. This is partially because of the complexity of the process with individual gases, particulates, and bioaeresols all responding differently to various environmental conditions and the limited amount of information available on actual emissions from most of these compounds. It is well known that methane emissions from animal agriculture, or any other source, contribute to global warming (Hogan 1993). As such, methane and other greenhouse gas emissions from animal agriculture have an impact far beyond the immediate location of their source. Other gas emissions such as volatile organic compounds and hydrogen sulfide are thought to have a more localized impact since they are oxidized rapidly in the environment. Zahn (Zahn and others 1997) showed evidence of this in a recent study measuring the concentrations of various volatile organic compounds at the source and at 100 meters from the source. Just how localized these impacts are has not been well defined. However, it is common knowledge that since odors are sometimes detected several miles from their source, leading to the obvious conclusion that these odorous gasses and possibly others have impacts beyond the source property line.

The transport of any airborne emissions is affected by dispersion, settling, and chemical reactions in the atmosphere. Unfortunately, these relationships have not been well defined in literature for most compounds.

One gas whose fate has been studied intensively is ammonia. This research involves the transport and deposition of ammonia in the environment and the conversion of ammonia to other nitrogen species. Ammonia has received special attention because of its role in nitrogen enrichment and acidification of the environment. The fate of ammonia is quite complicated involving direct deposition, diffusion into the atmosphere where it reacts with many acidic species to form a variety of ammonium aeresols (Apsimon and Kruse-Plass 1991). The amount of ammonia deposited locally is shown to be quite dependent on downwind land-cover with transport and deposition being quite variable across the landscape (Sutton and others 1998). Other research has shown that local deposition is concentrated in the first 500 meters from the source (Fowler and others 1998; Pitcairn and others 1998; Nihlgard 1985).

The fate of these airborne compounds is directly related to the accumulation of these compounds in the ambient air. If the compounds quickly disperse, react, or are deposited within 500 meters of the source, then the accumulated impact is limited. If, however, these compounds persist, then there is some potential for increasing ambient concentrations in areas with several emission sources. At this time, information to predict these cumulative impacts is limited.

INSECTS

Table 13. Different types of insects emanating from breeding substrates at livestock and poultry production facilities in the Upper Midwest, by animal species and facility type. "+" indicates likely presence, "-" scarcity or absence.

		Types of insects around agricultural animals (and principal breeding substrates*)						
Animal species	Facility type	House fly (F,B,M)	Stable fly (F,B,M)	Fruit flies (F)	Manure gnats (M)	Blow flies (C,M)	Darkling beetles (L)	Face fly (D)
Swine	Pasture	+	+	-	-	-	-	-
	Open front	+	+	-	+	-	-	-
	Slat floor	+	-	+	+	-	-	-
	Crate	+	-	+	+	-	-	-
Dairy	Pasture	+	+	-	-	-	-	+
	Tie- or free-stall	+	+	-	+	-	-	-
	Drylot	+	+	-	+	-	-	-
	Slat floor	+	+	+	+	-	-	-
Beef	Pasture	+	+	-	-	-	-	+
	Drylot	+	+	-	-	-	-	-
Sheep	Pasture	+	+	-	-	-	-	-
	Drylot	+	+	-	-	-	-	-
Horse	Pasture	+	+	-	-	-	-	-
	Stable	+	+	-	-	-	-	-
Egg layer	High- or low-rise	+	-	-	+	+	-	-
Broiler	Pasture	-	-	-	-	+	-	-
	Litter barn	+	-	-	-	+	+	-
Turkey	Pasture	-	-	-	-	+	-	-
	Litter barn	+	-	-	-	+	+	-
Substrates: F = rotting feed, B = soiled bedding, M = manure (old feces), C = carcasses, L = poultry litter and manure, D = cow dung pats. Compiled from various sources.								

Seven types of insects (Table 13) can become abundant enough during summer to affect air quality and human comfort in and around animal enterprises. These insects develop in larval breeding sites that occur around animals and other places, and then disperse as adults into the surrounding landscape. Depending on the type of insect, their presence can lead to a variety of problems. House flies and blow flies can reach annoying densities and pose a threat to public health. Adults of stable flies have painful bites that irritate cattle, dogs, horses and people. Other types of insects are small enough to be inhaled, and swarms can interfere with human comfort in the workplace.

No scientific surveys have been conducted to assess insect abundance at different kinds of livestock and poultry enterprises in Minnesota or elsewhere, so comparisons among animal species and housing styles lack an objective basis. Available evidence suggests that abundance of the principal types of insects (Table 13) varies with kind of insect, with supply of breeding medium, and with distance from source (Greenberg 1971; Greenberg 1973; Thomas and Skoda 1992; Thomas and Skoda). Size of animal facility, per se, is not as important as how potential breeding media are managed in a given kind of facility.

House flies (*Musca domestica*) are common wherever livestock and poulty are housed (Thomas and Skoda). This insect can reach extraordinary densities if feedstuffs and manure are handled improperly, in much the same way that mishandled household garbage can create summer fly outbreaks in urban environments. House flies lay eggs in fermenting organic media that are 40-80% water. Larvae (maggots) can survive and develop to maturity in the same substrates if they remain within 30-80% water. Fermenting grain meal, soiled livestock bedding and accumulated wet manure are ideal substrates for house fly reproduction. It takes less than a thimble of wet manure to produce one fly, and time from egg to adult can be as little as 12 days. Studies in Ohio (Winpisinger-Slay and Berry unpubl.) and Maryland (Pickens and others 1967) indicated that density of dispersing house flies decreased exponentially with distance from animal facilities; densities declined to less than 10% at distances beyond 1.0 mile.

Similarly, abundance of stable flies (*Stomoxys calcitrans*) is governed by substrate supply and moisture, although in comparison to house flies, there tends to be more stable flies in fiberous media such as wet hay, wet grass clippings, soiled straw bedding, and older, drier manure (Meyer and Shultz 1990). Consequently, stable flies tend to be more abundant around cattle, sheep and horses than around swine and poultry. The dispersal distances of stable flies appear to be somewhat less to those of house flies (Stein 1986).

Relatively less is known about the remaining types of flies and beetles (Table 13) that are common around livestock and poultry in the Upper Midwest. Several species of fruit flies (Drosophilidae) breed in fermenting, grain based feeds, and can reach annoying densities around swine, dairies and caged layers if wet, spilled feed is allowed to accumulate (Harrington and Axtell 1994). Manure gnats (Sphaeroceridae) (Marshall and Richards 1987) will colonize and reproduce in liquid manure storage systems wherever manure solids collect at or above the water surface. Swarms of fruit flies and manure gnats if inhaled can interfere with human comfort in the workplace (Harrington and Axtell 1994). Dispersal distances of these two types of insects from animal facilities have not been studied, but absence of complaints from citizens living near livestock and poultry facilities suggests these flies are more sedentary than house flies.

Blow flies (Calliphoridae) develop as larvae in decaying wild or domesticated animal carcasses and other nitrogen-rich organic substrates (Broce 1985; Hall 1948). Blow flies will become abundant wherever animal carcasses or slaughterhouse offal are not promptly buried, composted or rendered. Blow flies can also reach excessive densities if broken eggs are allowed to contaminate manure under caged laying hens. Adults of these shiny, metallic flies can disperse more than a mile from point of origin (Greenberg 1973).

Darkling beetles (*Alphitobius diaperinus*) breed successfully in dry manure under caged laying hens and in broiler and turkey house litter. Larvae of these beetles (a form of wireworm) are known to damage insulation in certain styles of poultry barns (Despins and others 1989), and dispersing adults have annoyed residents adjacent to agricultural fields where infested poultry manure and litter had been spread (Anonymous 1997).

Finally, the face fly (*Musca autumnalis*) is often noticed as a household nuisance when adults aggregate in buildings in autumn and again when they exit in spring (Krafsur and Moon 1997). This type of fly reproduces exclusively in cattle dung pats in pastures, so face fly nuisance problems are traceable to grazing cattle, and not to feedlots and barns where animals are confined.

Effects of all seven types of insects (Table 13) on the environment are difficult to evaluate. All types can be considered beneficial in the sense that they are scavengers that aid in the natural decomposition and recycling of organic matter. Furthermore, all serve as food for other insect eating animals, including other insects, spiders, amphibians and birds.

On the negative side, people can become annoyed and suffer a reduced quality of life if their yards and homes are populated with extraordinary numbers of any of the seven insect types. It does not take many insects to interfere with human comfort (Thomas and Skoda). Beyond annoyance, stable flies are known to bite and suck blood from a wide variety of animals, including dogs and people, and stable flies are known to reduce the comfort and economic productivity of dairy and beef cattle (Thomas and Skoda 1992). Finally, house flies and blow flies are a potential health risk to humans and animals, because these manure and carcass breeding species have the potential to transport microbes from their breeding media to human foods (Greenberg 1971). These connections with human and animal health will be reviewed in greater detail under GEIS topic K on human health and topic L on animal health.

Summary

Flies and other insects that are produced on animal production sites can have an impact on nearby communities and neighbors if there numbers are of sufficient size. It seems that the manure management system or presence of insect breeding areas is more predictive of an insect problem than physical size of the animal operation. Insects that are commonly seen on animal production farms are mostly a nuisance concern, but certain fly varieties can poses a human and animal health concern.

HEALTH RISKS AND IMPACTS AS FUNCTION OF SPECIES, SIZE, AND MANAGEMENT (QUESTIONS 2 AND 3)

INTRODUCTION

Airborne contaminants within and emissions from animal facilities include gases, odors, particulates or dust, pathogens (bacteria, viruses, bacterial toxins, fungi and mites) and a host of microbial byproducts including endotoxins and glucans. Individually and combined they have potential direct and indirect impacts on human and animal health.

The potential direct impact on human health can be:

- physical impairment of the biological/mechanical defense mechanisms by dust and irritant gases such as ammonia and hydrogen sulfide (e.g. damage to the respiratory epithelium of the airways, including dysfunction of the cilia that transport mucus and foreign bodies out of the upper respiratory tract) and damage to the goblet cells changing the functional capacity of the mucus that normally flows on the surface of the airways to trap and transport out foreign material,

- chemical irritation of the upper respiratory tract lining by gases (e.g. damage of the epithelial barriers to inflammatory substances, respiratory bacterial or viral pathogens; decreased cilia function and increased inflammation of the airways involving increased cellular infiltration and release of inflammatory mediators),

- immunological sensitizing to allergens (e.g. organic dust particles such as feed ingredients, fungi, animal epidermal scales, and mites), and

- infection with bacteria or viruses that have a pathogenic potential for the human respiratory tract (e.g. Influenza-A-Virus, Streptococcus, Staphylococcus, Pasteurella, Salmonella, Leptospirosis, Cryptosporidiasis, Giardia, and Haemophilus) and toxins from the organism pfiesteria.

- The potential indirect impact on human health can be:

- gaseous emissions such as NH_3, washed down by precipitation, can contribute to the nitrogen content of ground and surface waters that are used for drinking water,

- zoonotic bacteria emitted from livestock and poultry facilities may contribute to an increased population of these same microorganisms in the ecosystem (such dust-borne, non-respiratory, bacteria pose hardly any direct risk to human health, even to passers-by near animal houses),

- bacteria from animal excretions (emitted via exhaust air) that contain genetic determinants for antimicrobial resistance can contribute to an increase of bacterial resistance in the ecosystem but the risk is unknown and needs further study.

The potential direct impact on animal health can be:

- physical impairment of the biological / mechanical defense mechanisms by dust (e.g. damage to the respiratory epithelium of the airways, including dysfunction of the cilia that transport mucus and foreign bodies out of the upper respiratory tract),

- chemical irritation of the membranous lining of the respiratory tract by gases (e.g. damage of the epithelial barriers to inflammatory substances, respiratory bacterial or viral pathogens;

decreased cilia function and increased inflammation of the airways involving increased cellular infiltration and release of inflammatory mediators),

- infection with bacteria or viruses that have a pathogenic potential for the animal respiratory tract (e.g. Influenza-A-Virus, Streptococcus, Staphylococcus, Pasteurella, Salmonella, Leptospirosis, Cryptosporidiasis, Giardia, and Haemophilus). These may be spread from animal to animal or from animal unit to animals in other units by transference.

HEALTH RISKS OF ANIMAL AGRICULTURAL EMISSIONS ON FACILITY WORKERS

The health of people working in animal housing facilities, especially in swine and poultry units, has become a concern to the producers, health officials, and researchers. Chronic respiratory problems for workers in these environments are common including symptoms such as cough, sputum production, chest tightness, shortness of breath, and wheezing due to the airborne dust, gases, and other particulates (Donham 1989). Acute worker health and safety concerns also exist during short-term events like manure pit agitation that can result in large emissions of toxic gases like hydrogen sulfide. Seven fatalities have been reported since 1992 in Minnesota from exposure to these gases during the agitation and transfer of manure in or near storage tanks or pits.

A number of studies have found workers in intensive animal facilities with a high prevalence of respiratory health problems (Patni and Clarke 1991; Iversen and Takai 1990; Hellickson and others 1989; Zejda and others 1994). Most of these studies were done in pig barns but several (Hellickson and others 1989; Nicolai and Janni 1998a) were carried out in poultry (turkey) facilities. Assessment was done by measuring the reduction in lung function of animal facility workers (Iversen and Takai 1990). (Patni and Clarke 1991) compared to non-exposed people. Lung function also decreased as workers aged (Hellickson and others 1989).

Several studies compared the health or respiratory function between workers in pig facilities and those on farms without swine and workers not associated with farms. A number of studies reported a higher frequency of respiratory symptoms, more colds, wheezing, coughing, and pneumonia in swine workers than in other farm workers not exposed to pig barn environments (Donham and others 1984; Holness and others 1987; Vohlonen and others 1987; Dosman and others 1987; Wilhelmson and others 1989).

Dust

Airborne dust is suspected as the major cause of chronic worker health symptoms (Rylander and others 1989). Dusts in and around animal facilities include bits of feed, dried skin, hair or feathers, dried feces, and soil particles (Koon and others 1963; Anderson and others 1966; Curtis and others 1975a; Alegro and others 1972; Sweeten and others 1998; Sweeten and others 1998). Feed was found to be the primary component of the dust (Curtis and others 1975b; Heber and others 1988). Airborne biogenic particles include bacteria, viruses, fungi spores, amoebae, algae, pollen, plant parts, insect parts and wastes, endotoxins and mycotoxins. Endotoxins are naturally occurring substances in the cell walls of gram negative bacteria that are released when the microogranisms die. Mycotoxins are toxins produced by fungi.

Numerous studies have reported dust concentrations in animal buildings. Mean inhalable dust levels in various catttle, swine, and poultry buildings in Europe ranged from 0.22 to 4.58 mg/m3 (Takai and others 1998). Inhalable dust represents the dust inhaled through a human's nose and mouth (Mark and Vincent 1986). Mean respirable dust concentrations ranged from 0.09 to 0.64 mg/m3 (Takai and others 1998). Respirable dust represents the dust that can penetrate deeply into the respiratory tract and lungs.

Total dust concentrations in turkey barns in Minnesota ranged from 0.4 to 13.8 mg/m^3 across two studies (Mulhausen and others 1987; Reynolds and others 1994). Concentrations were highest in the winter. Respirable dust concentrations ranged from 0.1 to 2.6 mg/m^3 (Reynolds and others 1994).

Total dust concentrations in broiler barns in North Carolina ranged from 0.02 to 11 mg/m^3 (Jones and others 1984). Respirable dust levels ranged from 0.02 to 0.62 mg/m^3. Bird age, litter age, and animal activity were factors (Jones and others 1984).

Total dust concentrations in an Italian horse stable ranged from 0.26 to 10.82 mg/m^3 with a mean concentration of 1.95 mg/m^3. Respirable dust concentrations ranged from 0.03 to 1.46 mg/m^3 with a mean of 0.38 mg/m^3 (Navarotto and others 1994).

Total and respirable dust concentrations in caged layer barns in Sweden were comparable or less than those in barns without cages (alternative housing) (Martensson 1995). Total dust concentrations in the conventional caged layer barns ranged from 1.3 to 2.7 mg/m^3 while respirable dust concentrations ranged from 0.08 to 1.04 mg/m3. Corresponding total and respirable dust concentrations in the alternative barns ranged from 2.6 to 4.1 mg/m^3 and 0.08 to 1.13 mg/m^3, respectively.

Research in swine buildings indicates that total dust concentrations are higher in finishing barns than either nursery or gestation barns. Donham, Scallon, et al. (Donham and others 1986) reported mean total mass dust concentrations to be 3.2 mg/m^3 in farrowing units, 5.2 mg/m^3 in nursery units, and 15.3 mg/m^3 in finishing buildings. The respirable fractions were 20%, 13.4%, and 12.4% of the total dust in the farrowing, nursery, and finishing buildings, respectively. Maghirang, Puma, et al. (Maghirang and others 1997) reported a mean total dust concentration of 0.72 mg/m^3, ranging from 0.12 to 2.14 mg/m^3 in a test swine nursery. The respirable fraction ranged from 2 to 30% of the total dust, with an overall mean of 11%.

Time-weighted average (TWA) total and respirable dust exposure thresholds of 2.4 mg/m^3 and 0.16 mg/m^3, respectively for workers in livestock and poultry facilities have been suggested (Donham and others 1989; Donham K. and others 1995; Reynolds and others 1996; Donham and Cumro 1999a). Time-weighted average threshold limits are based on eight-hour work days and a 40-hour work weeks.

Worker health can be mitigated using dust respirators or masks. Studies report reduced incidence of common respiratory symptoms and substantial respiratory protection (Iversen and Takai 1990; Hellickson and others 1989; Barber and others 1999; Senthilselvan and others 1999).

Summary

Dust concentrations in animal facilities can vary widely. Sampling techniques (i.e., aerial versus personal) and building conditions vary widely making direct comparison very difficult. They depend on many management and animal factors. Aerial and personal sampling techniques differ and will give different results. The results indicate that animal buildings can be quite dusty and generally depend on numerous factors including ventilating rate, humidity level, litter use and condition, animal density and activity level, feed form and content, feeding system, amount of cleaning, and other management practices. Dust in animal facilities can be a major contributor to worker health symptoms. Researchers have suggested time weighted average limits for total and respirable dust for workers in livestock and poultry. Respirators and masks can provide substantial respiratory protection.

Gases

In addition to the dust there are irritating gases in the environment of animal facilities which can have an additive or synergistic effect (Reynolds and others 1994; Donham and Cumro 1999b). Groot-Koerkamp et al. (Groot Koerkamp and others 1998) reported mean and maximum ammonia concentrations in cattle, pig, and poultry houses in northern Europe. Mean ammonia concentrations ranged from 0.3 to 30 parts per million (ppm). The maximum concentrations ranged from 1.7 to 73 ppm. The data indicates that health risks would be greater due to ammonia in the pig and poultry buildings than in the cattle buildings.

Ammonia concentrations in pig buildings in Minnesota were less than 30 ppm averaging only 10-15 ppm (Jacobson and others 1996).

Ammonia levels in turkey grower barns in Minnesota were higher in the fall and winter season compared to the spring and summer (Mulhausen and others 1987). Seasonal average values ranged from 10 to 35 ppm. Mean ammonia concentrations in turkey buildings ranged from 1.9 ppm in brooder barns in the summer to 46.2 ppm in grower barns with hens in the winter (Reynolds and others 1994).

Concentrations of carbon monoxide, hydrogen sulfide, nitrogen dixoxide, and methane in turkey grower barns were below detectable levels (Mulhausen and others 1987). Mean sulfur dioxide concentrations in turkey barns ranged from 0.13 to 0.36 ppm (Reynolds and others 1994).

Ammonia concentrations in three broiler barns in North Carolina had average concentrations around 25 ppm ranging from 6 to 75 ppm. Carbon dioxide concentrations ranged from 500 to 1,000 ppm. Carbon monoxide, hydrogen sulfide, nitrogen dioxide, oxides of nitrogen (NOx), methane, mercaptan, formaldehyde, and hydrocarbons concentrations were all below the detection limits of the detector tubes used (Jones and others 1984).

MidWest Plan Service (MidWest Plan Service 1990) lists TWA concentrations for NH_3 at 25 ppm and for H_2S at 10 ppm. However, Donham and Cumro (Donham and Cumro 1999a; Donham and Cumro 1999b)have shown synergistic effects between ammonia and dust and suggest an ammonia TWA threshold limit of 7 ppm inside livestock and poultry facilities. Other gases like carbon dioxide (CO_2) and carbon monoxide (CO) have TWA levels of 5,000 ppm and 50 ppm, respectively. Methane (CH_4) has a safety consideration because of possible explosiveness at 30,000 ppm (MidWest Plan Service 1990).

Summary

Ammonia and hydrogen sulfide were the most commonly monitored gases in animal buildings. Concentrations varied widely and depend on animal species, housing, and manure handling. Research evidence strongly suggests that ammonia and dust have synergistic effects. Researchers are suggesting TWA threshold limits for workers in livestock and poultry facilities. Most other gases have not been found at levels of concern.

Biogenic Particles

Researchers have reported biogenic concentrations for bacteria, fungi and endotoxins in animal buildings. Microbial sources include the animals, bedding, feed, manure or exterior (outside) sources.

Airborne endotoxin concentrations were measured in cattle, pig, and poultry buildings in Europe (Seedorf and others 1998). Mean inhalable endotoxin concentrations ranged from 11.8 to 786 nanograms/m^3 (ng/m^3). Mean respirable endotoxin concentrations ranged from 0.6 to 72 ng/m^3. In general both inhalable and respirable concentrations were higher in poultry buildings than pig buildings and lowest in cattle buildings. Generally daytime concentrations were higher than nighttime concentrations.

Seedorf et al. (Seedorf and others 1998) measured airborne microorganism concentrations in animal buildings, mostly in Germany. The highest mean bacterial concentrations were measured in broiler buildings where the mean concentration was 6.43 logrithim of colony-forming-units per cubic meter of air (log cfu/m^3). Mean bacterial concentrations in layer and pig houses ranged from 4 to slightly over 5 log cfu/m^3. Mean bacterial concentrations in cattle barns were generally slightly over 4 log cfu/m^3. Mean daytime Enterobacteriaceae concentrations ranged from 3.2 to 4.5 log cfu/m^3. Mean daytime fungi concentrations were 3.8 for cattle, 3.7 for pigs, and 4.0 for poultry log cfu/m^3, respectively with similar values for nighttime (Seedorf and others 1998).

Hartung (Hartung 1994) noted some generalities in a review regarding airborne microbes in poultry buildings. Airborne microorganisms found in poultry buildings, as in most livestock facilities include: staphylococci, streptococci, pseudomonas, E. coli/Enterobacter, fungi, molds and yeasts. Of the fungi, several different species were found – some of which considered to be allergenic (Penicillium, Aspergillus, Cladosporium, and Alternaria) (Hartung 1994).

Airborne bacteria concentrations in three broiler barns in North Carolina were around 150,000 cfu/m^3 (Jones and others 1984). Fungi concentrations were 10,000 cfu/m^3. Endotoxin concentrations ranged from 0.77 to 61 ng/m^3 in the total dust samples and from 0.71 to 15 ng/m^3 in the respirable dust.

Because methods of microbial determination (i.e., bacteria and/or fungi) and differentiation (i.e., fungi species), sampling times and sites differed between studies, there may be limited value in reported quantities of airborne particulates as absolute values. For instance, three papers reported widely varying airborne microbial concentrations in egg layer houses for layers in cages: range of 360 to 3781 cfu's per liter of air (Hartung 1994); range of 17 to 5860 cfu's per liter of air (Muller 1987); and, range of total bacteria of 290,000 to 680,000 cfu's per cubic meter (Clark and Rylander 1983).

The effects of independent variables can be assessed when measurements are taken using the same standard procedures for specific comparison purposes. For instance, the type of poultry and housing shows an effect on airborne microorganism concentrations. (Hartung 1994) indicated that airborne microorganisms in houses with chicken layers on litter (bedding) had approximately 5 times the concentrations compared to chicken layers in cages, perhaps reflecting the difference in hen activity and contributions of the litter material.

In the Midwest, season had a significant affect on airborne microorganisms in turkey houses. (Mulhausen and others 1987) found that airborne Aspergillus concentrations in a turkey barn in Minnesota never exceeded 73 cfu/m^3, which was less than background levels found in two ambient air studies (Calvo and others 1980; Jones BL and Cookson JT 1983). Reynolds et al. (Reynolds and others 1994) found that mean bacteria concentrations in turkey barns ranged from 300,000 to 38,700,000 cfu/m^3. Higher levels of bacteria, approximately 5 fold, (Debey and others 1995) and higher levels of Aspergillus, approximately 3.5 fold (Janni and others 1985) were found in rearing facilities in the winter compared to summer. The large difference is most likely due to ventilation rates targeted toward keeping barns warm in the winter and heat removal in the summer time.

There is limited research information on microbial populations as affected by feed type, animal activity, bedding type and management, manure handling system, stocking density, air temperature, and relative humidity. Bedding provides environmental conditions appropriate for bacterial growth and fungal spores (Beran 1991). Populations change with bedding use. Fungi populations in fresh and used litter in broiler houses had different specie populations. Aspergillus spp. and Scopulariopsis brevicaulis were predominant in the litter after one cycle of birds (Dennis and Gee 1973). Research reported by Jones et al. (Jones and others 1984) for broiler farms in North Carolina indicated airborne fungal counts were an order of magnitude higher in a house with fresh litter compared to a flock housed on old litter (same age birds).

Some researchers have noticed episodes of organic dust toxic syndrome (ODTS) in animal facilities workers (33% of workers), mainly during high dust exposure times like sorting or moving animals and during power washing of the building interior. These situations may be related to inhaling endotoxins from aerosolized gram negative bacteria (Rylander and others 1989). Donham et al. (Donham and others 1988) found endotoxin levels to be significantly related to the one-second forced expiratory volume (FEV1) and the forced expiratory phase at 25-75% lung volume (FEV25-50) of swine workers in a dose dependent way. Donham & Cumro (Donham and Cumro 1999a) suggest TWA threshold concentrations of 614 EU/m^3 for total endotoxin and 0.35 EU/m^3 for respirable endotoxin.

Summary

Biogenic particles are a broad class of organic particulates including bacteria, fungi, and endotoxins. Concentrations differ depending on animal species, manure system and management, bedding use, feed form and quality, feeding system, animal activity, and management. Measurement techniques vary making direct comparison between studies very difficult. Endotoxins can reduce respiratory capacity and researchers have suggested threshold limits for workers in livestock and poultry facilities.

COMMUNITY HEALTH EFFECTS OF ANIMAL AGRICULTURAL EMISSIONS (PARTICLES, GASES/ODORS, PATHOGENS)

The Association of Health Effects with Exposure to Particles

There is little research on the health effects of ambient dust concentrations downwind of animal facilities and their impact on human health. Ambient dust is regulated by the U.S. Environmental Protection Agency (EPA) under the National Ambient Air Quality Standard (NAAQS) (EPA 1998c).

Dust from animal facilities and feed mills can contribute to the ambient dust levels. Emissions from large beef cattle feedlots in Texas and California are regulated (Sweeten and others 1998). Dust mitigation methods are used to reduce emissions from these sources. No research was found reporting on the health effects of ambient dust from animal facilities in the Midwest or Minnesota. This might be a topic for future research.

Human Health Effects with Exposures to Gases and Odors

Several studies investigated the health effect of ambient odors downwind of industrial and agricultural sources. Shukla (Shukla 1991) stated that the immediate physiological stresses produced by odors can cause loss of appetite and food rejections, low water consumption, poor respiration, nausea, and even vomiting and mental perturbations. In extreme cases, offensive odors can lead to deterioration of personal and community well-being, interfere with human relations, deter population growth, and lower its socio-economic status (Shukla 1991).

Shusterman et al. (Shusterman and others 1991) reported on three studies which were conducted in California regarding odor and health complaints. The odorants identified in each of the studies were reduced sulfur gases and compounds with odor thresholds three to four times lower than thresholds that cause respiratory irritation or systemic toxicity. These studies found great variability at when different people in the community could detect odors. Females were more sensitive, while elderly and smokers were less sensitive to smells. The study notes that these differences are important when the community responds to odor abatement measures. It also found that repeated exposure to an odor resulted in enhanced odor recognition and detection. Most symptoms reported by individuals were acute in onset, self-limiting in duration, and subjective, making it difficult or impossible to substantiate objectively (Shusterman and others 1991).

Shim and Williams (Shim and Williams 1986) reported that many patients complain that some odors worsen their asthma. Perfume and cologne are two of the most frequently mentioned offenders. Four patients with a history of worsening asthma on exposure to cologne underwent challenge with cologne, and their pulmonary function was tested before, during, and after the exposure. Forced expiratory volume in one-second declined 18 to 58 percent below the baseline period during the 10-minute exposure and gradually increased in the next 20 minutes. Saline placebo pretreatment did not affect the response to subsequent challenge. A survey of 60 asthmatic patients revealed a history of respiratory symptoms in 57 of them on exposure to one or more common odors. Odors are an important cause of worsening of asthma. From a practical standpoint, sensitive asthmatic patients should be advised to eliminate odors from their environment as much as possible (Shim and Williams 1986).

Shusterman et al. (Shusterman and others 1991) also presented theories as to why the body may respond to odor. He sets them out in various categories.

- Relationship between Odor Detection and Acute Toxicity: Acute odor-related symptoms could and do occur without toxic exposures. For example, symptoms reporting of sulfur gases begin at levels that barely exceed their odor threshold.

- Innate Odor Aversion: A built-in mechanism for all people to react to pleasant and unpleasant odors. Even babies respond predictably.

- Innate Pheromonal Phenomena: Odors trigger some hormonal responses in animals. Still under study with humans.

- Odor-related Exacerbation of Underlying Conditions: One pre-existing medical condition that may coincide the hyper susceptibility to odors is bronchial asthma. Pre-existing psychological conditions might cause some individuals to respond more to odors.

- Odor-related Aversive Conditioning: After a traumatic exposure, some people report symptoms in response to low-level exposures. While initial symptoms occurred with traumatic exposure, subsequent attacks and symptoms occurred both with and without odor triggers.

- Odor-related, Stress-induced Illness: Persons who believe the odor source is a toxic risk have more symptoms and psychological distress when exposed to odors. This was shown to be the most important variable in people's response to odor.

- Mass Psychogenic Illness: Clusters of people experience similar symptoms. Odors frequently play an important role in causing alarm. Not usually seen in a community setting.

■ Recall Bias: This can occur when an adverse health outcome, the publicity surrounding an environmental issue or odor perception, affects the accuracy of recall for a particular symptom.

Knasko (Knasko 1993) reported on the effects of intermittent bursts of pleasant, unpleasant, and no odor on human task performance, mood and perceived health. Odors did not influence any of these measures; however, subjects who had been exposed to the malodors reported retrospectively that they thought the odors had a negative effect on all of these factors (Knasko 1993).

Retrospective symptom prevalence data, collected from over 2000 adult respondents living near three different hazardous waste sites, were analyzed with respect to both self-reported environmental worry and frequency of perceiving environmental (particularly petrochemical) odors (Shusterman and others 1991). Significant positive relationships were observed between the prevalence of several symptoms (headache, nausea, eye and throat irritation) and both frequency of odor perception and degree of worry. Headaches for example, showed a prevalence odds ratio of 5.0 comparing respondents who reported noticing no such odors and 10.8 comparing those who described themselves as very worried versus not worried about environmental conditions in their neighborhood. Potential explanations for these observations are presented, including the possibility that odors serve as a sensory cue for the manifestation of stress-related illness (or heightened awareness of the underlying symptoms) among individuals concerned about the quality of their neighborhood environment.

Cavalini (Cavalini 1994) noted that with regard to general health complaints, it was found that when exposed to (industrial) odorant concentrations, some people are annoyed and of these people, only some report general health complaints. Exposure in itself does not directly cause general health complaints. Annoyance is the intervening variable between exposure and general health complaints. A possible explanation for the relation between annoyance by malodor and general health complaints might be found in the personality and attitudes of the exposed individual. Caralini (Cavalini 1994) found confirmation for the appraisal hypothesis, i.e., the extent to which individuals regard malodor as threatening is positively related to odor annoyance.

In a Terre Haute Indiana study (U.S. Public Health Service 1964), concentrations of hydrogen sulfide ranged from 22 to 300 ppb and were sufficient to cause public complaints and discomfort and paint blackening of lead-based paint. While Terre Haute, Indiana, had many potential sources of odorous air pollutants, the most probable source, which caused the public complaints and discomfort, was a 35-acre lagoon used for the biodegradation of organic industrial waste. Many public complaints were generated about odors, health effects, and property damage. Main symptoms reported were nausea, loss of sleep and abrupt awakening, shortness of breath, and headache. Few citizens sought medical attention. In the opinion of the medical observers, the hydrogen sulfide and other odorous materials were the likely cause of the symptoms.

Odors have also been reported to affect cognitive performance (Lorig 1992; Ludvigson and Rottman 1989) and physiological responses including heart rate and electroencephalographic patterns (Lorig 1989; Lorig and others 1991; Lorig and Robers 1990; Lorig and others 1993; Lorig and Schwartz 1988; Manley 1993). Learning (via conditioning) may also play a role in the psychological and physical effects from odors. Conditioned aversions to odors are documented in the scientific literature (Dyck and others 1990; Goodwin and others 1992; Hunt and others 1993; Meachum and Bernstein 1992; Murua and Molina 1990; von Kluge and Brush 1992).

Animal Odor Sources

Odor complaints have been reported to be most frequent among new, large, or recently expanded animal facilities that are located near existing residences or shopping areas (Miner 1980; Sweeten and Miner 1993).

Odorant molecules contained in emissions from hog farms may cause nasal and respiratory irritation (Bundy 1992; Cometto-Muniz and Cain 1991; Donham 1990; Miner 1980; Blaha 1999). Nasal irritation has been shown to elevate adrenaline (Allison and Powis 1976) which may contribute to feelings of anger and tension. The volatile organic compounds (VOCs) responsible for odors may also be absorbed directly by the body (into the bloodstream and fat stores) via gas exchange in the lungs. Many VOCs that are inhaled into the lungs are known to reach blood and adipose tissue. Persons who have absorbed odorants through the lungs can sometimes smell the odor for hours after exposure due to slow release of the odorants from the bloodstream into expired air activating the olfactory receptors. Volatile organic compounds are well known to be eliminated in breath after exposure (Raymer and others 1991; Wallace and others 1991), and methods for measuring VOCs in breath have been described as abnormal smell functioning.

A Michigan study (Warner and others 1990) was designed to assess the impact of a 50,000 animal swine-growing facility as an odor source and potential health problem. In parallel with the measurement of odor intensity, the Michigan Department of Public Health conducted a health survey to obtain information regarding the pervasiveness of the odor in the community and its possible health implications. Citizen's complaints reported included physical symptoms such as breathing difficulties, burning sensations in the nose and throat, nausea and vomiting, and headaches. A survey of residents within 0.5 miles of the center of the facility (58 households / 89 persons) and those between 0.5 and 1.25 miles away (176 households / 225 persons) resulted in response rates of 55% and 49%, respectively. The authors concluded the following: "These responses contained complaints of symptoms attributable to the swine facility. As with any population, symptoms as general as those which relate to complaints as noted are difficult to correlate to specific health problems. However, the clear excess of complaints stands as a fact of record. Perhaps further study is needed to surface a better understanding of individual health effects and symptoms as these relate to perception of odor. "Information is not provided on the type of complaints nor was there any report on frequency of symptoms or whether they differed by proximity to the farm” (Warner and others 1990).

From 1984 to the mid-90s, a large scale and long-term epidemiological study on the frequency of respiratory disease in children comparing rural and urban areas was conducted in Germany by the German Medical Association. The results showed that in the rural areas a non-significant higher proportion of allergic disease in children was recorded, however, no conclusions on any causal relation to livestock operations could be drawn, since there were too many confounding factors (Blaha 1999).

Schiffman et al. (Schiffman and others 1995) evaluated forty-four individuals living near hog operations and forty-four control subjects in North Carolina. These two groups were matched on the basis of age, gender, race, and educational level. Compared to controls, the experimental group had statistically significant increases in tension, depression, anger, fatigue, and confusion scores from the standardized Profile of Moods State Questionnaire. Schiffman deemed these findings consistent with other previous studies where odors of varying hedonic properties have been found to affect mood (Baron 1990; Ehrlichman and Bastone 1992; Rotton 1983; Schiffman and others 1994a; Schiffman and others 1994b; Blaha 1999; Winneke and Kastka 1977). Schiffman states that the mood alteration could be caused by "a) the unpleasantness of the sensory quality of the odor; b) the intermittent nature of the stimulus; c) learned (via conditioning) aversions to the odor, and are well documented in the scientific literature; d) potential neural stimulation of immune responses via detect neural connections between odor centers in the brain and lymphoid tissue; e) direct physical effects from molecules in the plume including nasal and respiratory irritation; f) possible chemosensory disorders; and g) unpleasant thoughts associated with the odor."

Thu et al. (Thu and others 1997) reported on the association of health effects with exposures to environmental odors from animal operations. The study collected mental and physical health information by personal interviews from a small random sample of 18 residents living within two miles of a 4,000-sow operation in Iowa. Data was compared to that collected from a demographically comparable sample of 18 rural residents living in an area with minimal livestock production. The results of the comparison indicated that "neighbors of the large-scale swine operation reported experiencing significantly higher rates than the controls of four clusters of symptoms that are known to represent toxic or inflammatory effects on the respiratory tract. These clusters of symptoms have been well documented among swine confinement workers." The specific symptoms reported are quite similar to the list of symptoms reported by hog farm workers: cough, increased sputum production, shortness of breath, chest tightness, wheezing, nausea, dizziness, headaches, runny nose, scratchy throat, burning eyes, muscle aches and pains, skin rash, and fever. Among the control group in this study, symptoms of skin rash, muscle aches, and fever were more frequently reported. There was no difference in the frequency of reported symptoms and distance from the swine facility. This study found that neighbors did not suffer higher rates of psychological health effects, such as depression or anxiety, when compared to controls. Thu et. al. (Thu and others 1997) also states that all responders felt the owner of the farm was creating social and class divisions within that community.

A recent study (Wing and Wolf 1999) was prompted by the rapid expansion of intensive hog productions in North Carolina. Residents of three rural communities were surveyed, one community in the vicinity of a 6000-head hog operation, one community in the vicinity of two intensive cattle operations, and a third rural agricultural community where residents lived at least two miles from livestock operations that use liquid waste management systems. The average number of episodes of most symptoms was similar in the three communities with the exception of respiratory, gastrointestinal, and mucous membrane problems. The study found "a number of symptoms that have previously been reported to be elevated among persons occupationally exposed in swine confinement houses were elevated among residents of the hog community compared to the community with no livestock operations. In particular, headache, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes were reported more frequently in the hog community. Members of the cattle community did not report similar elevations, nor did they report reduced quality of life. The quality of life measures concerning opening of windows and ability to go outdoors even in nice weather showed a large excess in the hog community." Long-term physical and mental health impacts of reduced quality of life could not be investigated in this study.

O’Neil and Phillips (O'Neill and Phillips 1992) conducted a literature review of the chemicals detected in and around livestock facilities or livestock wastes. The most commonly reported compounds in the literature review were volatile fatty acids (acetic, propionic, butanoic, and pentanoic), phenol, p-cresol, and ammonia. Some of these compounds have been identified as respiratory tract, skin, or eye irritants. The following table lists those chemicals identified in the literature review that have some acute or chronic health value associated with them, either from the Minnesota or California Departments of Health or from USEPA (Table 14).

The information in Table 14 can be used in risk assessment. The EPA inhalation reference concentrations (RfCs) can be used to estimate a level of environmental exposure at or below which no adverse effect is expected to occur. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population that is likely to be without appreciable risk of effects during a lifetime. In general, the incidence of human disease or the type of effects that chemical exposures have on humans cannot be predicted. This is due to the numerous uncertainties involved in risk assessment, those associated with extrapolations from animal data to humans and from high experimental doses to lower exposures. The organs affected and the type of adverse effect resulting from chemical exposure may differ between study animals and humans. In addition, many factors besides exposure to a chemical influence the occurrence and extent of human disease (EPA 1999).

The U.S. EPA’s critical effects are those listed in the EPA’s Integrated Risk Information System (IRIS). Critical effects are the first adverse effect, or its know precursor, that occurs as the dose rate increases (EPA 1999).

A few researchers have considered the effects of biogenic emissions from animal facilities and their potential as a respiratory health hazard and disease transmission to other animals (Bohm and Hartung 1994; Homes and others 1996; Seedorf and others 1998). Local topography, weather, emission rates and source characteristics will effect potential transmission (Seedorf and others 1998). Measurements at one swine facility found total bacteria concentrations decreased dramatically between inside and outside a swine facility. Concentrations were higher than background levels at 200 m but not at 300 m downwind of a swine facility (Homes and others 1996).

Summary of Outdoor Airborne Contaminants on Human Health

Airborne dust, gases, and biogenic particles can negatively impact human health. There are a number of research reports documenting that neighbors of large swine facilities experience higher incidences of health symptoms than comparable rural residences near minimal livestock production. Similar studies around other animal production facilities are limited. Clearly more research is needed to relate emissions from animal facilities to airborne concentrations and the health effects on individuals living near animal production facilities.

Table 14. Volatile organic compounds and gases identified in livestock wastes with documented subchronic, chronic, or acute health values.

Compound (names)	Minnesota's Proposed Inhalation Health Risk Values (µg/m3) Chronic	Subchronic	US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects	California's Acute REL (µg/m3) and Toxicologic Endpoints	EPA Hazardous Air Pollutant Listing
acetaldehyde ethanal	5				yes
acetone dimethylketone (2-)propanone			not available at this time		
acetophenone acetylbenzene methylphenylketone			not available at this time		yes
acrolein 2-propenal acrylaldehyde		0.07	0.02 squamous metaplasia and neutrophilic infiltration of nasal epithelium	$1.9*10^{-1}$ eye irritation	yes
ammonia	80		100	$3.2*10^{3}$ eye and respiratory irritation	
benzaldehyde benzen-carbonal			not available at this time		
benzene	1		not available at this time	$1.3*10^{3}$ reproductive developmental	yes
bis(2-ethylhexyl) phthalate					yes
carbon disulfide	700		700 peripheral nervous system dysfunction	$6.2*10^{3}$ reproductive developmental	yes
carbonylsulfide carbon oxysulfide					yes
chloroform trichloromethane			not available at this time	$1.5*10^{2}$ reproductive developmental	yes
crotonaldehyde trans-2-butenal			not available at this time		
ethyl acetate acetic acid, ethyl ester			not available at this time		
formaldehyde	0.8		not available at this time	$9.4*10^{1}$	yes

Compound (names)	Minnesota's Proposed Inhalation Health Risk Values (µg/m3) Chronic	Subchronic	US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects	California's Acute REL (µg/m3) and Toxicologic Endpoints	EPA Hazardous Air Pollutant Listing
methanal				eye irritation	
formic acid methanoic acid			not available at this time		
hexane					yes
hydrazine	0.002		not available at this time		yes
hydrogen sulfide		10	1 inflammation of the nasal mucosa	$4.2*10^{1}$ respiratory irritation	
isobutyl alcohol 2-methyl-1-propanol			not available at this time		
methanol methyl alcohol			not available at this time	$2.8*10^{4}$ CNS[4]-mild	yes
2-methoxyethanol methyl cellosolve methyl glycol		50	20 testicular effects		
naphthalene	1		3 nasal effects: hyperplasia and mataplasia in respiratory and olfactory epithelium, respectively		yes
phenol carbolic acid benzenol hydroxybenzene				$5.8*10^{3}$ eye and respiratory irritation	yes
pyridine azine			not available at this time		
sulfur dioxide				$6.6*10^{2}$ respiratory irritation	
toluene	400		400 neurological effect	$3.7*10^{4}$ CNS-mild eye and respiratory irritation	yes
triethylamine		70	7	$2.8*10^{3}$ CNS-mild, eye irritation	yes
xylene dimethylbenzene (isomer not specified)			not available at this time	$2.2*10^{4}$ eye and respiratory irritation	yes

THE IMPACT OF AIRBORNE CONTAMINANTS ON ANIMAL HEALTH

An animal's response to airborne contaminants will depend on the dose of contaminant absorbed, inhaled, or ingested and the impact that the contaminant has on the animal. Dose through the respiratory tracts is extremely difficult to measure because it depends in part on animal activity and respiration rate. Exposure is typically used as a surrogate for dose. Exposure describes the contact between the animal and contaminant in terms of contaminant concentration and duration of contact. Exposure also describes the contact in terms of the surfaces that are exposed to the contact (i.e., eyes, skin, respiratory tract, other).

Animals exhibit their responses to airborne contaminants in many ways and through various biological systems. Changes in production (e.g., average daily gain, feed conversion) or reproduction are common response indicators. Other indices include health, morbidity, mortality, and thermal comfort. Animals can also exhibit physiological and behavioral changes. Responses can be seen in the respiratory, circulatory, immunological, and thermoregulatory systems. Individual responses vary, requiring extensive studies to develop the statistical base to describe the probabilistic response of the animal population. The number, diversity, and interactions of response variables to multiple stressors, including air quality, makes quantification of the effects difficult at best (Janni 1989).

The impact of airborne contaminant on animals raised for food has been very difficult to assess. There are a number of published papers dealing with this issue, but there is no consensus to date as to whether airborne contaminants at levels found commonly in animal facilities has an impact on animal health and performance.

Particulates

Airborne particulate or dust is considered to be a health risk for workers exposed over a prolonged period of time. There is no literature demonstrating any effects of dust on the health of pigs, cattle, or poultry (Heber and Stroik 1988). Pigs exposed to ammonia, hydrogen sulfide, and airborne dust at concentrations at or higher than those typically found in pig finishing houses had little effect on body weight, rate of gain, or respiratory tract structure (Curtis and others 1975a).

Gases

Animals housed in intensive production systems (essentially housed indoors) such as those commonly found in Minnesota, are exposed to a number of different atmospheric gases at levels that are higher than those found outdoors. Although many gases were identified in and near animal housing systems only two, ammonia and hydrogen sulfide, have been studied extensively for their effect on animal health. Many of the other gases are at trace levels and are not normally considered to limit farm animal productivity (Scott and others 1983). Concentrations of carbon monoxide, hydrogen sulfide, nitrogen sulfide, and methane were below detectable levels in Minnesota turkey barns (Mulhausen and others 1987).

Studies on the effect of ammonia on swine have yielded mostly negative results, when studied with levels found in commercial farms (Jacobson and others 1985). Pigs exposed to ammonia and hydrogen sulfide concentrations at typically found in pig finishing houses had little effect on body weight, rate of gain, or respiratory tract structure (Curtis and others 1975a). A couple of studies have shown that pigs exposed to high ammonia concentrations, greater than 50 ppm, develop more lung lesions due to Ascaris larvae migration and more Atrophic Rhinitis lesions when challenged with the causative organism for this disease (Hamilton and others 1999). Studies performed at farm ammonia levels have also found negative effects on growth, up to a 1-6% difference in feed efficiency in gilts. However, these studies compared two different production systems. The differences observed could have therefore been the result of less microbial exposure and not only the effect of the presence of ammonia (Diekman and others 1997; Diekman and others 1993).

Studies on turkeys have shown that ammonia can affect turkeys. Nagaraja et al. (Nagaraja and others 1983) found that prolonged exposure to ammonia at concentrations as low as 10 and 40 PPM damaged tracheal tissues in turkeys.

Hydrogen sulfide (H_2S) is a very toxic gas, as mentioned previously, which is also derived from the decomposition of manure. Unlike ammonia, which is water soluble and lighter than air, H_2S is heavier than air and tends to stay in the lowest points in a barn such as the pit area. As with the human safety concern when manure in pits or tanks are agitated and pumped onto cropland, the sudden death of housed animals in these confined barn has been reported (Curtis 1981). Several (estimated to be 5 to 10 per year) of these occur each year in Minnesota, even though numerous organization, including the University of Minnesota Extension Service, recommend that buildings be empty of animals when deep pits are agitated and pumped.

Biogenics

Airborne endotoxins, microbes, and pathogens are other airborne contaminants that may pose a health risk to animals housed inside buildings. Although colony forming units (CFU) have been measured in animal facilities, especially poultry units, the significance of this microbial exposure on the impact of health and performance of poultry is not well established. As noted by Hartung (Hartung 1994) this could be due to different responses to airborne microorganisms. One response causes respiratory disease if specific microbes (pathogens) are present in the environment in sufficient number to cause infection. Another response may be non-specific where the immune system is stimulated by exposure and over time it is compromised (Hartung 1994).

Another reason why it is difficult to separate the impact of microbial insult from that of other air contaminants, such as dust and ammonia, is that pathogens may attach themselves to dust particles thus making it difficult to distinguish or isolate the impact they have on an animal. For example, on-farm air quality monitoring of turkey flocks and their performance has indicated higher rates of carcass condemnation for turkeys marketed in the winter as compared to the summer (Debey and others 1995; Janni and Redig 1986). This carcass condemnation is most often attributed to air sacculitis indicative of respiratory disease.

However, overall air quality in the winter season is poorer with higher observed levels of ammonia, dust, bacteria, and fungi.

Many poultry veterinarians are of the opinion that the microbes are opportunistic and that other conditions need to be present in order to allow infection to occur which is supported by research. Barnes (Barnes 1982)cites evidence that reproduction of respiratory disease is difficult in a research laboratory using the infectious agent alone. Poss (Poss 1994) has indicated that respiratory disease in turkeys is often preceded by exposure to ammonia and dust, which reduces defense capabilities of the respiratory system. In fact Janni and Redig (Janni and Redig 1986) found that direct exposure of turkeys to aspergillus spores did not cause the expected development of aspergillosis in turkeys. Rearing of turkeys in the presence of varying levels of ammonia without dust exposure also resulted in no negative effects. However, exposure of poultry to ammonia followed by challenge to respiratory diseases often worsens infection rate (Anderson and others 1966; Nagaraja and others 1984). Dust is of concern as well due to the association of some bacteria and virus with dust particles of respirable sizes (Carpenter and others 1986). Once the disease organisms are introduced to the flock, dust plays a role in the transmission among the birds.

Thus the interaction of the air contaminants and other environmental conditions may be as important as defining the airborne microbial environment. As indicated in a review (Halvorson and Noll 1989), there are many factors in the environment and management of poultry houses that could affect respiratory disease. Litter moisture, ventilation rate, environmental temperature, heat stress, vaccination programs, and water sanitation.

Summary

Although a large number of studies on the effect of air contaminants on animal health have been published, the results are inconclusive. Some effects have been shown with some gases such as ammonia, but generally at levels that were higher than those found in farm conditions. Airborne pathogens may show the most potential for impacting animal health but even there it seems to take a combination of dust, gases, and pathogens to obtain a measurable health effect. Some studies have been able to show adverse effects of these air contaminants, but others have not.

MITIGATION AND EMISSION CONTROL TECHNOLOGIES (QUESTION 4)

INTRODUCTION

Odor and gas emissions from animal production sites originate from three primary sources: buildings, manure storage and treatment facilities, and land application of manure. In this review, a detailed description of the methods and technologies to control odor and other emissions from animal and poultry facilities include the following: dietary manipulations, dust control techniques, ozone systems, biofilters, covers, mechanical solid separation, composting, anaerobic treatment systems, aerobic treatment systems, electrolytic treatment, injection and incorporation of manure during land application, and various product additives that can be incorporated into the feed, waste treatment, handling or storage systems. A summary is provided in Table 15.

The table includes a short description of the system/process, advantages and disadvantages, cost (when available), and research status. Advantages and disadvantages are usually in terms of the ability or effectiveness of the process/system in reducing odor and gaseous emissions. There is also some information on costs (mainly capital costs), but this has not been standardized. Cost may be given on a per pig basis (because most research has essentially focused on swine manure) or on a per area basis (in terms of the amount of material needed). On the research status column, there is information on when research was done under a particular process/system, if there is on-going research, and if there is need for more research. Specific references have not been included in this table. Detailed information is given in the main text. In most topics, background information (*i.e.* how the mitigation technology works) is given in order to allow the reader better understand the concept behind the management, effectiveness and cost of different systems.

DIET MANIPULATION

Until recently, most of the research related to technologies for reducing livestock-related gases and odors has focused on manure handling and storage systems. Research related to diet manipulation to reduce excretion of odor and gas producing products from animal manure has been limited. However, several researchers believe that our ability to modify livestock diets to significantly reduce odors is a promising mitigation measure. In order to explore the full potential of diet modification for reducing odors, significantly more research is required to identify practical, cost effective dietary changes for each species. Most published research results have focused on dietary modification to reduce ammonia emissions, with only a few studies attempting to determine the effects of diet modification on odor or other odorous gases. Furthermore, the majority of studies have focused on swine, with fewer studies being conducted for poultry, dairy, and beef.

Livestock diets have been manipulated by adding feed additives to bind ammonia, change digesta pH, alter specific enzyme activity, and mask odors (Sutton and others 1999). However, these dietary modifications have either been costly or not consistently successful (Sutton and others 1999).

Binding Agents

Krieger et al. (Krieger and others 1993) tested the ammonia binding ability of a naturally occurring zeolite (clinoptilolite) in pig manure and found no benefit. Furthermore, Shurson et al. (Shurson and others 1983) fed a diet containing 5% zeolite A (synthetic zeolite) to growing pigs and found an increase in fecal nitrogen excretion and an increase in urinary p-cresol excretion. Miner (Miner 1995) reported that addition of 5% charcoal to diets of weanling pigs showed a reduced odor score.

Change Digesta pH

In an earlier literature review, feeding microbial compounds resulted in no consistent effects on reducing odors (Kreis 1978). Attempts to reduce digesta pH of weanling pigs by feeding *Lactobacillus acidophilus* in liquid or dry form had no effect on odor panel scores (Miner 1975). However, feeding dry *L. acidophilus* and yeast reduced skatole and indole after a two-week incubation period (Miner 1975). Risely et al. (Risley and others 1992) showed that adding the organic acids, fumaric or citric acid, to the diet at a rate of 1.5%, had little effect on pH and volatile fatty acid production, suggesting little effect on odor control. Fermentable carbohydrates (i.e. soybean hulls) were included in the diets of finishing pigs by Canh et al. (Canh and others 1996)to lower the pH of the feces excreted which resulted in lower ammonia emissions but made an increse in VFA concentrations, and thus odor.

Alter Specific Enzyme Activity

Yucca schidigera extract has been shown to reduce ammonia emission from manure by inhibiting urease activity (Ellenberger and others 1985; Gibson and others 1985; Goodall and others 1988). Sutton et al. (Sutton and others 1992) showed that ammonia emission was suppressed by 55.5% in swine manure from pigs fed sarsaponin extract at a rate of 4 oz/ton of feed, but Kemme et al.(Kemme and others 1993) was unable to verify this response, and showed that much higher amounts of the extract (6000 ppm) was needed for maximal suppression of ammonia from urea. Similar results have been obtained with poultry.

Masking Agents

Work by Matsushima reported in *Feedlot Management* (Feedlot Management 1972) showed that adding sagebrush to cattle diets reduced cattle feedlot odor. However Kellems et al. (Kellems and others 1979)add sagebrush up to 1.5% of the diet for cattle and found no effect on reducing odor in cattle manure, but when 0.25% peppermint oil was added to the diet, odors were reduced.

IMPROVING DIETARY NUTRIENT UTILIZATION TO REDUCE EXCRETION PRODUCTS

The use of improved feeding management practices, selective feed ingredient use, precision in diet formulation, and dietary electrolyte balance have been shown to reduce nutrient excretion, and subsequent, odor and gas emissions from livestock manure.

Reduced Crude Protein Diets

Reduced crude protein diets containing synthetic amino acids have been shown to reduce nitrogen excretion by 25 to 30% in pigs, which can lead to reduced ammonia emissions (Bridges and others 1994; Cromwell and Coffey 1993; Jongbloed and Lenis 1993; Hartung and Phillips 1994). Reductions in ammonia emissions from 28 to 79% through diet modifications in swine have been reported (Sutton and others 1999). Reducing the crude protein content in dairy cattle rations has been shown to reduce hydrogen sulfide content of manure and emissions (Stevens and others 1993). Feeding excessive levels of the amino acid tyrosine (3% of the diet), increases p-hydroxphenylacetic acid and p-cresol in urine of pigs (Radecki and others 1988)

Table 15. Summary of technologies for odor control

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Diet manipulation	Feed Additives	Binding agents (zeolite, charcoal)	May reduce odor	Increase in fecal N excretion	N/A	Research done in 1975, 1984 and 1993.
		Change digesta pH	Apparently none	Little effect on odor control	N/A	Research done in 1975, 1978 and 1992.
		Alter specific enzyme activity (*Yucca schidigera*, sarsaponin extract, etc.)	May reduce odor and NH_3 emissions.	Not known yet	N/A	Research done in 1992, 1993 and 1998. Needs more research.
		Masking agents	May reduce odor	Inconsistent results	N/A	Research done in 1972 and 1979.
		Add fat or oil to the feed	Reduces dust and may reduce odor	Not known yet	N/A	Research previously done in 1975, 1982, and 1987. Recent and on-going research.
	Improving dietary nutrient utilization	Synthetic amino-acids and low crude protein content	Lower N content in the manure, reduces odor, H_2S and NH_3 emissions	Excessive levels of synthetic amino-acids may increase concentration of odorous compounds in urine	N/A	Recent and on-going research.
		Ingredient selection and feed processing (reduced sulfur feed ingredients, distiller's dried grain, carbohydrates, etc.)	Reduces odor, H_2S and NH_3 emissions depending on the type of ingredient used	Not known yet	N/A	Recent and on-going research.
		Dietary electrolyte balance	Affects urinary pH and may reduce NH_3 emissions	Not known yet	N/A	Recent and on-going research.
	Manipulating microflora metabolism in the digestive tract	Non-starch polysaccharides and oligosaccharides that alter the microflora	May reduce odor emissions	Little effect on NH_3 emissions	N/A	Very little research has been done. Needs more research.
		Specific microbial cultures	May reduce odor, H_2S and NH_3 emissions	Not known yet	N/A	Very little research has been done. Needs more research.
Diet manipulation	Manipulating microflora metabolism in the digestive tract	Antibiotics	May reduce odor emissions	Not known yet	N/A	Very little research has been done. Needs more research.

		Tea polyphenols	May reduce odor and NH_3 emissions	Not known yet	N/A	Recent and on-going research. Needs more research.
Dust reduction	Oil sprinkling	Vegetable oil is sprinkled daily at low levels in the animal pens	Helps in the reduction of airborne dust and odors	Creates an oily environment and greasy residue on the floor and pen partitions if too much oil is sprinkled	$1.00 per pig space	Recent research efforts. Needs more research, especially for curtain sided, naturally ventilated barns.
	Air filtration	Single and dual phase air filters, electrostatic precipitators	Very efficient in removing dust from air streams	Expensive and not very practical	N/A	Previous research done in 1981, 1984 and 1989. More recent research done in 1995.
	Biomass filters	Uses chopped cornstalks and corncobs as the filter substrate	Efficient removal of dust and odor (60 to 90%) at low ventilation rate	Lower efficiency at summer ventilation rates	N/A	Recent and on-going research. Needs more research.
	Wind-break walls	A wall made of tarp or with any other material (wood panels, metal sheets, straw) is placed about 10 to 20 ft from exhaust fans.	Trap dust particles in wall surface. Help disperse and dilute odors. Reduces dust and odor emissions.	Periodic cleaning of dust from the walls is necessary for sustained odor control. May be difficult to apply in naturally ventilated barns.	$1.50 per pig space	Recent and on-going research. Needs more research.
	Shelterbelts	Rows of trees and other vegetation are planted around a building, thus creating a barrier for both dust and odorous compounds removal from building exhaust air.	Help disperse and dilute odors. May reduce dust and odor emissions.	It may take several years to grow an effective vegetative wind-break	N/A	Recent and on-going research. Needs more research.
Dust reduction	Biological and chemical wet scrubbers	Odorous gases are passed through a column packed with different media types; water (and/or chemical) is sprayed over the top of column to help optimize biological and chemical reactions.	Reduce dust, odors, H_2S and NH_3 emissions effectively	Capital and operational costs; disposal of collected pollutants	N/A	Recent and on-going research.

	Washing walls	A wetted pad evaporative cooling system is installed in a stud wall about 1.5 m upwind of ventilation fans and downwind of hogs in a tunnel ventilated building.	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 per pig space	Recent and on-going research. Needs more research.
	Other controls	Building hygiene, water sprinkling in open feedlots, increase air exchange rates	Reduce dust emissions	May expose worker to high levels of airborne dust during cleaning operation or when higher ventilation rates are used	N/A	Research done in 1978, 1982, 1988, 1989, 1993 and 1996.
Air treatment	Ozonation	Odorous gases are oxidized by ozone that is distributed inside the barn at low concentrations	May reduce dust, odor, H_2S and NH_3 emissions	Ozone can be toxic to humans and animals at 0.1 ppm for an 8-hour exposure period	$6.00 to $11.00 per pig space	Recent and on-going research. Needs more research.
	Non-thermal plasma	Odorous gases are oxidized when passed through plasma	Reduces H_2S and NH_3 emissions effectively (from laboratory scale experiments)	Not known yet	N/A	Recent and on-going research. Needs more research.
	Biofilters	Odorous gases are passed through a bed of compost and wood chips; bacterial and fungal activity help oxidize organic volatile compounds	Reduce odors and H_2S emissions effectively	May need special fans because of pressure drop; some management required	$0.50 to 0.80 per pig space	Recent and on-going research. Needs more research on media characterization, design model, leaching and application to pit ventilation only.
Covers	Rigid covers	A roof or concrete lid is placed on the top of the manure storage tank. Gases that are produced must be vented and may undergo treatment (*e.g.* through biofilters)	Reduce odor, H_2S and NH_3 emissions effectively	More expensive than other types of covers; the cover concept may affect the overall water balance on the farm; more land is needed for manure application (higher N content)	$50,000.00 (capital cost of a concrete cover for 200 sow to finish operation)	Recent and on-going research. Needs more research related to the effects on water balance and nutrient content of the covered manure.

	Flexible covers	Plastic cover is placed on the top of the manure storage tank. Cover may be inflated. Gases that are produced must be vented and may undergo treatment (*e.g.* through biofilters)	Reduce odor, H_2S and NH_3 emissions effectively	Usually need supporting structure; difficult to apply on earthen basins; require some management by the farmer for agitation and pumping; the cover concept may affect the overall water balance on the farm; more land is needed for manure application (higher N content)	\$1.50 to 2.00 per ft^2 for a plastic cover; \$90.00 to \$100.00 per linear ft of diameter for an inflated cover)	Recent and on-going research. Needs more research related to the effects on water balance and nutrient content of the covered manure.
	Permeable floating covers	Straw and other materials (geotextile, polystyrene foam, air-filled clay balls, etc.) are placed on the surface of manure	Reduce odor, H_2S and NH_3 emissions	Straw covers are a temporary solution only; require some management by the farmer for agitation and pumping; geotextile may sink; the cover concept may affect the overall water balance on the farm; more land is needed for manure application (higher N content)	\$0.10 per ft^2 for a straw cover; \$0.20 to 0.25 per ft^2 for geotextile; \$2.00 to 5.00 per ft^2 for air-filled clay balls	Recent and on-going research. Needs more research related to the effects on water balance and nutrient content of the covered manure.
Manure treatment	Solid separation	Solids are separated from liquid slurry through sedimentation basins or mechanical separators	May reduce odor and NH_3 emissions; reduces liquid volume; easier agitation and pumping	Capital and operational costs; reliability; adds another “waste” stream to be dealt with by the farmer	\$1.00 to 3.00 per pig	Some past research was related to separators’ efficiency in removing solids, organic matter and nutrients. Needs more research related to the effect of separation techniques on odor and gaseous emissions.
	Chemical addition	Different chemicals are added to the manure prior to agitation and pumping in order to bind odorous compounds, keeping them in solution or facilitating their precipitation to the bottom of the tank	May reduce odor, H_2S and NH_3 emissions; may also precipitate P if needed	Chemicals may be expensive and hazardous in nature (*e.g.* corrosive)	N/A	Some past and recent research have focused on chemical addition for improving solid separation and precipitating phosphorus. Needs more research related to the effect of chemical addition for odor and gaseous emissions reductions during agitation and pumping.

	Solid and liquid composting	Biological process in which aerobic bacteria convert organic material into a soil-like material called compost;	Reduces odor and organic matter in the final product; produces a saleable product; can include other by-products	Capital and operational costs; actual composting operation may emit odor and gases (NH_3) if not properly managed; marketing skills required if product is to be sold	$0.20 to 0.40 per pig for solid composting; up to $6.00 per pig for liquid composting	Recent and on-going research. Needs more research related to odor and gaseous emissions control in composting facilities.
	Aerobic treatment	Biological process where organic matter is oxidized by aerobic bacteria; mechanical aeration is required in order to supply oxygen to the bacterial population	Reduces odor, organic matter effectively; also can reduce nutrients if needed	Capital and operating costs; separation step is necessary for most slurries	$2.00 to 6.00 per pig	Research done in the past focused on reduction of organic matter. Recent and on-going research is focusing on odor control and potential gas emissions. Needs more research on partial aeration strategies.
Manure treatment	Anaerobic digestion - lagoons	Biological process where organic carbon is converted to methane by anaerobic bacteria under controlled conditions of loading; there is no control over temperature and gaseous emissions	Stabilizes organic matter; produces biogas (that is not usually collected);	Periodic overloading and turnover in the spring may result in odor emissions; there have been concerns on the leaching of earthen basin lagoons and NH_3 emission from the surface	$0.50 to 1.00 per pig	Research done in the past focused on reduction of organic matter and nutrients. There has also been some research related to leaching. Recent research on NH_3 but needs more research on this and other gaseous emissions.
	Anaerobic digestion - digesters	Biological process where organic carbon is converted to methane by anaerobic bacteria under controlled conditions of temperature and pH;	Stabilizes organic matter; produces biogas; retains nutrients; easier handling of liquid	Capital cost; may require a reasonably skilled operator; attractive where energy supply is an issue	$250,000 capital cost; may produce $$$ worth of energy if properly operated	Research done in the past focused on stabilization of organic matter. There has also been research related to the land application of anaerobically digested manure in terms of odor and NH_3 emissions.
	Electrolytic treatment	A pair of copper electrodes is used to treat stored manure; small quantities of metal ions dissolved through electrolysis are apparently able to kill some microorganisms	May reduce odor, H_2S and NH_3 emissions	Process is not completely understood and can be costly	N/A	Needs more research.

Product additives	Microbiological additives	Contain mixed cultures of enzymes or microorganisms designed to enhance solids degradation and reduce gaseous emissions	May reduce odor and gaseous emissions	Inconsistent results; variable success; may not achieve desirable results under field conditions	$0.25 to 1.50 per pig	Recent and on-going research.
	Masking agents	Made from a mixture of compounds that have a strong odor of their own; cover one smell with another "more pleasant"	Low cost and non-hazardous nature	Effectiveness is difficult to predict	$0.25 to 0.50 per pig	Recent and on-going research.
Product additives	Counteractants	Reduce the perceived odor level by eliminating objectionable characteristics of the malodor	Easy and safe to handle	Effectiveness is difficult to predict	$0.25 to 0.75 per pig	Recent and on-going research.
	Adsorbents and absorbents	Chemical or biological materials that can collect odorous compounds on their surfaces (adsorb) or interiors (absorb)	May reduce odor in certain conditions	Effectiveness is difficult to predict	$0.25 to 1.50 per pig	Recent and on-going research.
Land application	Manure incorporation	Manure is rapidly incorporated in the soil after spreading with ploughing	Reduces odor and NH_3 emissions	Requires some management by the farmer and additional energy for incorporating	N/A	Most research has been done in Europe. Very little research done in the U.S. More research needed on odor emission from manure spreading operations.
	Band spreading	Manure is discharged at ground level through a series of trailing pipes	Reduces odor and NH_3 emissions	Manure must be rapidly incorporated to avoid odor emission and NH_3 losses	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.
	Manure injection	Manure is injected into the soil (shallow and deep injection)	Reduces odor and NH_3 emissions effectively	Expensive equipment	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.
	Treated manure	Aerobically treated or anaerobically digested manure is applied to the soil	Reduces odor effectively	Biological treatment of manure is expensive	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.

	Acidified manure	A chemical compound is added and mixed into the manure just before spreading	Reduces NH_3 emissions effectively	Chemicals may be expensive and are hazardous in nature (*e.g.* corrosive)	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.

Ingredient Selection and Feed Processing Methods

Ingredient selection and feed processing methods designed to reduce antinutritional factors have been shown to reduce nitrogen excretion (Jongbloed and Lenis 1991). Research that has been carried out at University of Minnesota (Whitney and others 1999) showed that use of reduced sulfur feed ingredients in diets for nursery pigs reduced sulfur excretion, tended to reduce hydrogen sulfide and odor emissions, but had no effect on ammonia emissions or pig growth performance. Additional studies at University of Minnesota are being conducted to determine if adding 20% distiller's dried grains with solubles to swine diets will reduce odor, hydrogen sulfide, and ammonia (Shurson 1999). Imbalances of the dietary carbon:nitrogen ratio in the intestinal contents of the pig will increase the level of odor producing compounds and reduced nutrient utilization efficiency (Drochner 1987; Kaufmann 1986). In swine, feeding diets containing a higher proportion of complex carbohydrates such as cellulose, B-glucans and other non-starch polysaccharides shift nitrogen excretion toward feces and away from urine, which reduces ammonia emissions (Kreuzer and Machmuller 1993; Mroz and others 1993). Feeding a low carbohydrate, high fiber diet (alfalfa meal and rice bran) to pigs reduces excretion of fecal volatile acids compared to pigs fed a corn starch and glucose diet (Imoto and Namioka 1978). However, Hawe et al. (Hawe and others 1992) showed that feeding a diet containing increased fiber from beet pulp, increased the concentration of two odorous compounds, skatole and indole, in feces, but levels of these two compounds tended to be reduced when pigs were fed the antibiotic tylosin phosphate. Lactose had no effect on reducing indole concentrations but did reduce daily excretion of skatole.

Dietary Electrolyte Balance

Canh (Canh and others 1998) and Mroz et a*l*. (Mroz and others 1996) showed that dietary calcium salts and electrolyte balance significantly affect urinary pH and subsequent pH and ammonia emissions from slurry. Mroz et al. (Mroz and others 1998) showed that increasing the levels of calcium benzoate in sow diets reduced urine pH from 7.7 to 5.5 and reduced ammonia emissions up to 53%.

Manipulating Microflora Metabolism in the Digestive Tract through Nutrition

Although some studies have been conducted to show that the addition of nonstarch polysaccharides and specific oligosaccharides to the diet alters the route of nitrogen excretion and reduces odor emission, more research is needed to determine the effects of digestive microflora changes when various substrates are added to the diet. Furthermore, the effects of feeding specific microflora cultures (probiotics) to livestock on reducing odor, and the conditions where these microbial cultures have the ability to compete with indigenous populations are poorly understood. Very little research has been done to determine the effectiveness of feeding antibiotics on odor and gas reduction. Some microbial groups that have an ability to produce or utilize odorous compounds have been identified, but considerably more research is still needed to identify groups of microflora that significantly contribute to the production of odorous compounds.

Nonstarch Polysaccharides and Specific Oligosaccharides

Feeding diets containing complex carbohydrates (fructooligosaccharides, mannan oligosaccharide, lactulose, galactan, ammonium propionate, and sucrose thermal oligosaccharides) or organic acids to swine alters the microflora in the digestive system (Bailey and others 1990; Mathew and others 1993; Orban and others 1997; Sutton and others 1991). Feeding fructooligosaccharides and sucrose thermal oligosaccharides to pigs and broilers increase bifido bacteria and reduce odorous compounds in manure (Hidaka and others 1986; Orban and others 1993; Orban and others 1997). However, including galactan (Mathew and others 1993) or ammonium propionate (Sutton and others 1999) in the diet had little effect on ammonia emissions, increased the volatile fatty acid propionate, and decreased production of butyric and acetic acids.

Specific Microbial Cultures

A study at the University of Minnesota is being planned (Shurson 1999) to determine the effectiveness of a *Bacillus subtilus* microbial feed additive on reducing odor, hydrogen sulfide and ammonia emissions. This product has apparently been successful in reducing odors in pig operations in Japan.

Antibiotics

Very little research has been conducted to determine the effectiveness of feeding antibiotics to livestock on reducing excretion of odorous compounds. One study conducted with swine showed that effectiveness of antibiotics in reducing excretion of odorous compounds appears to be antibiotic specific. Feeding the antibiotic combination of chlortetracycline, sulfamethazine, and penicillin, reduced urinary excretion of p-cresol, but feeding lincomycin sulfate had no effect on p-cresol excretion in swine (Yokoyama and others June 1982).

Tea polyphenols

Dietary inclusion of tea polyphenols has been shown to reduce the production of ammonia, phenol, p-cresol, ethylphenol, indole, and skatole in swine feces and chick cecal contents (Sutton 1998). Tea polyphenols have also been shown to reduce some pathogenic organisms including *Mycoplasma pneumonia, Staphylococcus aureus*, and *Clostridium perfringes* (Hara and Ishigami 1989; Chosa and others 1992). However, Veum et al. (Veum and others 1997) did not observe any effects of tea polyphenols on odor compounds.

Summary

The use of feed additives and/or dietary modifications for livestock and poulty to reduce odors from excreted manure has produced varied results. the chemical and biological processes of animal digestive systems are complex, often resulting in some odorous compounds being reduced but others increasing in concentration, as a result o fsome change or addition in the diet. Further research is necessary to make sure an integrated approach is used and the effects are found.

Dust and bioaerosols control

Airborne dust levels in and emissions from animal facilities are an increasing concern for animal production systems. Dust in and from animal facilities consists of mainly organic materials like: feed, bedding, animal dander (skin and feathers), dried manure, and inert particles (Koon and others 1963; McQuitty 1985).

Dust has been shown to exert adverse health effects on animal and human health. It may also impair the performance of equipment (Carpenter 1986; Dawson 1990).

A multi-country northern European study (Seedorf and others 1998; Takai and others 1998; Wathes and others 1998) of emissions of airborne pollutants within and from livestock buildings has been recently carried out. Authors of this study note that the European Union requires its member states to develop limits on pollutant emissions from new, large production sites for poultry (>40,000 birds) and pigs (>2000 fattening pigs or 750 sows). European levels for animal exposures to pollutants are: 20 ppm ammonia, 3000 ppm CO_2, 3.4 mg/m^3 inhalable dust, and 1.7 mg/m^3 respirable dust.

Discussion of the results of this study describe the following techniques and issues with respect to airborne pollutant emission control:

No single technique will control airborne emissions due to complexity of sources

Care must be taken not to raise one pollutant while lowering another; calling for an integrated solution

A combination of husbandry practices and engineering controls will provide the best control of dust and airborne pollutants

More research is needed on preventing emissions at the source or cleaning the air prior to emission

Multiple demands are placed on ventilation systems, including the control of 1) air temperature, 2) relative humidity to relieve heat stress and suppress dust generation from bedding, and 3) airborne pollutants to lower animal and worker exposures as well as to prevent discharge of unwanted pollutants to the environment. Design algorithms are not sophisticated enough to handle all of these control needs.

Because of the relatively large concentrations of dust in livestock facilities, controlling dust in these environments is a problem. Takai et al. (Takai and others 1998) and Maghirang et al. (Maghirang and others 1993) suggested that there are three ways to reduce dust in ventilated animal facilities: reduce the generation or emissions of dust, remove or capture the airborne dust, and increase the dilution or ventilation rate. An example of each of these would be: (1) addition of animal fat in feed to lower dust generation rates; (2) circulating air through a dust filter to capture it from the air; and (3) using an open sided building (natural ventilation) to allow for greater levels of air exchange.

Change in Feed Composition

Reducing the generation of dust in and from animal facilities generally involves preventing particulate matter from becoming airborne. Some research has suggested that feed is perhaps the greatest source of dust in livestock buildings. Evaluation of changes in feed composition or feed coatings indicate that such changes can result in lower dust levels (Chiba and others 1985; Chiba and others 1987; Pearson and Sharples 1995; Takai and others 1996). Numerous studies have shown a sizable reduction (35 to 70%) in dust levels inside barns when anywhere from 1 to 4% fat/oil is added to the feed (Chiba and others 1987; Heber and Martin 1988; Takai and others 1996). This technique or practice has been used extensively in the pig and poultry industries, partially because of the dust reduction capabilities, but also because of the nutritional (additional energy) benefits of the diets. Feeding system alternatives (Bundy and Hazen 1975), such as using pelleted vs. ground feed, using wet vs. dry feeders, and even the use of liquid feeding have not been extensively evaluated in regard to how they control dust levels in animal buildings (Pearson and Sharples 1995). It has been noted, however, that the benefits to animal and human health must be made more explicit to encourage farmers, feed producers and feed delivery system manufacturers to consider changing feed formulation or delivery as a means of lowering dust levels.

Oil Sprinkling

A similar approach to reducing dust is by spraying various types of vegetable oils inside animal buildings to reduce indoor airborne dust levels. Dust suppression by the sprinkling of oils and other materials have shown to effectively reduce airborne dust levels, with few apparent side effects (Mankell and others 1995; Takai and others 1995). Takai et al. (Takai and others 1993) found that dust levels could be reduced from 60 to 80% when canola oil was sprayed daily with a high pressure dispensing system in a pig nursery building. They also found that little or no health problems existed with the pigs that were exposed to this oil treatment. Zhang et al. (Zhang and others 1996) showed a similar reduction of dust by simply spraying or sprinkling canola oil once a day with a hand-held sprayer in the pens of a pig-finishing barn. Jacobson et al. (Jacobson and others 1998) used this same oil sprinkling technology (Zhang 1997) to determine if lowering the dust generation also reduced odor emissions from a pig nursery barn. Somewhat mixed results were found as were some disadvantages to this practice, including worker safety issues (slippery floors) and more time needed to clean the room between groups.

Air Filtration

Carpenter and others suggest that air filtration is the most cost-effective and efficient method for removing dusts (Carpenter 1986). Air filtration can serve many purposes, including the prevention of disease entry into the building by lowering the concentration of bacteria of inlet air and the minimization of cross-infection between buildings. Carpenter (Carpenter 1986) states that, “However, it is not normally practiced because of the high costs that would be incurred due to the large volumes of air and high dust loadings involved.”

While external sources of dust are important, most of the larger particles and airborne microorganisms are generated by sources within livestock buildings. Internal recirculating filtration systems can be used to lower internal levels from these sources. Research with washable electrostatic filters demonstrated significant decreases in airborne dust levels (Carpenter 1986). A dual-phase filter (a coarse cleanable pre-filter followed by a more efficient filter for fine particles) also demonstrated significant decreases in dust levels (50 to 60 % of the dust mass) in swine confinement buildings (Carpenter and Fryer 1990).

Electrostatic precipitators have been used to reduce dust in the US (Bundy 1984; Bundy 1991) by 55 to 60 % and in Europe (Moller F.) by 40 to 60%. Several studies used a commercial wet scrubbing process to remove dust from the air with water (Wark and Warner 1981; Pearson and Sharples 1995) and one investigation reported up to a 90% reduction in dust levels in the exhaust air (Pearson 1989) by use of wet scrubber technology.

Using water to scrub odorous dust, ammonia, hydrogen sulfide and other gases from the airflow from swine building ventilation fans can be an effective method of controlling dust, odor and some gaseous emissions. Many industrial air pollution control systems use sprays of water to scrub dust, NH_3, SO_x and NO_x from various polluting air streams. In a wet scrubber an alkali is usually added to react with acidic pollutants. This can be calcium oxide, quicklime calcium carbonate, or a magnesium or sodium alkali. The wastes produced in scrubbing must either be regenerated using additional energy, disposed of as a solid, or used in some manner.

Some swine producers in the U.S. and Taiwan have tried spraying water into the fan airflow (*e.g.* spray nozzles are mounted on the fan housing) with limited success (Bottcher 1999). However, this approach may require a large amount of water unless the spray is collected and recirculated.

Chiumenti et al. (Chiumenti and others 1994) used an air washing system in a mechanically ventilated swine unit in Northern Italy. Air cleaners were installed behind the fans to filter all the exhaust air. The air cleaning system operates using a two-stage mechanical wet separation system. Exhaust air (0.4 to 0.7 ft/sec) passed through a pre-cleaning chamber provided with 20 water sprinklers. It then passed through the main separation chamber that was made of steel with polycarbonate panels. A continuous fresh water curtain was created in this chamber by running water over a plastic net. Maximum water flow was 28 ft^3/hour. Wastewater was periodically discharged into the farm’s manure treatment system. The air cleaning system reduced dust by 44% and ammonia levels by 58%. The estimated energy consumption for this system was 83 watts/pig-day.

A wet scrubber design that recirculates most of the water through the system has been tested in North Carolina (Bottcher and others 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. The scrubber is comprised of an evaporative cooling pad system with water recirculation, using 6 in. thick plastic evaporative pad media. A 1,500 gal. sump outside of the building contains system water and facilitates solids settling. The producers and system designers have termed this a washing wall, since all of the ventilation airflow passes through the wet pad before being exhausted through the fans, and some contaminants are washed from the air. The term wetted pad wall is more descriptive.

Recent measurements taken by Bottcher et al. (Bottcher and others 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. Results from the model tests are consistent with these data. Particle reductions ranged from 0 to 63% at a pad face air velocity of 17 ft/min and from 14 to 77% at a face velocity of 63 ft/min. The estimated total dust mass, computed based on particle diameters (Parbst and others 1998), was reduced by 32% and 69% at the low and high airflow rates, respectively. Although the changes in odor levels across the wet 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 (Hoff and others 1997a). The wetted pad wall also reduced ammonia levels in the ventilation airflow by 50% at low ventilation rates and 33% at a medium ventilation rate. It is possible that chemicals can be added to the pad water to enhance removal of ammonia, hydrogen sulfide and other gases and odorous compounds, but the contact time is probably too short for the chemical products to work effectively. In fact, air may spend as little as 0.1 seconds inside the pad at high 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).

Table 16. Operating data and removal efficiency from a biomass filter.

Filter type	Surface area	Air Flow	Dust removal	Odor reduction
Three-tiered horizontal	20.4 m^2	2298 m^3/h	67 %	61 to93 %
Vertical cascade impactor	8.8 m^2	3060 m^3/h	62 %	0 to 84 %

Several researchers have evaluated bioscrubbers (where the packed bed of the scrubber is seeded with microbes) and wetscrubbers for the reduction of ammonia, odor and dust, especially on swine and poultry farms. Recent research has been reported in the Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities held in Vinkeloord, The Netherlands, between October 6 and 10, 1997. Dong et al. (Dong and others 1997) reported average ammonia removal efficiencies between 32% (wet scrubbing) and 54% (bioscrubbing) from laboratory experiments. Lais et al. (Lais and others 1997) evaluated three different bioscrubbers installed on pig farms. Ammonia reductions varied from 22 to 36% and odor reductions from 61 to 89 %. Siemers and Van den Weghe (Siemers and Van den Weghe 1997) evaluated the effect of different moisturizing methods on ammonia and odor efficiency of wetscrubber/biofilter combinations. Ammonia reductions ranged from 13 to 95% and odor reduction averaged 40%. Bioscrubbers and wetscrubbers can be effective in removing ammonia and odor from animal houses but have not been widely adopted because of difficulties in cleaning sufficient volumes of air at a reasonable cost. Lais et al. (Lais and others 1997), for example, reported capital costs ranging from $9.00 to $17.00 per finishing pig; thus, all of these technologies, although effective, may be quite expensive and not very practical for most animal production units because of the large physical size needed with the high ventilation requirements in animal buildings.

Particulate removal from livestock ventilation exhaust air could be used to control, but not eliminate, odor emissions (Hammond and Smith 1981). Researchers at Iowa State University, for example, have been testing biomass filters to remove particulate material and odorous dust from swine buildings (Hoff and others 1997b). Biomass filters use the principle that dust, if removed from the ventilation exhaust stream, will capture a large portion of the odors with it (Hartung 1985; Borrelli and others 1989; Hagen and Skidmore 1971). To achieve particulate removal Hoff et al. (Hoff and others 1997b) tested two designs of a biomass filter using chopped cornstalks and corncobs as the filter substrate. The first was a three-tiered horizontal filter and the second was a vertical cascade impactor. Table 16 summarizes the data.

The results indicated that using readily-available crop residue configured as a biomass filter for retaining exhausted particles and the adhered odors may prove to be a worthwhile strategy (Hoff and others 1997a). Dust concentrations were reduced, especially for particles in excess of 10 microns, and rodents can become a management problem as well as changing the biomass periodically. Odor threshold reductions followed closely the particle reduction, although removing 100 percent of the particles will only remove about 75% of the exhausted odors. The above reductions occurred with low resistance to airflow at cold weather ventilation rates.

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 in order to reduce dust and odor emissions onto neighboring land (Hsia 1998). 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 tarp have been used in several places. Walls are placed 10 to 20 ft downwind of the exhaust fans of tunnel ventilated barns. Another variation of the windbreak wall is called a straw wall. Such a system has been built in North Dakota. It is made with a wood structure and “chicken wire.” Straw is placed inside the structure, thus providing a barrier to dust and other air emissions. It acts as ab “impaction” plate as well as providing some filtration capability.

Windbreak walls work by reducing the forward momentum of airflow from the fans, which is beneficial during low-wind conditions, as odorous dust settles out of the airflow and remains on the farm. In addition, the walls provide a sudden and large vertical dispersion of the exhausted odor plume, which 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. (Bottcher and others 1998) using scentometers at a full scale windbreak wall site in Duplin County, North Carolina have shown that:

- dust builds up on the wall surfaces;
- the walls redirect airflow from the building exhaust fans upward;
- dust and odor levels are greater in the airflow from the fans than 10 ft downwind of the windbreak wall, which also results from the upward deflection of the fan airflow.

A study done in Iowa using a model predicted that tall wind barriers placed around a manure storage or lagoon would reduce odor emissions (Liu and others 1996). 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.

Research to evaluate windbreak walls for dust and odor control is continuing in North Carolina and also in other states (Iowa, North Dakota). Currently, 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, odors emitted from nearby lagoons and earthen basin storages may complicate the situation. Several researchers believe that measurement of the impact of windbreak walls on airflow and the dust and odor levels in the airflow at the wall location should be incorporated into dispersion models to predict the downwind impacts of those emissions (Swine Odor Task Force 1998).

Rows of trees and other vegetation known as shelterbelts, which have historically been used for snow and wind protection in the Midwest, may also have value as odor control devices. They will also create a visual barrier. A properly designed and placed shelterbelt could conceivably provide a very large filtration surface (Sweeten 1991) for both dust and odorous compound removal from building exhaust air and help disperse and dilute odors, particularly under stable nighttime conditions (Miner 1995; National Pork Producers Council 1996). Currently, there are no studies available that directly address the total impact of vegetative barriers on odor reduction from animal farms, but many people give testimonials to their benefit. Shelterbelts should be inexpensive, especially if the cost is figured over the life of the shelterbelt, but it may take 3 to 10 years to grow an effective vegetative windbreak. Research is needed to determine if vegetative windbreaks concentrate odor.

Other Controls

Building hygiene is also noted by some to be an important factor in dust levels; poor care of floor litter is related to higher dust concentrations (Heber and Stroik 1988). Removing dust with a vacuum cleaner in a barn has been done (Nilsson 1982; Dawson 1990; Pedersen 1992) and did lower total dust concentrations but it also exposed the worker during the cleaning process to very high levels of airborne dust. Phillips and Thompson (Phillips and Thompson 1989) noted that buildings that are ventilated naturally have significantly higher levels of dust than those ventilated with fans.

The issue of reducing dust emissions also is a concern for outdoor feedlots or feedyards. Techniques are being developed to reduce dust release from large beef feedyards. One experimental system being used sprinkles water periodically (every two hours) using irrigation nozzles over the surface area of the feedyard to prevent the dust from being aerosolized. This has subjectively reduced dust emissions from the outdoor yards but levels have not been quantified (personal communication with Brent Auvermann).

The final way of lowering or reducing dust levels is to increase the air exchange rates in a barn. Although this approach is valid for some units, there are some situations (Jacobson and others 1996) when dust levels were actually increased by high ventilation rates because it lowered the air humidity levels, resulting in a higher dust generation rate. Thus, ventilation or dilution of the air inside a building may have only a limited effect (Harry 1978) in controlling dust in an environment like an animal building with so many dusty surfaces and sources. Several studies have shown some benefits by manipulation of the ventilation system. Robertson (Robertson) “purged” a pig building with a high volume of air exchange for a 10 minute period to expel dust (60 % dust reduction) which can be a useful management tool for workers. Another study (van't Klooster and others 1993) modified the inlet system, in a standard negative pressure ventilation system, to bring in fresh air in the worker’s zone and exhausted air underneath the slatted floor, resulting in a 40% reduction in dust exposure to the workers.

Control of dust and associated gaseous compounds attached to dust particles, is difficult to accomplish in animal production units. The most accepted methods seem to be adding fat or oil to feed that if fed to the animals or directly sprinkling it in the room where the animals are housed. Other techniques are being evaluated which either lower the indoor concentration sof dust for worker health safeguards and for lowering the emission of dust from builings to reduce the impact on nearby neighbors and properties.

OZONATION

Ozone is a powerful oxidizing agent and a very effective biocide. Ozone high in the atmosphere acts to protect the earth from solar radiation. At ground level, however, the gas can be toxic. A general consensus is that high ozone levels can cause harmful respiratory effects. The current OSHA permissible exposure limit for ozone is 0.1 ppm for an 8-hour, time-weighted average exposure (Occupational Safety and Health Administration 1998). Ozone has been used for drinking water treatment on a municipal scale since 1906, when it was installed in treatment facilities in 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 disinfection, taste and odor control (Tate 1991). There are currently about 100 plants in the US and Canada using ozone (Droste 1997). Ozone has also been used in processing food for human consumption (EPRI 1997).

Many of the ozone generators use a process called corona discharge. Corona discharge occurs by producing controlled sparks in the presence of oxygen. Ultraviolet irradiation (wavelengths < 200nm) of a gas containing oxygen is another alternative method to generate ozone. Irridations greatly enhances the ability of ozone to decompose humic acids and other organic compounds.

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 will begin to smell like an “electrical fire”. The decomposition of ozone to oxygen is very fast. The half-life of ozone is near 20 minutes at typical conditions, but it can reach 60 minutes in a cool, sterile environment.

Ozone reacts with most organic material. It attacks organic compounds directly or free radical species formed by ozone decomposition (such as the hydroxyl radical, OH) oxidize organic matter. The most common products of a complete oxidation process are water vapor and carbon dioxide.

In animal production facilities, only limited published studies have been done evaluating the use of ozone for odor reduction. Ozonation can potentially reduce odors in livestock facilities by killing the odor producing microorganisms thus controlling the rate of production of odorous metabolites, and by oxidation of the odorous metabolites produced during anaerobic fermentation. Some researchers suggested that non-odorous molecules can actually be broken down into compounds more odorous than the initial molecules. However, most compounds when oxidized are reduced in odor intensity.

ASHRAE (ASHRAE 1989) determined that ozone is not an effective means of eliminating odors in ventilated air inside of buildings, but the fact is that there are several ozone systems on the market, and some are being tested on livestock farms with positive results. There are about a dozen ozonation systems operating in hog farms both in the United States (mainly in Minnesota, Iowa and North Carolina) and Canada.

Priem (Priem 1977) found that in a sixteen-month experiment, 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. The respiratory tracts of 37 normal and treated pigs were sampled and evaluated by veterinarians and they found no differences between the tissues from the two groups. It was also observed that animals in the ozonated room had slightly greater feed efficiencies and daily growth rates than animals in conventional rooms. Animals in the ozone treated rooms also seemed to be quieter. No noticeable corrosive effects were observed on the equipment in the ozonated room. Limited gas chromatographic data indicated that ozone breaks down indoles.

Researchers at Michigan State University reduced odorous compounds and disease-causing bacteria by treating swine manure slurry with high concentrations of ozone (Watkins and others 1996). In this study, ozone was bubbled directly into fresh and stored swine manure in a continuously stirred batch reactor. Ozone concentrations of 0.06, 0.12 and 0.2 lb/ft^3 were used. Olfactometric determinations (odor intensity measurements) showed a significant reduction in odors in ozonated samples as compared to raw and oxygenated samples. Volatile fatty acids, nitrate, phosphate and ammonia concentrations were unchanged by ozonation. Biochemical and chemical oxygen demand (parameters used to quantify organic material) were essentially unaffected by ozonation. The concentrations of odorous phenolic microbial metabolites (*e.g.*, phenol, p-cresol, p-ethylphenol) and odorous indolic microbial metabolites (*e.g.*, 3-methylindole and indole) were reduced to non-detectable levels by ozonation. Hydrogen sulfide concentrations were reduced slightly, with a concurrent increase in the sulfate concentration. *E. coli* counts were reduced by a factor of 3 log units (99.9%) and total coliforms showed a 1 log unit decrease (90%) after treatment with ozone at 0.06 lb/ft^3.

A more recent publication from Michigan State University researchers (Wu and others 1999) describes the results obtained from a pilot-scale ozonating system to reduce odor from fresh and stored swine manure slurry. A minimum dosage of ozone, 0.03 lb/ft^3, was established in order to reduce the odor intensity of fresh and stored manure slurry to an acceptable level (measurements made through ranking samples in terms of their odor acceptability by a human panel).

Researchers at North Carolina State University are evaluating a commercial ozone air treatment system in a tunnel ventilated swine finishing house at safe ozone levels for odor and dust reduction (Keener and others 1999). Preliminary results suggest that a significant decrease in NH_3 ($P<0.01$) and total dust ($P<0.02$) occurred in the ozonated building compared to the control building. It also appears that the concentrations of dust particles with optical diameters less than 1.0 µm were lower in the ozonated house than the control house. The evaluation of a commercial ozone treatment system for air quality is still underway. Further research is being conducted on this system at average ozone concentrations of less than 0.1 ppm (the OSHA 8-hour exposure limit). The ozone production is also being staged with ventilation rate to control ozone levels in the house at all times. The olfactometry panel did not measure significantly different levels of odor parameters in the air samples from the ozonated and control buildings. The reason for this difference between field observations and laboratory evaluation is still being investigated. Apparently, ozone changes the character of the odor, but odor units measured from air samples taken from an ozonated barn can be as high as the odor units measured from air samples taken from a non-ozonated barn. This is because human panels are not usually able to distinguish different odors when they are measuring odor thresholds. It seems that other odor evaluation methods need to be used when evaluating ozone effects on the air of animal houses, like odor intensity evaluation and hedonic tone characterization. Further investigation of the fate of small dust particles during ozonation is also being investigated.

Additional work is needed to determine if the ozonation system adversely affects the pigs and to ensure that indoor ozone levels are adequately controlled.

Researchers at University of Minnesota have built an ozone generator and an automatic ozonation system (Ruan 1999). The system was primarily developed to produce ozonated water with a high oxygen-reduction potential in order to disinfect food products. Other potential applications of this system include the use of ozonated water for the washing and cleaning of animal barns. The idea is to achieve not only reduction of odor and gaseous emissions, but also disinfection of premises.

The cost of ozonation systems can be significant. One particular ozone system for a swine finishing farm is projected to cost about $10,000 per building ($11 per pig space) for the ozone generating equipment and fans and tubes to distribute air in the building, and $50,000 to $60,000 for ozonating equipment for a large lagoon (roughly $6 to $7 per pig space for 10 buildings served by the lagoon) (Swine Odor Task Force 1998). The electrical costs are likely to be the largest operating cost. Since this technology has not been thoroughly tested, the costs may come down as ozonating requirements become better known. Also, there is concern over exceeding the OSHA exposure limiot of 0.1 ppm for an 8 hour time weighted average for those workers inside facilities.

NON-THERMAL PLASMA

Non-thermal plasma (NTP) is an innovative air pollution control technique being researched in the Biosystems and Agricultural Engineering Department at the University of Minnesota. A NTP reactor creates highly reactive chemical species that convert target gases to non-toxic gases. NTP has the ability to decompose dilute, complex polluting gases, which makes it suitable for treating exhaust air from animal and waste facilities. With further research and development, NTP could become another option for treating odorous gas emissions.

Non-thermal plasma (NTP) is created by discharging electrical energy into gases (Rosocha 1996). The electrical energy creates high-energy electrons that dissociate and ionize background gases to produce highly reactive species. These species react with target gaseous molecules (oxidative or reductive reactions) and convert them into non-toxic molecules. There are several NTP systems including pulse corona, silent discharge, surface discharge, and packed-bed.

Laboratory results reported by Ruan et al.. (Ruan and others 1997) indicate that silent discharge non-thermal plasma is a promising technique for animal house and manure odor control. These researchers achieved 100% removal rate for air containing 100 ppm ammonia and 60 ppm hydrogen sulfide using a pulsed corona plasma reactor. Other studies have shown that NTP is capable of treating dilute polluting gases with high energy efficiency and removing different polluting gases and VOCs simultaneously (Rosocha 1996; Chang and others 1991).

Non-thermal plasma (NTP) is a developing technology for treating dilute mixtures of odorous gases. It is still being researched as a treatment technology that can be used after gaseous emissions have been captured. Cost per animal is still not know since a commerical scale unit has not been operated long enough to report findings.

BIOFILTERS

Principle

Biofiltration is a viable air pollution control technology in Germany and in the Netherlands (Noren 1985), and is attracting interest in North America (Leson and Winer 1991; Janni and others 1998). Biofiltration uses aerobic microorganisms to break down organic compounds (or to transform some inorganic compounds) into carbon dioxide, water, salts and biomass.

Basic Design

Figure 2 illustrates a typical open face biofilter. Odorous air is exhausted from the building with either a wall or pit fan that is 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. The air passes through the media before it is exhausted to the atmosphere.

The basic component of the biofilter is the filter bed and a piping system or air plenum that forces the gas to pass through the filter bed. Perforated pipe embedded in round, washed gravel is the most common plenum used in industrial installations. A perforated block aeration floor to distribute the air can also be used, but at a significantly greater cost. The air distribution system must be as symmetrical as possible to minimize short-circuiting effects. Well engineered air distribution headers with graduated hole sizes or spacing are highly beneficial to improve airflow distribution down the length of a header pipe (Boyette 1998). Nicolai and Janni (Nicolai and Janni 1998a) devised an air plenum made out of shipping wood pallets covered with a plastic net, for a full-scale biofilter built for the treatment of odorous air from 700-sow swine facility.

Because the air from livestock units is generally quite corrosive, equipment and building materials should be made from fiberglass, stainless steel, or PVC rather than galvanized and carbon steel to extend the life of these components.

Polyethylene or PVC liners are often laid down on the top of the soil for groundwater protection. Alternatively, a concrete pad can be used at a greater cost. Excess condensate or precipitation is either pumped or allowed to flow by gravity out of biofilters to a treatment or collection system.

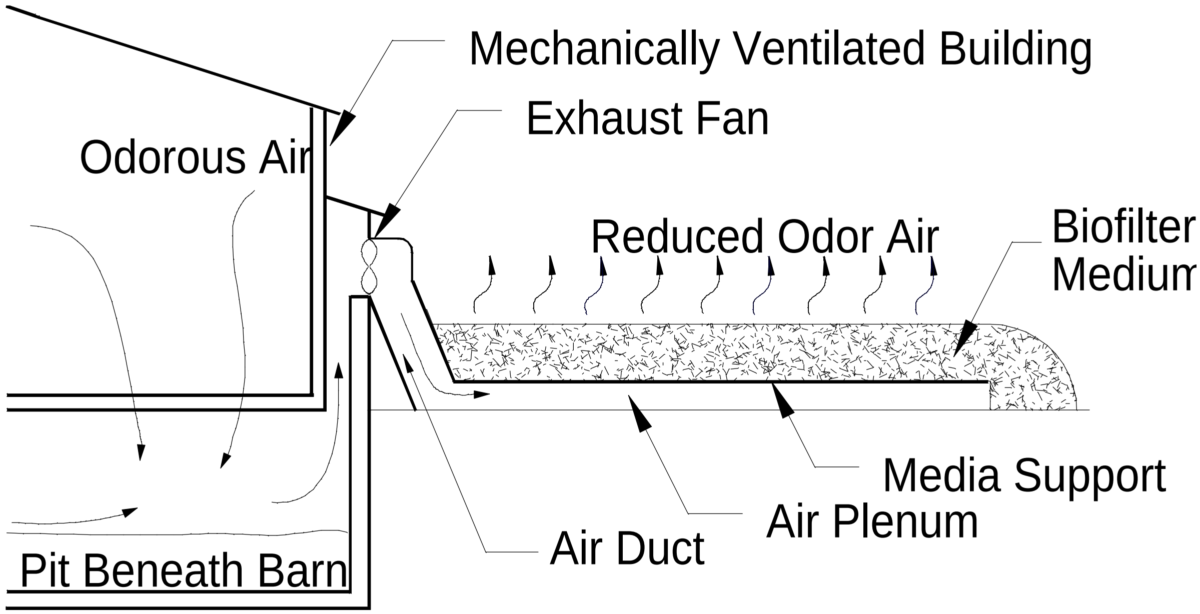

Figure 2. Open face biofilter.

The air stream should be ideally free from particulate matter, which would contribute to faster clogging of the media. Pre-treatment systems can be used to remove airborne particulates in order to minimize clogging of filter media pore space. Boyette (Boyette 1998) recommends building a system that is flexible enough so that field adjustments can be made in order to allow performance optimization. Complex pre-treatment schemes result in increased biofilter system cost.

Media consisting of mixtures of compost, wood chips, peat, soil or other materials are placed on top of the aeration plenum. Media thickness is dependent on density of media materials, but should be greater than 8 inches, in order to reduce possible air channeling, and less than 18 inches, to minimize pressure drop across the media. Media bed life is usually from three to five years. The full-scale biofilter studied by University of Minnesota research engineers has been operated for over one year (Nicolai and Janni 1997; Nicolai and Janni 1998a; Nicolai and Janni 1998b; Nicolai and Janni 1998c), and at this time, it is unknown when the media bed will need to be replaced.

The critical design features of the filter bed are to provide a high wetted surface area, a uniform airflow transmissibility and resistance to compaction and physical deterioration. Other important parameters include moisture content, temperature, oxygen level, and pH.

Beds are sized to provide a residence time of 30 seconds to 2 minutes or more (empty bed volume basis) for cases with high gas concentrations or other organic compounds. Adequate odor reduction can be achieved in livestock operations with much lower residence times, in the range of 5 to 15 seconds (Zeisig and Munchen 1987).

The system must be designed to allow for the irrigation of the media to prevent it from drying out plus for flushing the media for the removal of acids in the case where mineral anions are generated in the degradation process. Provision is also required for the capture and containment of condensate and leachate from the filter bed. In general, the biofilter should be placed on a sloped well-drained area to prevent water ponding.

Effectiveness

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 and others 1987). Noren (Noren 1985) reported ammonia and hydrogen sulfide average reductions of 80% with optimum moisture content from a swine barn biofilter.

Young et al. (Young and others 1997) in a pilot-scale biofilter recorded reductions on odor intensity from a swine barn ranging from 58% to 84%. Measurements were made with cotton swatches presented to a panel.

Nicolai and Janni (Nicolai and Janni 1997) reported an average odor reduction of 78% (minimum of 29% in April before a water sprinkling systems was installed 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 ranged between 0.10 and 0.19 in. of water (25 to 47 Pa).

Similar results were obtained by the same researchers using four small biofilters (5 ft by 7 ft) treating pit fan exhaust air from a deep-pitted swine nursery (Nicolai and Janni 1998c).

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 1998a; Nicolai and Janni 1998b). Average odor reduction was 82% over the first 10-months of operation. Average hydrogen sulfide reduction was 80% and ammonia reduction was 53% during the same period. Total pressure drop across the fans reached a maximum of 0.4 inches of water of which 0.2 inches could be attributed to the ventilation inlet system in the building.

Operation and Maintenance

Biofilter media plugging due to dust accumulation is expected to develop over time. When evaluating the performance of a biofilter, two areas to routinely examine are the airflow and the pressure drop. According to Boyette (Boyette 1998), pressure drop should be measured every week or every two weeks to establish a trend. This will help the farmer to identify when it is time to start replacing the media.

Inlet air temperature, and pH and moisture levels in the biofilter media are other parameters to be measured. The ideal moisture level is 55%, although it can be 60% or greater when a more porous mixture is used. Water addition to the biofilter can be automated with a soil moisture probe, a solenoid valve in the water supply system, and an electronic controller. The pH level has to be monitored because if it starts to decrease, some of the odorous gases might not be biodegraded sufficiently.

Walking by the biofilter and smelling gives a good indication if the biofilter is or is not working. Sometimes, observing the top of the biofilter is all it takes to evaluate its performance (e.g., looking for uneven dry and wet spots on the surface of the biofilter). Another way to verify biofilter performance at a reasonable cost is to conduct a smoke test. Smoke bombs placed into the inlets of the biofilter system will show where the air is going. The smoke emission will show whether the air is going through the biofilter or not. Periodic measurements of airflow by measuring pressure drop across the fans and referring to the fan performance tables are also important. They give an indication of the actual loading rate.

Good rodent control is essential. Mice and rats 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.

Excessive vegetative growth on the biofilter surface can reduce its efficiency by causing channeling and limiting oxygen exchange. Root systems can cause plugging. Noxious weeds need to be removed before they produce seed. Excessive vegetative growth may also subtract from the aesthetic appearance of the site.

Economics

The amortized construction and operating costs over three years for a full-sized biofilter installed on a 700-sow gestation/farrowing swine facility were $0.22 per piglet (0 to 12 lbs) produced per year (Nicolai and Janni 1998b). Generally, electricity to operate the blowers is the largest portion of the operating cost of a biofilter. Electricity for water pumps, controls, etc. add minimal cost (about $125 per year for the 700 sow farrowing to wean facility).

The second largest operating cost is potential media replacement. Depending on factors such as air temperature, gas concentration, loading rates, etc., media replacement may occur between 3 and 5 years. The cost for media replacement consists of removing the old media, obtaining new media, and placing it in the biofilter system.

Other costs tha may be incurred with a biofilter system include the following: Nicolai and Janni (Nicolai and Janni 1998b) estimated rodent control costs to be $275 per year for the 700-sow facility. Boyette (Boyette 1998) gives O & M costs for biofilter systems ranging from $2 to $14 per cfm of capacity for the exhausted gas treated. A few mechanical and electronic parts are associated with a biofilter system. As a result, maintenance costs are typically minimal. Labor and laboratory costs associated with monitoring and checking the biofilter system are also minimal.

Biofilters are a proven odor control technology for fan ventialted livestock facilities. Innovative designs are being developed to reduce the initial cost of these units plus minimize maintenance/operating costs and labor

COVERS

Description

Open manure storage facilities can be a very significant source of on-farm odors and volatile gases. They are the most apparent odor source, especially if there are no visual barriers from neighbors or passersby. A method to reduce odors and gaseous emissions from open manure storage units is to place some type of cover on the surface. This seems to be an effective method, since reasonably low emissions have been observed from dairy manure storage basins that have a natural crust.

Rigid and Flexible Covers

A concrete or wood lid can reduce odor release until the storage is agitated and emptied. Other options for the containment of odorous gases include lightweight roofs (fiberglass, aluminum, etc.), and flexible plastic membranes. Figure 3 shows the two different types of rigid covers used for odor containment.

Minimal headspace serves to reduce air exchange volumes and related odor control equipment when treatment is an option. Generally, odorous gases contained in a storage tank covered with a lid are either vented, or flared off. There are also various alternatives for their treatment (*e.g.*, biofiltration).

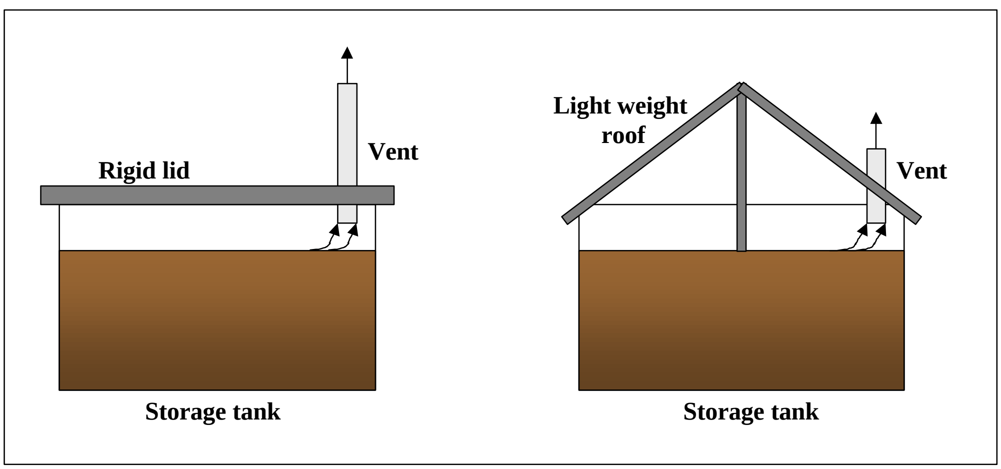

Figure 3. Rigid covers used for odor containment

Mannebeck (Mannebeck 1985) have found greater odor reduction percentages for permanent roofs constructed of wood or concrete (>95%). De Bode (De Bode 1991) showed that a roof over the storage tank could reduce ammonia losses by more than 80%. Sommer et al. (Sommer and others 1993) observed less than 5% ammonia losses from storage tanks with either cattle or pig manure covered with a wooden lid.

Rigid covers are usually more expensive than other types of covers, but they usually last longer (10 to 15 years, depending on the material). Zhang and Gaakeer (Zhang and Gaakeer 1996) estimated that a concrete cover for a 200-sow farrow to finish operation might cost as much as $50,000. But depending on the type of material used, this cost can be significantly reduced.

Another type of cover used for the containment of odors that is becoming popular, especially in Canada, is the inflatable cover (Figure 4). In this system, a tarp is fastened to the tank perimeter as tight as possible. A center support column with radiating straps supports the outer shell. Air is delivered through a low-pressure blower. The cover is maintained at a constant operating pressure (usually about 1 in H_2O, or 250 Pa). Zhang and Gaakeer (Zhang and Gaakeer 1996) observed that at an operating pressure of 0.4 in H_2O (100 Pa), the air leakage was 60 l/s. This leakage is approximately equivalent to the rate of a bathroom exhausting fan.

For agitation and pumping, the structure is deflated allowing the tarp to lay over the radiating straps. Access doors are then opened for the introduction of pumping equipment.

The odor reduction efficiency of an inflated cover can be as high as 95 % (Mannebeck 1985). Zhang and Gaakeer (Zhang and Gaakeer 1996) measured over 95% reduction in ammonia and hydrogen sulfide emission rates using an inflated cover with an operating pressure of 0.4 in H_2O (100 Pa).

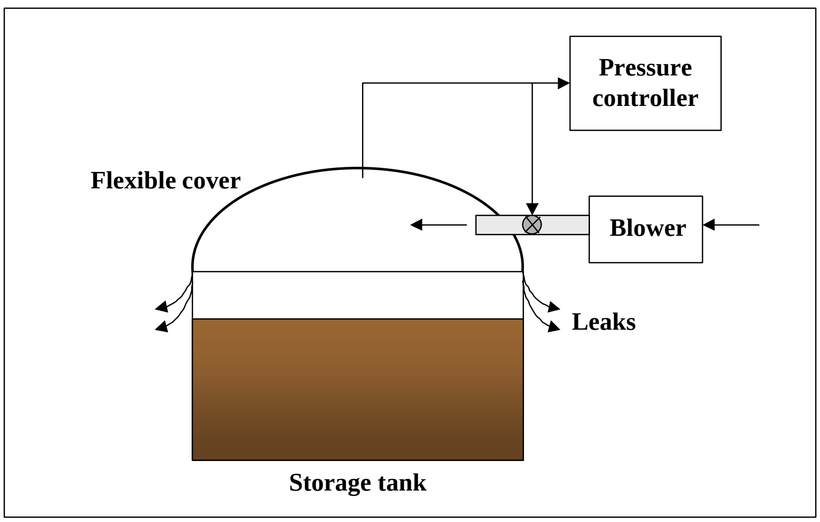

Figure 4. Flexible plastic inflated cover and control systems (Zhang and Gaakeer 1996)

The cost of an inflated cover varies between $90.00 and $100.00 per linear ft of diameter. The life expectancy is about 10 years.

Floating Covers

Floating covers can be made with a variety of materials. Natural floating covers are those formed by the fibrous material in the manure (*e.g.*, crust). Artificial floating organic covers, also called biocovers, include straw, chopped cornstalks, sawdust, wood shavings, rice hulls, etc. Polystyrene foam, plastic mats, air-filled clay balls like Leca® and Macrolite®, and geotextile have also been used as floating covers.

Basically, there are two types of floating covers (Figure 5). The first is an impermeable material (plastic or hydrocarbon-based material), which simply captures the odors that are later treated with a biofilter or are flared off (in the same way as if there was a rigid cover). The impermeable covers have had limited success because of high initial and operating costs, difficulty in collecting the odors, and the need to treat the odors before releasing into the atmosphere. Managing the system has been difficult and time consuming.

The second is a permeable cover that increases the surface-to-air resistance, and possibly causing a biofilter effect, which reduces odor emission. Floating organic materials, such as straw, are relatively low cost and have little labor requirements to maintain. Other floating permeable covers, such as geotextile materials, may provide a better solution than straw for certain type of storage basins which are not annually agitated and pumped, even at a higher initial cost.

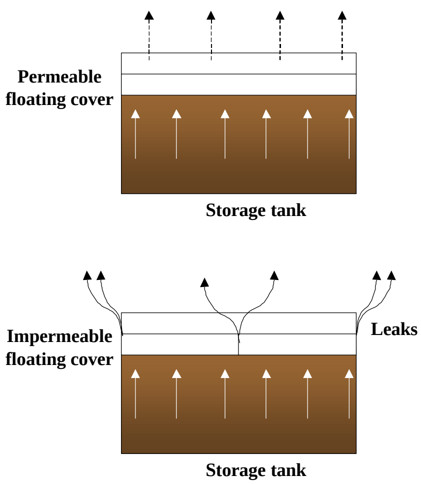

Figure 5. Schematics of odor reduction using permeable and impermeable floating covers

Adding a cover to the manure surface reduces the transfer of hydrogen sulfide and other odorous compounds from the liquid to the atmosphere, basically due to an increase of the surface-to-air resistance at the liquid-air interface. When a cover is placed directly over the manure surface, the following processes apparently take place:

- resistance to mass transfer is increased;
- gas concentration builds up under the cover;
- the rate at which a gas diffuses out of the manure is significantly reduced (because the gradient has decreased);

- volatile compounds are mostly kept into solution.

Permeable covers, such as straw, have been shown to be more suitable for reducing odor from livestock manure facilities than impermeable material. An aerobic layer is established on the top of the cover, so that some of the odorous compounds that escape to the atmosphere may be aerobically broken down. Impermeable floating material allows odorous compounds to escape through leaks at joints and near the tank walls.

Natural floating covers are those formed by the fibrous material in manure. Artificial floating crusts are composed of chopped straw, plastic foam pellets, a combination of straw and pellets, mats, or tarpaulins. Tight covers include plastic covers sealed at the edge and light constructed roofs. Mannebeck (1995) estimated the lives of the covers in his study: straw, six months; plastic pellets, two years; mats and tarpaulins, 10 years; and a lightweight roof, 15 years.

De Bode (1991) stated that covering manure storage could reduce ammonia emissions by 70 to 90%. However, if exchange was not adequately prevented between air above the manure and the outside air, the reduction was only 50%. Sommer(Sommer 1992) determined that an uncovered pig manure storage unit could emit approximately 4 g/m^2 day of ammonia-N. This figure was roughly reduced to 1.0 g/m^2 day when covered by a natural crust, 0.5 g/m^2 day when covered with straw, 0.5 g/m2 day when covered with Leca® clay balls, and 0.25 g/m^2 day when the surface was covered with oil and the storage facility had a sealed lid.

Meyer and Converse (Meyer and Converse 1982) evaluated several manure storage covers: chopped cornstalks, sawdust, wood shavings, rice hulls, ground corncobs, and grass clippings, alone or mixed with waste oil. Ammonia and hydrogen sulfide emissions were measured and a five-member odor panel ranked air samples. Covers made of rice hulls with oil resulted in the lowest ammonia and hydrogen sulfide emissions at 31% and 4% of uncovered facilities, respectively. The odor panel rated the cover made of grass clippings combined with oil as producing the least odor emissions, followed by corncobs with oil, cornstalks with oil, and rice hulls with oil.

Bundy et al. (Bundy and others 1997) compared chopped straw, cornstalks, polyethylene open mesh with a liquid surface film, Leca® clay balls, and foam generated from air bubbles and manure solids. They concluded straw and cornstalk covers may be cost-effective and Leca® has an excellent ability to control odor. Sommer et al. (Sommer and others 1993), reported about 15% ammonia losses from cattle slurry, and between 5 and 12% from pig slurry covered with Leca®, as compared to 100% losses from uncovered control tanks.

Miner and Pan (Miner and Pan 1995) developed a permeable blanket of straw and/or zeolite to cover manure storage units. They found odors were absorbed and oxidized on the moist aerobic bacteria-entrained surface of the fabric blanket. These authors also indicated that this type of technology has resulted in a 90% reduction in ammonia and hydrogen sulfide concentration in the space above the manure liquid.

Miner and Suh (Miner and Suh 1997) studied ten different polystyrene foam materials that reduced ammonia concentration by 45% to 90% compared to uncovered manure storage. The more effective cover materials were those with sufficient gas permeability to allow gases to pass through the cover material and breakdown aerobically, compared to less effective impermeable covers that allowed ammonia to pass around them. In a field study, Williams and Nigro (Williams and Nigro 1997) found that a supported corrugated plastic-coated steel cover reduced ammonia emissions by 68%. In a laboratory study, the team increased the reduction to 93% with a better designed cover and improved sealing, thus a reduction in leakage. They also found emissions increase about fourfold when temperature increases from 4 to 25^{o}C (39 to 77^{o}F).

Clanton et al. (Clanton and others 1999) studied seven covers including no cover (control), straw mat, vegetable oil mat, straw/oil mat, clay ball mat, PVC/rubber membrane, and geotextile membrane. The six covers reduced odor units and hydrogen sulfide concentration at various points in the study, but not in a consistent manner. The straw mat and PVC/rubber membrane significantly reduced both odors units and hydrogen sulfide concentration consistently up to a 94% reduction. Mixing vegetable oil with straw appears to increase longevity of the cover as compared to straw only with approximately the same removal efficiency. The vegetable oil layer, when mixed with the manure, produced a distinctively offensive non-swine odor. The clay ball mat reduced emissions, although not as well as other covers with only up to a 64% reduction. A geotextile membrane may be a possible cover choice, since the fabric is self-floating and the biofilm that grew on the mat could self-seal the cover with a removal efficiency up to 71%. A straw mat (possibly including vegetable oil) and PVC/rubber membrane appear to be the most effective covers in reducing both odors and hydrogen sulfide. Oil alone should not be used as a cover because of the offensive odor it emits.

Longevity plus the cost to install and maintain covers are important issues. Mannebeck (Mannebeck 1985) estimated the useful life of their evaluated covers varied from 1/2 year for straw up to 20 years for a concrete cover. Others have indicated that a 2- or 3-inch layer of straw will only last for several weeks. Canadian researchers (PAMI 1993) found that a 6-inch depth of barley straw lasted the full season (three to five months) with some reapplication of straw to small exposed areas of the storage unit. Jacobson (Jacobson 1998) observed both barley and wheat straw covers of 12-inches thick floating from two to four months with only an initial straw application on swine manure earthen basins. A single large round straw bale (6-ft diameter) covered about 500 ft^2 of storage area (100 bales/acre) and the cost for purchasing the straw varied from \$5 to \$10 per 100 ft^2. Application costs for straw are not well established but could equal the cost of the straw itself. Mannebeck (Mannebeck 1985) estimated that straw would cost as little as \$5 per 100 ft^2 while a floating tarpaulin would be \$250 per 100 ft^2. Geotextile covers have been estimated to cost between \$20 to \$40 per 100 ft^2 which includes both the initial and application costs.

Effectiveness

Covers can be an effective method of reducing odors and gaseous emissions from open manure storage units on farms. Reductions in odor levels are variable but are relatively high (greater than 70 %) for most types of covering materials. The main challenge in using this technology is to make it economically feasible for producers by reducing both initial and operating costs along with minimal maintenance. Other important issues include the effect of covering manure on the overall water balance on a farm and the potential need for more land to apply the manure (because there will be more nutrients retained in the manure). Floating organic covers like straw also create agitiation and solids/sludge accumulations and removal concersn which can be managed with the proper agitiation (chopper) and pumping equipment.

MECHANICAL SOLID SEPARATION

Solid-liquid separation has been generally used in the last few years as a physical treatment process for animal wastes, mainly for the improvement of manure handling properties by taking coarse solids and fiber out of slurry. Relatively low cost and simple technologies, such as settling basins and screen separators, have been applied for the removal of solid material from dilute slurries. Expansion of animal production in some regions with highly specialized operations, and increasing public concern with odors, water and air pollution is leading towards the utilization of more advanced technology and equipment (press augers, decanter centrifuges, etc.). Such equipment have long been employed in both municipal and industrial wastewater operations, but have not been commonly used for livestock wastes because these wastes are typically applied to land for fertilizer value and this utilization has not required solids and nutrient removal. However, in regions of concentrated confined animal production, there is more interest and need to remove nutrients and transport them from the farm.

There are several advantages related to mechanical separation of liquid manure including reduction of (i) nutrient content in manure; (ii) the solid content and improvement of homogeneity in the liquid phase; (iii) energy requirements for pumping and mixing before land application; (iv) ammonia emissions during land application of the separated slurry; and (v) energy requirements for aerobic treatment (Burton 1997). However, it must be realized that storage, handling and spreading techniques for both liquid and solid manure are required, higher investments for equipment have to be made as well as for operation and maintenance, and more farm management skills are needed.

Zhang and Westerman (Zhang and Westerman 1997) did a recent review on solid-liquid separation of animal manure for odor control and nutrient management. They also reported performance and economics of solid-liquid separators. Performance data of mechanical separators vary widely. Total solids content in separated solids vary from as low as 5% with a stationary screen, up to 27% with centrifuges. Separation efficiencies for TS varied from less than 10% to about 60%. Presses and centrifuges are found to have higher separation efficiencies and produce drier solids than screen separators. These large variations are not only due to the different testing and reporting procedures, but also because the characteristics of the manure used were sometimes largely different.

Unfortunately, there is limited research on how solid-liquid separation affects odor and ammonia emissions. Zhang and Westerman (Zhang and Westerman 1997) concluded from their review that fine particles in the manure decompose faster than coarse particles and most of the reduced carbon compounds, protein and nutrient elements are contained in fine particles. Because these compounds are the precursors for odor generation and the carriers of organic nitrogen and phosphorus, they recommend that solid-liquid separation processes are designed to remove both coarse material and particles smaller than 0.25 mm in order significantly reduce odor and nutrient contents. Therefore, if the goal of solid-liquid separation is odor reduction, it is important to have a separation process that removes the smaller particles.

Solid-liquid separation processes do not necessarily produce fewer odors. Additional treatment may be necessary. Theoretically, the separation of the solid and liquid portions of animal manure can reduce odor from subsequent storage and treatment facilities. If the separated liquid contains less solids and organic matter, it is likely that it will generate less odor and gases when stored. Unfortunately, quantitative information about this reduction is scant or it is not available.

The addition of chemicals to enhance mechanical solid separation is drawing more research attention (Gao and others 1993; Brionne and others 1994; Barrow and others 1997), but there is little or no information regarding odor and ammonia emission reductions from such systems. Recently, Westerman and Bicudo (Westerman and Bicudo 1998) reported on an innovative treatment system for swine manure that includes physical and chemical separation of solids. A few samples were analyzed for odor intensity (concentration), odor irritation intensity and odor quality (pleasantness or unpleasantness) using descriptive scales by a human panel. Statistical analysis performed with the experimental data indicated that there was no significant difference in odor (intensity, irritation and pleasantness) between flushed swine wastes and the liquid slurry after mechanical separation at the 5 % probability level. The chemically treated effluent was found to have less odor intensity and irritation than either flushed wastes or the separated liquid. However the odor intensity was “strong” and irritation was “moderately strong.” There was no significant difference in pleasantness between flushed wastes and the treated effluent or between the separated liquid and treated effluent ($P < 0.05$).

Sneath (Sneath 1988) studied the effects of removing solids from aerobically treated piggery slurry on volatile fatty acids (VFA) levels during storage. Stability was measured in terms of the time taken to reach two specific concentrations of VFA, 0.23 and 0.52 kg/m^3 (1 lb/gal = 120 kg/m^3). Slurries stored until a VFA concentration reaches 0.23 kg/m^3 were found not to cause odor problems, while those containing above 0.52 kg/m^3 have shown to release offensive odors. It was found that removal of solids using fine sieves or decanting centrifuge extended the storage times of the liquid portion by one-third before the VFA level indicated that offensive odors had returned to the slurry.

Solid-liquid separation theoretically should reduce odors if small manure particlas are removed from the liquid fraction. Practically, this is difficult to accomplish and thus relatively low odor reduction levels have been reported in the few studies done. There is a need to develop a better understanding of the impact of solids-liquid separation (including chemical addition) at different separation levels on odor and ammonia emissions in the subsequent liquid manure storage and/or treatment units, and the economics of the different methods. The odor potential of the separated solids must also be considered. While separated solids have potential as a valuable nutrient product, if not properly handled, they can be a significant source of odors. Composting or drying immediately after separation may help keep the odors of manure solids at a minimum level.

Composting

Composting is an aerobic, biological process in which microorganisms convert organic materials such as manure, sludge, leaves, paper and food wastes into a soil-like material called compost. It is the same process that decays leaves and other organic debris in nature. It offers several potential benefits including improved manure handling, enhanced soil tilth and fertility, and reduced environmental risk. The composting process produces heat, which drives off moisture and kills pathogens and weed seeds.

Composting can be used as a treatment system in animal or poultry farms where solid manure and solid material removed from liquid slurries by mechanical separators (with at least 15 percent dry matter content) are available. It is usually necessary to blend together several materials, in suitable proportions, to achieve a mix with the desired overall characteristics. Composting can reduce manure volume, stabilize manure nutrients, kill pathogens and weed seeds, and produce a homogeneous non-odorous product.

Researchers from the Agricultural University of Norway reported on the development of a liquid composting reactor using aeration for the treatment of animal manures (Skjelhaugen and Saether 1994). An insulated, cylindrical tank with a conical bottom was used. A submerged aerator supplied air that was used by aerobic bacteria to break down organic matter. Because of intense activity within the reactor, the biological process releases a large amount of heat that raises the temperature of the reactor content up to 140 ^{o}F. The duration of the treatment is adjusted to suit the needs related to the material being processed. A stable and hygienic product can be obtained after a retention time of 7 days. Hahne and Schuchardt (Hahne and Schuchardt 1996) described a similar system developed by the Institute of Technology, FAL Volkenrode, in Germany, that worked with three days retention time.

Although composting is a relatively expensive and labor intensive process, most of the operations that were established in dairy farms, for example, are self-contained. Farmers compost the manure produced on their farm, manage the effort themselves and own the finished product. Factors relating to the quality, handling, and distribution of the manure are the main reasons why people start and continue a composting operation (Rynk 1994).

Ammonia and odor emissions are perhaps the most common problems associated with composting, and failure to adequately address them can lead to neighbor complaints and the closure of large-scale facilities.

Gaseous and odorous emissions from animal and poultry manure composting are usually high during both the initial stages of composting and during the process of turning the material (Kuroda and others 1996). Emissions of carbon dioxide and ammonia during composting of various materials, including animal and poultry manure, have been well studied, particularly in respect to the degradation of organic matter and nitrogen losses (Martins and Dewes 1992; Lau and others 1992; Piccinini and others 1996). Martins and Dewes (Martins and Dewes 1992) measured gaseous losses during composting of poultry, cow and swine manures. The average gaseous losses ranged from 51 to 59% of the total N and consisted mainly of NH_3 (more than 95%). Kuroda et al. (Kuroda and others 1996) measured emissions of nitrous oxide (N_2O), hydrogen sulfide, methylmercaptans, dimethyl sulfide, dimethyl disulfide, methane and VFA. Emissions of N_2O, NH_3, and sulfur compounds changed with temperature and occurred during the periods of high temperature and after turning. VFA rapidly declined in the gas from the initial and did not increase afterwards. Methane emission was high in the beginning of the composting process, but then fall steadily throughout the monitoring period. Schmidt and Moon (Schmidt and Moon 1998) measured emissions from a composting site in Minnesota that processed caged-layer manure. They reported nitrogen losses to be about 70% of the initial nitrogen content. Emission of odor paralleled hydrogen sulfide emissions, *i.e.* emissions were higher from the 5-day old pile than from either raw manure or the older piles. Emission rates from the 5-day old pile were 3.74 odor units/s-ft^2, 1.5 μg H_2S/s-ft^2, and 55 Mg NH_3/s-ft^2. Emission rates from a 27-day old pile were reduced by more than 90% as compared to the 5-day old pile.

The research that has been carried out so far indicates that the use of sufficiently high initial C:N ratio and drier materials can help minimize odor and gaseous losses from composting operations. Lower ammonia emissions can be achieved by adding a large amount of dry, high-carbon amendment or bulking agent, such as straw. Other products, such as zeolite, have also been added to compost mixtures in order to minimize ammonia volatilization (Burton 1997). Zeolites have high cation exchange capacity and marked ammonia ion selectivity, and are thus able to reduce ammonia losses. Georgacakis et al.(Georgacakis and others 1996) reported results from a study on the composting of separated solids from swine manure mixed with ground lignite, ginned cotton residues and rice seed peels. Ground lignite residues were used as an odor absorbent and mixed with separated solids at a ratio of about 1:1 (by volume). The other two amendments were used as bulking agents and also to increase the C/N ratio. However, there was no quantification of odors or gaseous emissions from such a system.

Liquid composting at high temperatures usually lead to large ammonia emissions. Researchers from Norway developed a system to trap ammonia in the outlet air from their reactor using a heat exchanger together with a biofilter (Saether 1997). The heat exchanger condensed the humid outlet air to bring ammonia back to the composting process as ammonium. Excess ammonia was removed through a biofilter filled with peat. Saether (Saether 1997) claimed that 100% of the ammonia was removed by such a system. Skjelhaugen and Donantoni (Skjelhaugen and Donantoni 1998) reported on odor emission from the same liquid composting reactor. Odor from the untreated slurry was considered unpleasant during the whole experimental period (45 weeks). Odor from the composted liquid was noticeable, but not unpleasant. It varied during the storage period and had a different character to that of untreated slurry. The system was also able to reduce significantly the number of microorganisms due to the high operating temperatures (between 130 and 140 ^{o}F). Thermotolerant coliform bacteria were reduced from 10^4 per gram of slurry to less than 10^2 per gram of slurry, i.e. a 2 log units reduction or about 99% removal.

At many composting sites odors originate with the incoming ingredients, which may have been stored anaerobically for a week or more before transport to the site. Once these ingredients are incorporated into the composting system, subsequent odor problems are usually a result of low oxygen or anaerobic conditions. Odors and gaseous emissions from composting operation appear to be more significant in the early stages of the process and also during turning. Management seems to be a key factor in reducing odors and gaseous emissions from composting operations.

Because of limited experimental data on actual odor and gaseous emissions from real composting sites, it has been difficult or even impossible to assess the effect of composting on the overall air quality near or in livestock and poultry buildings. Up to now, composting has not been viewed as a treatment technology intended to reduce odor and gas emission from solid manure systems. Rather, composting has been viewed as a process that produces an odorless value-added material. If managed properly, or more importantly correctly, the composting process does not seem to produce significant odor and gas emissions.

AEROBIC TREATMENT

Process

In the last few years, researchers and producers have had a renewed interest in aerobic treatment of livestock wastes, especially swine wastes. Recent research has shown that the amount of aeration required to control odor could be much less than required for significant treatment of the manure to reduce the biological oxygen demand. New technologies include low-rate aeration systems, liquid-solid separation prior to aerobic treatment, and aerobic treatment following anaerobic treatment. Many of these new technologies are still in the development phase, and additional basic and on-farm research is needed.

Aerobic treatment is usually suitable for separated liquid slurry or dilute effluents. It is a natural biological degradation and stabilization process. Optimizing the oxygen supply to microorganisms accelerates the biodegradation process. The degree of oxidation depends on the amount of oxygen provided and the reaction time allowed in the treatment process. Slurry aeration allows microorganisms to metabolize dissolved components such as organic acids, phenols, indoles, nitrogen and sulfur compounds, low molecular weight proteins, etc., which are responsible for most offensive odor emissions. Since complete stabilization of livestock manure by aerobic treatment is normally not economically justifiable (Westerman and Zhang 1997), lower levels of aeration have been recommended for partial odor control. Continuous aerobic treatment may remove odor from hog manure within three or four days (Evans and others 1986; Sneath and others 1990). It has also been demonstrated that aerobic treatment can reduce odor emissions from land spreading operations up to 90% (Pain and others 1990).

Biodegradable organic material contained in animal manure can be oxidized into stable inorganic end products by aerobic bacteria. When slurry is sufficiently aerated, aerobic microbial activity dominates and free oxygen becomes the final electron acceptor. The relatively strong oxidizing environment leads to a more extensive breakdown of organic compounds, with water, carbon dioxide and other simple molecules being the products. In this way many of the organic compounds related to offensive odors are removed. A complete oxidation process can be expressed as (Westerman and Zhang 1997):

$$\text{Organic matter (C, H, O, N, S)} + O_2 \rightarrow CO_2 + H_2O + NO_3^- + SO_4^{2-}$$

The fate of the nitrogen component of the slurry in an aerobic process is of particular importance. Nitrogen in livestock slurries is approximately equally divided between organic and inorganic nitrogen (ammoniacal nitrogen). The composition of nitrogen compounds can be changed during aeration and these changes are dependent on the treatment time, temperature and dissolved oxygen concentration (Svoboda 1995).

Between 5 to 35% of slurry organic nitrogen can be converted to ammoniacal nitrogen by aeration. Ammoniacal nitrogen (NH_3-N) can be conserved or oxidized, first to nitrite (NO_2) and then to nitrate (NO_3). Treatment times over 3 days with aeration level over 1% of the saturated value for dissolved oxygen enable populations of nitrifying bacteria to develop (Smith and Evans 1982). Nitrate nitrogen in the treated slurry acts as a reservoir of oxygen and is utilized during storage. This helps prevent the development of anaerobic conditions in storage and emission of offensive odors. In the absence of nitrification, large ammonia losses are likely, particularly if airflow rates are excessive.

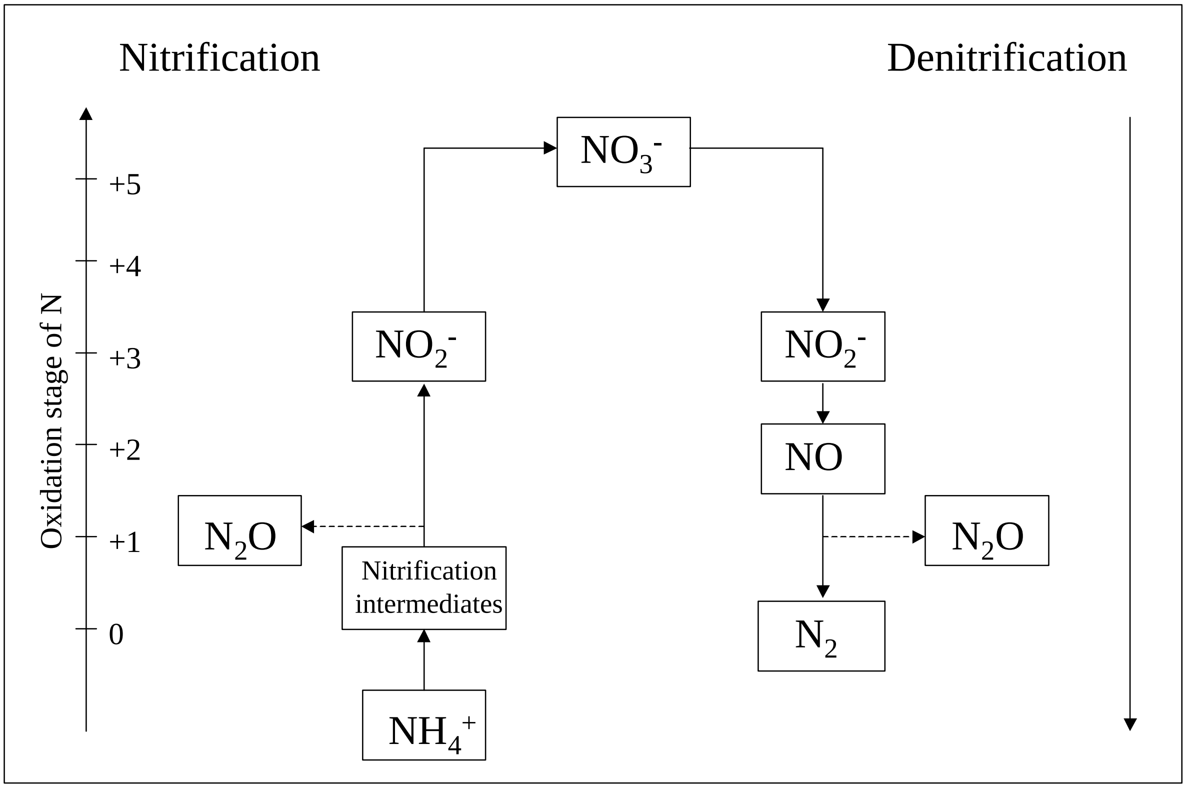

Figure 6. Possible routes (dotted lines) of N_2O production from nitrification/denitrification pathway (Pahl and others 1997)

Denitrification, i.e. reduction of nitrate to nitrogen gas, can occur during storage of nitrified slurry or during treatment if the aeration level is kept close to the minimum for nitrifying activity (Smith and Evans 1982). More recently, research carried out in the United Kingdom and The Netherlands has shown that the slurry nitrogen can also be released in the form of nitrous oxide (N_2O) during combined aerobic/anoxic treatment (Burton and others 1993; Willers and others 1996). N_2O is a strong greenhouse gas and depletant of stratospheric ozone and therefore a serious pollutant. The emission of N_2O are undesirable and may jeopardize the environmental benefits of treatment.

Both nitrification and denitrification are reported to be a possible source of N_2O. Figure 6 (Pahl and others 1997)shows the possible routes of N_2O production from the nitrification/denitrification pathway. It is still unclear if either nitrification or denitrification is a major contributor to the production of N_2O during aerobic/anoxic treatment. Sulfur compounds in the manure are converted to sulfate (SO_4^{2-}) in the aerobic environment, thus preventing emission of odor-causing sulfide and mercaptan compounds to the atmosphere.

Volatile fatty acids (VFA) are almost completely removed from manure with aerobic treatment, and apparently, VFA destruction is independent of treatment time in the range 1 to 4.5 days. According to Williams et al. (Williams and others 1989), VFA are the main soluble biodegradable components of slurry and are probably the most readily biodegradable substrate, given that simple sugars are unlikely to be found in significant quantities. Thus, as treatment time decreases, the microbial population must rely increasingly on simple soluble substrates. As a consequence, VFA becomes the largest fraction of substrate degraded.

The environmental conditions within aerated slurry (temperature, ammonia concentration, predation by microorganisms, etc.) are unfavorable for the survival of pathogenic microorganisms. Munch et al. (Munch and others 1987), for example, showed that Salmonella species could be significantly reduced in 3 to 7 days with aerobic treatment.

It should be noted that aerobic systems would likely require screening or removing the larger solids in the manure before the aeration treatment and would also produce biosolids from the treatment system. Both of these by-products would tend to have more odor than the liquid discharged from the treatment system and would likely require more treatment, such as the addition of lime or other chemical compounds to eliminate odor.

The main disadvantage of aerobic digestion systems for the control of odors from animal operations is the cost of supplying air. The cost of aeration, depending on the objective, if partial or complete stabilization odor control, may vary between $1 and $6 per pig-year.

Oxygen Requirements

The energy requirement for aeration constitutes a major proportion of the running costs of the aerobic treatment of any organic waste. It is normal practice in the activated sludge process for sewage treatment to maintain a dissolved oxygen (DO) concentration of around 2 mg/l. These high DO concentrations are used to ensure an adequate supply of oxygen to all cells within the floc. The air supply must also be adequate to provide adequate mixing throughout the aeration tank.

The theoretical oxygen requirements can be determined from the biochemical oxygen demand (BOD) or chemical oxygen demand (COD) of the waste. The minimum oxygen capacity should be twice the total daily BOD loading for complete oxidation of organic matter and also for converting ammonia (NH_3) to nitrate (NO_3) through nitrification processes, with a hydraulic retention time (HRT) of 10 days or more (NZAIE 1984).

Lower levels of aeration have been recommended for partial odor control from livestock manure. According to some reports, aeration for odor control requires only sufficient oxygen to equal the 5-day BOD of the manure during the six warmer months of the year, though this is not a well proven concept. Other sources recommend oxygenation capacity to supply 1/3 to 1/2 the BOD load for partial odor treatment (NZAIE 1984). Using a lower rate of aeration (compared to that needed for complete stabilization) reduces the release of volatile acids and other odorous gases and compounds as well as allowing some oxidation to less odorous compounds (Westerman and Zhang 1997).

According to Williams et al. (Williams and others 1989), two oxygen requirements can be defined:

- oxygen required to eliminate odors;

- oxygen required to stabilize the slurry during any subsequent storage.

Smith and Evans (Smith and Evans 1982) investigated the effects of reducing DO as low as 1% of saturation (equivalent to 0.1 mg/l) in continuous culture treatment of piggery slurry (residence time of 4 to 8 days). They found out that aerobic treatment at low DO levels would substantially reduce energy requirements. The efficiency of aeration was greatest when the DO content was minimal, and there was no loss in the efficiency of oxidation either by the heterotrophs or by the nitrifiers. The oxygen requirement for nitrification continued even at the lowest DO level used. Unlike the situation at high DO where the total oxygen requirement is the sum of heterotrophic and nitrification oxygen requirements, at low DO the total oxygen requirement is closer to the heterotrophic oxygen requirement only. This is because most of the oxygen used by the nitrifiers subsequently becomes available to the heterotrophs through denitrification. The main advantage of nitrification during treatment is that inhibition of the methanogenic bacteria that utilize volatile fatty acids (VFA) by free ammonia is minimized (Williams and others 1984). As a consequence, VFA destruction is accelerated and threshold levels of VFA may not be reached or will be reached later than would otherwise be expected.

Williams et al. (Williams and others 1989) found that the minimum oxygen requirement for treating separated pig slurry containing 39 kg/m^3 total solids to control odor was 0.11 kg/pig-day, which assuming an aerator efficiency of 1 kg O_2/kwh input, gives a minimum energy requirement of 0.11 kwh/pig-day. For very dilute slurries containing 14 kg/m^3 total solids, they found that 2-day residence time treatment would give complete stability for an energy requirement of 0.135 kWh/pig-day. The cost of aeration was estimated to be between $1.19 and $2.38 per finishing pig.

Williams et al. (Williams and others 1989) also investigated the stability of the treated slurries during subsequent anaerobic storage. VFA were used as indicators of odor offensiveness. Stability was measured in terms of the time taken to reach two specific concentrations of VFA, 0.23 and 0.52 kg/m^3. Slurries stored until a VFA concentration reaches 0.23 kg/m^3 was found not to cause odor problems, while those containing above 0.52 kg/m^3 have shown to release offensive odors. They found that the stability of treated slurries during subsequent anaerobic storage increased significantly (P=0.001) with residence time (between 1 and 5 days).

Burton et al. (Burton and others 1998) have recently reported that a farm scale continuous aerobic treatment was able to reduce odor concentrations by 50 to 75% with treatment times between 1.7 and 6.3 days. A reduction in the offensiveness rating of the slurry odor was achieved in all cases. The target aeration level was a redox potential in the slurry in the range of –50 to –150 mV E_{cal}. The effect of the duration of treatment on odor abatement was also quantified. No odor regeneration was discerned over the first 28 days after anaerobic storage of pig slurry treated for 2.4 days.

Aerobic and Facultative Lagoons

Aerobic lagoons are either mechanically aerated or designed to be naturally aerobic. Required design volume for a mechanically-aerated lagoon is about half that of an anaerobic lagoon; whereas the volume of a naturally-aerobic unit should be 4-5 times greater than the anaerobic type. This volume, together with a 3-5 foot depth limit, requires a land area so large as to make naturally-aerobic lagoons generally impractical for farm use.

Aerobic lagoons that are mechanically aerated are called aerated lagoons. Usually, surface aerators are used to add air to wastewater and promote growth of aerobic bacteria. Aeration rapidly reduces hydrogen sulfide emissions from swine manure, but less volatile and less offensive compounds such as phenols can persist (Sweeten 1991). Aerated lagoons are an alternative when space constraints limit the area available for manure storage or to reduce an odor nuisance problem. Aerated lagoons are able to reduce odor significantly by avoiding the anaerobic treatment environment that can produce odorous compounds. The biggest drawbacks to aerated lagoons are 1) the cost of energy to run the aeration units; 2) biosolids production, which is higher than in anaerobic systems; and 3) the potential for release of ammonia if the aeration level is not correct. More recently, research carried out in the UK and The Netherlands has shown that significant amounts of the slurry nitrogen can actually be released in the form of nitrous oxide (N_2O) during combined aerobic/anoxic treatment (Burton and others 1993; Willers and others 1996).

Aerators should be sized to provide sufficient oxygen to minimize odor production potential and promote decomposition of organic matter. Oxygenation capacity sufficient to satisfy at least the five-day biochemical oxygen demand (BOD), or the majority or all of the chemical oxygen demand (COD) plus the nitrogenous oxygen demand, is generally required (ASAE 1994). If only part of the organic waste is converted under aerobic conditions, lagoon odor emissions will be reduced somewhat. Partial aeration would, of course, lower the energy cost of aeration.

The biosolids produced during aerobic treatment of manure in lagoons and in other biological treatment systems must be collected, transported, processed, stored and utilized. There is the potential during all of these biosolid-related activities for significant odor production.

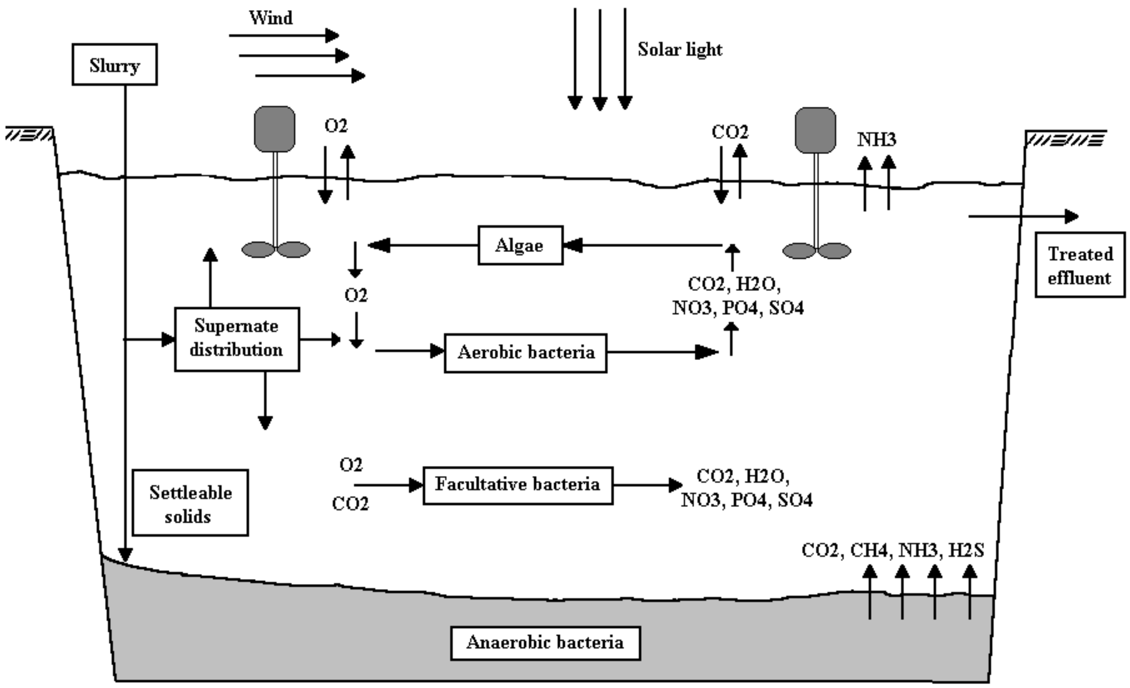

Figure 7. Schematic representation of a facultative lagoon with surface aeration

The concentration of biological solids produced is usually estimated by applying growth and substrate removal kinetics to biological treatment. The kinetic coefficients for different animal manures must be determined in the laboratory, with bench-scale studies. Bicudo and Svoboda (Bicudo and Svoboda 1995) estimated a biomass yield of 0.43 for an aerobic system treating pig slurry. The typical range for domestic wastewater is from 0.4 to 0.8. The endogenous decay coefficient varies from 0.025 to 0.075 day^{-1} for domestic wastewater; more specific data for animal manures are missing. An approximate estimate of the biosolids produced can be obtained by multiplying the assumed growth-yield constant (BOD basis) by the BOD removed.

It has been estimated that the electrical cost for running an aeration system continuously is about $6 per year per finishing pig using an electrical energy cost of $0.06 per kW-h. If each pig gained 200 lb during finishing, the energy cost would be $0.03/lb for the finishing period (Westerman and Bicudo 1999).

Facultative lagoons combine anaerobic and aerobic bacterial treatment (Figure 7). Although the concept of shallow aeration of deep treatment lagoons is not new, most information on the development of the process is from laboratory scale studies. There are two main mechanisms for organic matter and odor reduction in facultative lagoons:

- Sedimentation and subsequent anaerobic digestion of settleable solids;

- Aerobic bacterial oxidation of the non-settleable organic compounds together with the solubilized products of anaerobic digestion.

The oxygen needed for the aerobic oxidation is provided mainly by low rate surface aeration. A continuous loading scheme is recommended for best results. Schulz and Barnes (Schulz and Barnes 1990) tested this concept in two full scale lagoons and found that the process can effect up to 75% removal of organic material without generating nuisance odors, and using about 1/3 of the power required for a fully aerobic lagoon. This would cost about $1.80 per year per finishing pig space. However, aeration to supply only partial BOD removal could result in promoting ammonia volatilization depending on some specific operating conditions, which may be an undesirable tradeoff. In order to design such a system particular attention must be given to lagoon depth, specific power input and type of aerator.

Aerobic Digestion

Aerobic digestion is based on the biological principle that microorganisms metabolize their own cellular mass under aerobic conditions when the available food supply in the surrounding wastewater is inadequate. This phenomenon is called endogenous respiration. Cell tissue is oxidized aerobically to carbon dioxide, water, and ammonia. In practice, only about 75 to 80% of the cell tissue can be oxidized; the remaining 20 to 25% is composed of inert components and organic compounds that are either difficult to degrade or are not biodegradable. The ammonia from this oxidation can be further oxidized to nitrites and nitrates, depending on the amount of oxygen supplied.

Some of the advantages of aerobic digestion system as compared to anaerobic processes are as follows:

- Volatile solids reduction is at least the same as that obtained in anaerobic digestion, but usually greater;
- Lower BOD concentrations in supernatant;
- Production of an odorless, humus-like biologically stable material;

The major disadvantages are that:

- A high power cost is associated with supplying the required oxygen;
- Digested biosolids are produced with poor mechanical dewatering characteristics;
- The process is affected by temperature.

An additional disadvantage is that a useful by-product such as methane is not recovered.

Aerobic digestion normally takes place in reactors or tanks. The process requires tankage, aeration equipment, a solid-liquid separation capability, pumping with its associated valves and pipes, and automated controls. The digestion units consist of separate concrete or steel tanks, rectangular or circular in shape. To prevent freezing in extremely cold climates, it may be necessary to cover the digesters. Aeration can be continuous or intermittent, and it is most efficiently done with diffuser systems.

The process operates on either a batch or a continuous basis. Many batch aeration treatments carried out in farms can be described as fed batch or semi-continuous, if slurry is either added or removed during the aeration process. This tends to be the result of practical needs rather than process requirements (Burton 1992). On the other hand, continuous aeration offers the option of a controlled steady-state process, and the phenomenon of the initial surge in activity is avoided.

The process is called *activated sludge* when the biosolids are separated and part of these are returned to the reactor (Figure 8).

The biosolids contain a variety of heterotrophic microorganisms, including bacteria, protozoa and higher forms of life that are responsible for the degradation of organic material. By returning these microorganisms to the reactor the overall biological process is significantly optimized. In this case, the oxygen requirements have to be adjusted since a portion of the waste is converted to new cells subsequently wasted from the system.

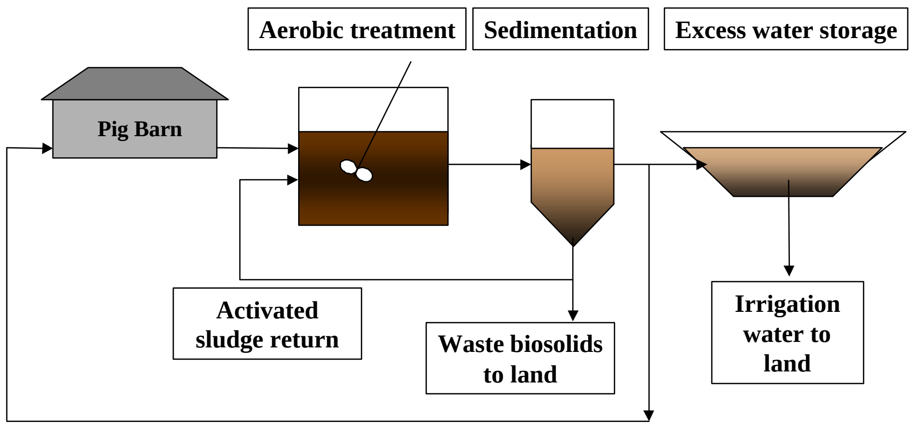

Figure 8. Activated sludge process for the treatment of flushed swine wastes

The application of the principles of the activated sludge process to the treatment of animal slurries has been investigated by a number of researchers (Osada and others 1991; Liao and Maekawa 1994; Bicudo and Svoboda 1995). Both carbon and nutrient transformations have been addressed in these studies, but there are only a few experimental data related to the performance of activated sludge treatment in reducing odor and gaseous emissions from animal manures (Voermans and Verdoes 1995; Willers and others 1996). Voermans and Verdoes (Voermans and Verdoes 1995) reported on a system similar to the one shown in Figure 7 that was able to reduce ammonia emission by 70%. Willers et al. (Willers and others 1996) described gaseous emissions measurements at a veal calf slurry treatment plant with capacity to treat 0.13 mgd. Ammonia emission was between 0.1 and 0.2% of total Kjeldahl nitrogen (TKN) in the slurry. Emissions of nitrous oxide were between 9 to 13% of TKN in slurry.

Operation of aerobic digesters as a fill-and-draw sequential process is called sequencing batch. A schematic of sequencing batch reactor operation is given in Figure 9 for a hypothetical pilot plant with capacity to treat 400 gal of manure per day. The unit processes involved in a *sequencing batch reactor* and conventional activated sludge systems are identical.

Aeration and sedimentation/clarification are carried out in both systems. The main difference is that in conventional plants, the processes are carried out simultaneously in separate tanks, whereas in a sequencing batch reactor, the processes are carried out sequentially in the same tank.

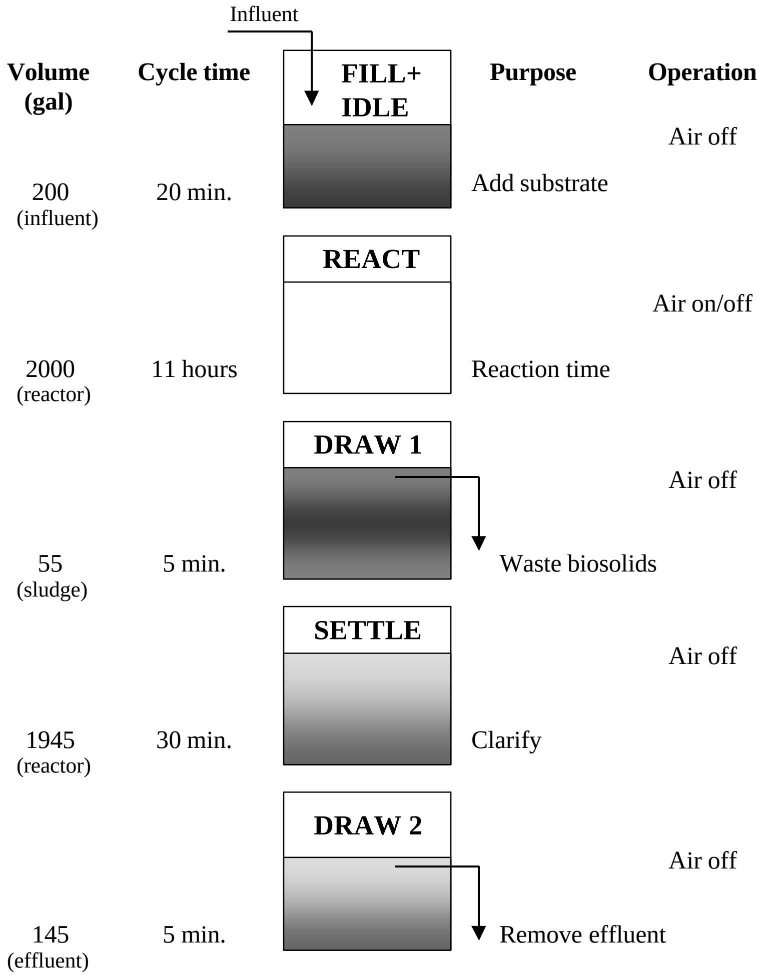

Figure 9. Typical SBR operation for 12-hour cycle

Bicudo et al. (Bicudo and others 1999a) have recently indicated that a sequencing batch treatment of flushed swine manure (5-day HRT and 30-day SRT) with intermittent aeration is able to significantly reduce odor intensity. Odor ratings decreases from 6.5 in the influent to 0.75 in the treated effluent, using a descriptive scale varying from 0 (none at all) to 8 (maximal). Results of the odor quality analysis also showed that the SBR significantly improved odor quality from a pretreatment odor descriptive of very unpleasant/extremely unpleasant to a post-treated descriptive of neutral odor for most operation conditions tested.

Other Aerobic Systems

There are different methods to promote retention of the bacteria responsible for biological treatment. One of these methods is usually referred as suspended growth. In this case bacteria are in suspension within the liquid. Aerobic lagoons and activated sludge processes, as discussed above, are good examples of the suspended growth method to retain bacteria. The other method is known as fixed growth, and bacteria grow attached to a certain material (plastic, rocks, etc.). Trickling filters and biofilters, for example, use fixed media to retain bacteria.

Packed bed reactors and biological aerated filters represent attached growth processes that have been utilized to some extent for nitrification of municipal wastewaters. Unlike trickling filters, the hydraulic design of these systems is such that the media are submerged in the reactor liquid. In packed bed reactors and biological aerated filters (also known as BAF), the media are stationary during normal operation, held in place by gravity. Westerman et al. (Westerman and others 1998) have summarized some of the most important aspects related to aerated biofilters and its applications for the treatment of municipal and industrial wastewaters, and agricultural wastes.

Westerman et al. (Westerman and others 1998) described a series of experiments that were carried out during 12 months in a pilot plant with capacity to treat up to 8 m^3/day of supernate from settled flushed swine wastes in North Carolina. The system was composed of two upflow-aerated biofilters connected in series and two polishing tanks, also connected in series. The aerated biofilters were evaluated in terms of reduction of organic matter, nutrients and odor. Average removals during warm weather conditions (about 80^{o}F) were over 80% for organic matter (BOD) and TKN. Operation at lower temperatures (about 50 ^{o}F) resulted in lower performances.

A mass balance average for the 12 months indicated that about 30% of the influent volume, 35% of Total-N and 60% of Total-P are removed with the biofilter backwash. Thus, management of the relatively low solids content backwash is a critical factor in implementing this type of system on a farm. The unaccounted-for nitrogen was about 24% and could have been lost as ammonia volatilization or possibly through denitrification within the biofilm.

Liquid samples were taken for evaluation by an odor panel on four different occasions during the monitoring period. They were analyzed for odor intensity (concentration), odor irritation intensity and odor quality (pleasantness or unpleasantness). Descriptive scales for odor intensity, irritation intensity and pleasantness utilized by odor panelists varied from 0 to 8. A trained odor panel evaluated all samples. Positive control (butyric acid) and blank samples (fabric and water, not exposed to odorants) were used throughout the evaluation. There were significant reductions in odor intensity from about 5.5 to about 2 and odor irritation from about 4.5 to less than 2 in the biofilter effluents, with most of the reduction taking place in the first biofilter. The backwash from the two biofilters was also sampled for odor on the three occasions. The backwashes had higher odor intensity, irritation, and unpleasantness than the effluents. If the backwash material is stored for a period of time, the odor could increase further. The backwash also has the capacity to be furthered settled and supernate removed. Thus, depending on how the backwash is managed, further analysis of odor potential may be needed.

Aerobic treatment of animal manure is not commonly done on livestock and poulty farms because of the high costs of operating, due mainly to electrical energy to supply the air or oxygen to the waste but also because of initial costs and management and labor requirements. If done properly, aerobic treatment will significantly reduce odor and other odorous gas concentrations, but the process is very sensitive to numerous factors which make it fairly unpractical in the short run.

ANAEROBIC TREATMENT

Process

Anaerobic processes are biological treatment processes that occur in the absence of oxygen. The goal of an anaerobic process is to stabilize the organic matter. This stabilization is the conversion of organic matter to gases (carbon dioxide, methane, water vapor, hydrogen, etc.) and microbial cell tissues. The process occurs in two steps. The first step, hydrolysis, converts long-chain carbon molecules to volatile short-chain organic acids (e.g., acetic and propionic acid). The second step, the methanogenic stage, converts these short-chain organic acids to methane and carbon dioxide. Most manure management systems are anaerobic which primarily include lagoons, digesters, and storage ponds.

These characteristics are associated with anaerobic treatment:

- Low initial and operating costs
- Simple operation
- Wide range of potential loading rates that remain constant
- Deep lagoons with less surface area
- Crusting and self-sealing in most soils
- Mixing is a function of gas production
- Takes one to two years to build up microbial population
- Odors are produced
- Cold temperatures and freezing limit the process
- Loses up to 80% of nitrogen through ammonia volatilization

The advantages of the anaerobic process are:

- High degree of stabilization
- Low production of biological sludge
- Low nutrient requirement by the microorganisms
- No oxygen requirement
- Methane can be a useful end product

The disadvantages of the anaerobic process are:

- Production of odors
- Slow rate of biological growth
- Slow adjustment to changes in temperature and loading rates
- Works best at elevated temperatures

Lagoons

The most popular anaerobic reactor is the anaerobic lagoon. They are generally unheated, uncovered and there is no control over gaseous emissions. Treatment by anaerobic lagoons is controlled mainly by the loading rate per unit volume and routine removal of liquid and eventual removal of sludge. An anaerobic lagoon is a basin specifically designed to treat (stabilize) manure even though some storage takes place. In Minnesota, an anaerobic lagoon contains six to eight times the volume of a storage unit that can be pumped out completely. This extra volume is used as the minimum design volume and this material is never removed. In the anaerobic lagoon process, there is little or no control of environmental conditions and loading rates can vary considerable. This can cause the two-step process to become unbalanced and volatile malodorous intermediate chemicals are allowed to accumulate unchecked. These products can then be emitted into the atmosphere as odors. Therefore, the loading rate and temperature in anaerobic lagoons are critical parameters for the minimization of odor, both in the biogas produced and in the treated effluent.

Periodic overloading and turnover in the spring season may result in complaints about odors being generated from lagoons. It was suggested by Barth et al. (Barth and others 1990) that increased odor levels from lagoons in the spring may be partially explained by over production of volatile acids by acid-forming bacteria during the winter. Apparently, acid-forming bacteria can be active under 4^{o}C, while methane-forming bacteria has very little activity under 15^{o}C. Therefore, volatile acids produced by acid-forming bacteria are not used or processed by methane bacteria when temperatures are in the 4 to 10^{o}C range, thus resulting in potential increase of odor levels in the lagoons in early spring.

Greater potential for odor emission occurs when retention times are too short, or lagoon loading rates increase due to expanding animal numbers, slug loading, concentrated waste streams, and/or inadequate water for dilution. Odor emission from anaerobic lagoons is more likely when the lagoon surface is disturbed during windy conditions, during agitation and pumping for land application, during spring turnover – defined as very vigorous bacterial activity during the spring due to incomplete metabolism of material during winter. An anaerobic lagoon will produce minimum odors when acid-forming and methane-forming anaerobic bacteria are in balance.

Odor tends to be proportional to lagoon loading rates (Fulhage 1995). Lagoon loading rate refers to the mass of volatile solids per unit of lagoon liquid volume reserved for treatment, in pounds per cubic foot (ASAE 1994). In general, this rate is reduced for lagoons in areas of lower temperatures, and is greater in areas of higher temperatures. The assumption is that increased lagoon volumes will provide similar end results in low-temperature areas as a smaller lagoon in a higher-temperature area. These loading rates have been developed largely through experience based on 40 years of research to optimize biological treatment processes for biochemical oxygen demand (BOD), odor and solids reduction (Swine Odor Task Force 1998).

Purple or pink colored lagoons, indicating the presence of purple sulfur bacteria, are less likely to be considered an odor nuisance than more typical non-purple lagoons. Design and management factors that encourage the growth of these bacteria are poorly understood. Schulte et al. (Schulte and others 1997), for example, have recently observed that organic loading may not be a critical factor for the growth of purple sulfur bacteria in anaerobic lagoons and that purple lagoons had a somewhat less reducing environment than did the non-purple lagoons, especially in the spring.

There have recently been some concerns on the ammonia emissions from anaerobic lagoons to the atmosphere, but there is little experimental data to support any definite conclusions. The impact of loading rate on mean lagoon TKN (Total Kjeldahl Nitrogen) and NH_3-N has been recently described by Bicudo et al. (Bicudo and others 1999b). It was found that lagoons that served finishing facilities typically had considerably higher TKN and NH_3-N concentrations for a given loading rate as compared to non-finishing facilities. The same observation is true for other parameters such as COD and Total-P. The effect of reducing loading rates on the ammonia emission from lagoons has not been quantified yet.

Ammonia losses from storage tanks are reasonably well documented (Sommer and others 1993), but there are only a few experimental data concerning ammonia emission from large open treatment/storage areas. Fulhage (Fulhage 1998) reported that both measured data and model results indicate that 50 to 60% of the excreted nitrogen may be volatilized in Missouri anaerobic swine lagoons. Initial attempts to quantify ammonia emission from lagoons were based on nitrogen mass balance (Koelliker and Miner 1973). A nitrogen balance of known quantities of nitrogen added, removed and accumulated in the lagoon had to be used and the unaccountable loss was assumed to be by ammonia desorption. A value of 3.6 g NH_3-N/m^2 day was obtained. This amount was equivalent to 64% of the total nitrogen going into the lagoon. More recent, Harper and Sharpe (Harper and Sharpe 1998) reported average NH_3 emissions estimated from measurements taken from two lagoons in North Carolina (micrometeorological mass balance technique). The values range from 0.29-2.2 g NH_3-N/m^2 day. It appears that NH_3 emissions from lagoons depend on NH_3 concentration in the lagoon liquid, pH and temperature in the lagoon liquid, and wind speed, a physical factor to account for turbulence. The same authors reported high N_2 emissions from anaerobic lagoons, ranging from 0.9 to 12 g N_2/m^2-day. They attributed these large N_2 emissions to chemical denitrification and biological denitrification (or combination of the two) processes.

Biogas production from anaerobic swine waste lagoons has been studied by several researchers (Chandler and others 1983; Safley and Westerman 1988). The rates at which biogas is produced from anaerobic lagoons are usually low compared to high rate digesters, and are mainly affected by temperature and organic loading. Measured rates vary from as low as 0.05 to over 1 m^3 biogas/m^2-day. Methane usually accounts for between 60 % to 80 % of the total biogas content. Temperature drop in the winter is reflected by a low biogas production rate, so that the reliability of such systems as an energy source is often questionable.

Digesters

An anaerobic digester is a system for biological conversion of biodegradable organic materials into collectable methane, carbon dioxide, water, and other gases under a controlled and maintained environment. The main components of the system are the digester chamber, slurry preparation, slurry storage, sludge sotrage, effluent storage, gas collection and usage, and the supporting mechanical equipment. This set of equipment integrates into an existing livestock manure management system and does not take the place of any other components.

Anaerobic digestion advantages include:

- Organic content of the residue is reduced and stabilized so that final disposal presents reduced pollution potential.
- Digested effluent is somewhat-odorless, free-flowing liquid.
- Fertilizer nutrients are preserved.
- Methane, a constituent of the gases produced by the process, has significant value as fuel.
- Weed seeds and some pathogens may be destroyed during digestion.
- Rodents and flies are not attracted to the digested residue.
- Particulate matter in sludge may have refeeding potential.
- Organic nitrogen will be hydrolyzed to ammonia nitrogen.

Anaerobic digestion disadvantages include:

- Equipment is complex and involves high initial investment.
- Daily feeding of digesters at controlled loading rates is desirable.
- Energy input is required.
- High standards of maintenance and management are required.
- Strict explosion-proof standards must be maintained.
- Temperature (and perhaps volatile acid concentration and pH) must be controlled to optimize gas production.
- Some chemicals, if present in excessive quantities, can inhibit the digestion process.
- Digestion systems will reduce (but not eliminate) solids content; digested liquid slurry remains a pollutant unless subjected to further treatment.

Centralized anaerobic digesters, facilities that serve most of the livestock farms within a 6-mile radius, are used in some areas Europe for manure and odor management. The country with the greatest experience using large-scale digestion facilities is Denmark, where 18 large centralized plants are now in operation. In many cases the facilities co-digest manure, clean organic industrial wastes, and source-separated municipal solid wastes. One of the key policy tools used to encourage technology deployment is “green-pricing,” *i.e.*

allowing manufacturers of biogas-generated electricity to sell their product at a premium (Danish Ministry of Energy and Environment 1996).

Types of Anaerobic Digesters

There are two broad categories of digesters: batch process (all-in / all-out) or continuous-feed in small amounts as a conventional stirred tank reactor (CSTR) or plug flow (PF). A CSTR is continuously mixed or mixed for a few minutes every hour. A PF system adds manure to one end of a tank, allowing the effluent to overflow and be removed from the other end into a storage unit. A PF system is not mixed, except for natural mixing by gas production. Both CSTR and PF rely on suspended growth, where the solids and particulate matter, along with the bacteria, float in suspension. Fixed-film digesters are those in which a media is added to the tank to increase the surface area and give the microorganisms a surface to which they can attach. Examples include spherical or ringed plastic media, PVC pipe, wood chips, corn cobs, and spheres. Another possible process is the sequencing batch reactor (SBR), in which the operation consists of filling, reacting, settling, draw-down, and idling.

Anaerobic Digestion Biogas

Biogas quality is as follows:

- Methane: 50-60%
- Carbon dioxide: 35-50%
- Water vapor: 2-12%
- Hydrogen sulfide: 0.35%

Biogas typically has an energy content about 60% that of natural gas. Hydrogen sulfide concentrations are usually too high for the recommended use in engines because of a decrease in engine life.

Biogas can be stored between the manure surface and a flexible top cover, at low pressure in a flexible bag or rigid tank, compressed to a medium pressure into rigid (propane) tank, or compressed into a high pressure vessel. The best option is to use the biogas as it is generated.

The most common method of biogas usage is in an internal combustion engine. These engines will be 15% to 30% efficient and have a 20% to 40% power reduction from the rated engine output. Some of this inefficiency can be recaptured by placing a heat exchanger on the water jacket and exhaust manifold to help heat the digester and passing incoming fresh ventilation air past the engine-generator set to preheat the air. Boilers and water heaters are about 70% efficient, with a typical 40% reduction in expected output compared to the rating of the heater.

Anaerobic Digester Effluent

Compared to digester influent composition, the effluent composition has 2% to 5% less volume, the same N, P, and K, and fewer odors. Note that in an economic evaluation of digestion, nutrients cannot be considered since these nutrients are present whether a digester is used or not.

Anaerobic Digestion Economics

The economics of digestion take into consideration operation size (larger is more economical), energy price (propane, fuel oil, and/or electricity), energy savings vs. energy selling, new vs. used equipment, labor cost, replacement costs, and odor control value with no cost savings for fertilizer value. Minimum operation size to consider installing an anaerobic digester is about 250 milking cows, 400 sows farrow-to-finish, or 100,000 layers. Table 17 provides guidelines for electricity generation (Parsons 1984).

A case study done by Edgar et al. (Edgar and others 1992) evaluated the feasibility of a centralized digester in Tillamook County, Oregon. The study included 26,000 dairy cows with 68% located within a 16-km radius and 92% within a 40-km radius. The digester-power plant was projected to operate at a $514,000/yr deficit. A $2.20/tonne surcharge was assessed to livestock producers for handling the manure.

Current Status of Anaerobic Digestion

Lusk (Lusk 1998) summarized the status of farm-based anaerobic digesters in the U.S. by indicating there are 28 digesters operating and 10 more under construction/planning phase. There are no operating digestors in Minnesota and only one under construction. The most common types of digesters found on U.S. farms are high-solids anaerobic digester, plug flow, complete mix and covered lagoon.

CSTR and PF digesters are the most popular options for the anaerobic treatment of animal manures. The PF digesters were adopted with some success in the cooler climate of the northeast, where dairy farms primarily use scraping systems for manure removal. Because flushing systems and anaerobic lagoons already are in widespread use in warm regions of the country, attention is being focused on earthen lagoon digesters with floating covers that operate at ambient temperatures. This type of digester would potentially be less costly to construct and operate; however, the biogas production rate would be lower (Swine Odor Task Force 1998).

According to Lusk (Lusk 1998), surveyed producers who have installed and continue to operate digesters are generally satisfied with their investment decisions. Some chose to install digesters for non-economical reasons, primarily to control odor or contain excess nutrient runoff. On the other hand, the performance data does not appear to be encouraging to a producer who is considering whether to install an anaerobic digestion system. Overall, the chance of failure, *i.e.* the chance of having a non-operating digester, is about 50% in the United States (Lusk 1998). The failure rates for CSTR and PF technologies are 70% and 63%, respectively. The list of reasons explaining why some anaerobic digesters fail is probably headed by bad design and installation. Poor quality equipment and materials selection is the second most common reason for failure.

The bottom line with anaerobic digestion is that the process is technically feasible, but economically unsound, especially for medium-to small-size operations. However, these shortcomings may be overcome in the future if environmental constraints and economic forces change.

Odor Control

Digestion will not completely solve the odor problems from animal production sites. However, it will help reduce odors by stabilizing organic (odorous) compounds. Hydrogen sulfide and ammonia concentrations are increased because of the conversion of organic sulfur and nitrogen to inorganic forms. Thus, there is the potential for increased hydrogen sulfide and ammonia emissions.

Odors are reduced when controlled loading and environmental conditions of the anaerobic digester keep the two-step process in balance. Most odors associated with anaerobic treatment are associated with overloading. An overloaded digester will sour when the pH drops due to overproduction of organic acids and the methanogenic bacteria that produce methane and carbon dioxide are inhibited by the lower pH and decrease their activity. These organic acids are the precursors of odorous compounds.

Using an 11-pt hedonic scale, Welch et al. (Welch and others 1977) determined that anaerobically digested swine manure dropped 1.9 units between the influent and effluent. They also found that operating the digester at higher temperatures (35^{o}C vs. 25^{o}C) was more effective at controlling odors provided that agitation occurred at least once per hour and solids retention time was greater than 10 days. After storing the manure for 30 days, the digested manure had lower odor ratings compared to stored undigested manure. Digested manure stored for three months had lower odor ratings by one unit compared to freshly digested manure.

Table 17. Guidelines for electricity generations (Parsons 1984)

	Animal Weight kg	Electricity production kW-h/d/animal
Holstein milking cow	570	2
Beef feeder	360	1
Feeder pigs	360	1
Sow unit*	590	2

*Farrow-to-finish, sow plus average weight of 16 pigs/yr

Increasing retention time will help reduce odors. Powers et al. (Powers and others 1997) found that odor intensity decreased linearly with increased hydraulic retention time (HRT) with an approximate 50% reduction in odor intensity (another measurement parameter) between the feedstock (untreated) and the treated effluent at a 20-day retention time. They also demonstrated that when more methane is produced, the less the odor intensity. Screening fibrous solids before loading the digester to reduce percent total solids (TS) from 2.0% to 1.3% increased treatment efficiency of the process, increased methane output, and helped reduce odors. Hydrogen sulfide concentrations in the head space did not follow this odor intensity pattern as the feedstock began at approximately 2 ppm, jumping to over 2000 ppm at a 6-day HRT, then dropping to approximately 1700, 780, and 580 ppm at 10-, 15-, and 20-day HRT, respectively.

Pain et al. (Pain and others 1990) studied land application of swine manure on grassland. Their work indicated that treating manure with anaerobic digestion could reduce odors by up to 80% during land spreading.

ELECTROLYTIC TREATMENT

The electrolytic treatment is based on oligodynamic action, where small quantities of metal ions dissolved through electrolysis may be able to kill some microorganisms. The treatment, as described by Italian researchers (Ranalli and others 1996), takes place in a storage tank and lasts for several months. Although this process is not completely understood, the effect seems to be based on the following actions (Ranalli and others 1996):

- Oligodynamic action: dissolved copper ions reduce the fermentation and/or respiratory activities of microorganisms in slurry;

- Binding action: odorous compounds are bound by dissolved copper ions;

- Electric action: fermentative and respiratory activities of the microorganisms in the slurry are reduced by means of electric current that can affect cellular membrane mechanisms and ATP (adenosine tri-phosphate) synthesis;

- Anti-flocculating action: the electric field in the slurry seems to affect the formation of a crust on the surface.

Recently, Skjelhaugen and Donantoni (Skjelhaugen and Donantoni 1998) described an electrolytic system for the treatment of cattle slurry. The unit described creates an electric potential of about 4 V and a current of 0.5 and 1.25 A between two copper electrodes. One pair of electrodes, each about 3-ft long, was used to treat about 8,000 gal. The electrodes were suspended in the slurry 3 to 4 inches above the bottom. The polarity of the electrodes was switched regularly in order to reduce the average resistance in slurry. The power required was 50 W per pair of electrode and the energy consumption was about 0.22 kWh/ft^3 of treated slurry. After 8 months iron electrodes replaced the copper electrodes. This operation allows for the replacement of dissolved copper ions in the slurry with iron ions.

The above researchers applied electrolytic treatment to aerobically treated cattle slurry. They concluded that a combined aerobic and electrolytic treatment helped kill thermotolerant coliform bacteria and minimize odor and gaseous emissions from storage. Aerobic treatment reduced hydrogen sulfide emission from about 1,400 ppm in the air above the untreated slurry to about 300 ppm. Additional electrolytic treatment reduced hydrogen sulfide levels to 150 ppm in the beginning of the storage period, and to zero after 10 weeks. Similar results were obtained in terms of odor reductions.

More research is necessary, especially concerning the odor reduction capability of this treatment, before an accurate assessment can be done.

PRODUCT ADDITIVES

As a result of the increased public, regulatory, and legal attention directed to the odor issue, many producers are considering the use of commercial manure and/or feed additives as an effort to minimize odor and other air emissions from livestock farms. In addition to odor control, many of these products are marketed as having other beneficial effects such as improved nutrient value of the manure, improved animal performance, fly control, etc. Product additives are generally described as compounds that can be added directly to freshly excreted or stored manure for purposes of odor abatement. They are generally made of enzymes, of a mixed/selected culture of microorganisms or are chemically based. Each product has a specific method of application, frequency, quantity, and length of time before the product is “most effective”. Some products are pH and temperature dependent and only work within narrow ranges of pHs and temperatures. Although bacteria usually to certain extent are able to adapt themselves to the changes in the environment, large deviations from their optimum growth conditions undoubtedly will interfere with the normal metabolic activities, thereby resulting in a slow growth. This was already evidenced by an evaluation on a commercial product containing enzymes and selected bacteria, which showed that the product did not accelerate the degradation of the malodorous substances even at 15^{o}C (Bourque and others 1987).

The idea of using manure additives to control odors was proposed about twenty years ago and a considerable amount of research effort has been spent in this field. Past researchers rarely found any of the pit additive products to be effective in reducing odor levels of swine manure (Cole and others 1975) (Ulich and Ford 1975) (Sweeten and others 1977) (Warburton and others 1980) (Ritter and Eastburn 1980) (Al-Kanani and others 1992). This is probably due to the complexity of odorous components in animal manure. However, Zhu (Zhu 1999) points out the fact that the key difficulty in the development of effective manure additive products rests with a lack of understanding of the biological activities occurring within the stored manure. The widely used trial-and-error methods to evaluate manure additive products not only are time consuming, but also provide little information on the biochemical mechanisms.

Commercial additives may control specific parameters such as ammonia and hydrogen sulfide from the array of odorants. Objective information regarding the actual impact of the products on odor, as perceived by smell, is becoming available through laboratory and field tests being carried out in different places. Zhu et al. (Zhu and others 1996), for example, tested the effects of five different commercial pit additives on the release of odor and volatile compounds from swine manure. Their results showed that all five products reduced the levels of odor threshold by different degrees ranging from 58 to 87% as compared to the control samples. Three of the five products showed reductions in volatile fatty acids and total volatile solids. Johnson (Johnson 1997) ran field tests with eight different pit additives. The tests were run comparing a barn treated with a manure additive product, against an untreated control barn on the same site with variables isolated. Results obtained showed statistically significant reduction in ammonia levels in the treated barns as compared to untreated control barns. Odor threshold results were variable, and most products tested had only a slight effect on odor reduction.

Microbiological Additives

Microbiological additives, or digestive deodorants, generally contain mixed cultures of enzymes or microorganisms designed to enhance the degradation of solids and reduce the volatilization of ammonia and/or hydrogen sulfide. The microorganisms are meant to metabolize the organic compounds contained in the manure. Digestive deodorants may act to inhibit selected biological or digestive processes by changing the enzyme balance (ASAE 1994). Most digestive deodorants are applied directly into the manure collection area and/or the lagoon and must be added frequently to allow selected bacteria to predominate (Sweeten 1991).

There have been only a few efforts made to investigate the bacterial decomposition of odorous compounds in swine manure by some specific bacterial species. Ohta and Ikeda (Ohta and Ikeda 1978) conducted a laboratory study regarding the possibility of deodorizing pig feces by *Streptomyces*, which is a genera belonging to a group of microbes encompassing a wide range of bacteria called *Actinomycetes*. They found that under optimum “deodorization conditions” (pH, 8.6 to 10; temperature, 35 to 40^{o}C; moisture content, 42-63%), two bacterial genera (*Streptomyces griseus* and *Streptomyces antibioticus*) demonstrated strong ability of deodorization. Bourque et al. (Bourque and others 1987) conducted research on microbial-degraded odorous substances of swine manure on a laboratory scale under aerobic conditions. The bacterial culture under study was inoculated into sterilized swine manure and incubated for a maximum of 6 days at 29^{o}C. They found that three bacterial species (*Acinetobacter calcoaceticus*, *Alcaligenes faecalis*, and *Arthrobacter flavescens*) could completely degrade all types of VFAs in swine manure while *Corynebacterium glutamicum* and *Micrococcus* sp. could only degrade acetic and propionic acids. Another laboratory experiment done by Jolicoeur and Morin (Jolicoeur and Morin 1987) also reported that *Acinetobacter calcoaceticus* could degrade VFAs in both sterilized and non-sterilized swine slurry incubated at 22 ^{o}C within pH 6.2-8.6 for 21 days.

Although there exist bacterial genera or species that can decompose odorous compounds like VFAs to reduce odor emission, little success has been reported in using these microbes as manure additives to control odor generation in the field.

According to Grubbs (Grubbs 1979), the key in using bacterial cultures for deodorization of manure is to have the added bacteria become the predominant strain of bacteria in the manure. In order for the added bacteria to flourish, the real environment should not deviate tremendously from the optimum growth range for the bacteria. Past work was mainly focused on determining the bacterial functions in digesting odorous compounds under optimum conditions. This usually does not guarantee that bacteria growing well under optimum conditions will also grow well in the field. Bourque et al. (Bourque and others 1987) showed in their study that none of the inoculated microorganisms became dominant in the non-sterilized swine manure samples. The indigenous flora (not necessarily those reducing odors) of the wastes always grew better than the inoculated microorganisms. In addition, the selected microorganisms may even use other organic compounds in preference to the malodorous substances when inoculated in some wastes, which impairs the values of the additives.

Miner (Miner 1995) reviewed several studies of digestive deodorants and concluded that "the variable success measured for the effectiveness of microbial and digestive agents to control odor may be due to the inability of these products to degrade many of the compounds which collectively make up odor from a swine operation." And "supplemental microorganisms, as additives, may not readily adapt to the natural conditions in manure handling systems and are often susceptible to competition from the naturally occurring indigenous microbial populations."

Masking Agents, Counteractants, Adsorbents and Absorbents

Masking agents cover one smell with another. They are made from a mixture of compounds that have a strong odor of their own (for example, pine), thus masking the undesirable odor. They can be effective as an emergency, short-term solution for the symptom, but generally, long-term control of the odor problem will be necessary.

Masking agents are normally used as vaporized material. They usually consist of organic aromatic compounds such as heliotropin, vanillin, eugenols, benzyl acetate, and phenylethyl alcohol. They are injected into the air right above the liquid surface of the odor source (in this case, stored manure).

Non-vaporized agents are applied directly to the manure. Miner (Miner 1995) concluded that "the organic chemical composition of most masking agents makes them susceptible to degradation by the microorganisms indigenous to manure." And thus, "the odor control capacity of most masking agents and counteractants may be too short lived for practical use in swine production environments."

The effectiveness of masking is difficult to predict due to varying odor characteristics and changing weather conditions. Masking agents primarily used where the level of odor is relatively low, always increase the total odor level. Without any chemical reaction, the individual constituents of the odor remain unchanged. The main advantages of masking agents are their low cost and non-hazardous nature (WEF 1990). The disadvantage is the tendency of the agent to separate from the odor downwind.

Counteractants do not react chemically with the malodor, but reduce the perceived odor level by eliminating the objectionable characteristics of the malodor. They usually have a neutral pH, are easy and safe to handle, and are moderately more expensive than masking agents (WEF 1990). Counteractant chemicals neutralize the following odor types:

phenols, amine, mercaptan, aldehydes, solvent odors, aromatics, and organic fatty acids. They usually lower or maintain the same odor level. Their effectiveness is not always predictable.

Adsorbents and absorbents are biological or chemical materials that can collect odorous compounds on their surfaces (adsorb) or interiors (absorb). Examples are Sphagnum peat moss, sawdust, rice straw, sodium bentonite, and certain natural zeolites. Absorbents with a large surface area, such as sphagnum peat moss, have been found to reduce odor in some lagoons (Swine Odor Task Force 1998). Floating organic lagoon covers (straw) and soil biofilters are other examples of the use of odor absorbing materials.

Chemically-Based Additives

This type of additive acts by chemically altering odorous compounds or enzymes. They may also kill the bacteria, which produce the volatile organic malodorous compounds. Chemical additives are made from chemical compounds that can promote oxidation or precipitation of undesirable odor compounds. Chemical compounds can also be added for pH control and also as electron acceptors. If properly applied, the operating cost of reactive chemicals may actually be less than for masking agents or counteractants.

When dosing chemicals into manure, side reactions will occur in addition to the desired reaction. In calculating dosing rates, a generous factor of safety must be allowed to account for these side reactions. Most of the chemical products are pH dependent and only work within a very narrow range. Pilot testing is recommended for all chemical-dosing systems. Chemical additives are usually classified in terms of their mode of action:

Oxidizing Agents: chlorine (as gas or sodium hypochlorite), potassium permanganate, and hydrogen peroxide will oxidize sulfides and inhibit sulfide production. Ozone has also been used as an oxidizing agent.

Precipitants: iron and zinc salts will react with sulfides to form insoluble compounds. Ferrous and ferric chloride have been used for that purpose.

pH Control: sodium hydroxide or lime can be added to manure to raise the pH, inhibiting sulfide production and preventing hydrogen sulfide off-gassing, but probably increasing ammonia production.

Electron Acceptors: electron acceptors are taken up preferentially to the sulfate ion, and thus prevent sulfide formation. Sodium nitrate can be used for this purpose.

Researchers in Iowa and Indiana are experimenting with products that are injected into the building air climate through high-pressure mister systems. The function of a periodic mist injection is to neutralize volatile odor compounds that accumulate in the building prior to being exhausted. Heber et al. (Heber and others 1997) reported on a 63-day field test in a 1000-head commercial naturally-ventilated swine finishing house. The chemical solution was sprayed into the top of the pit creating an aerial mist in the headspace and covering the entire surface of the manure slurry. Their results show a reduction of mean NH_3

emissions from 5.9 to 1.8 g/pig-day as compared to an identical untreated house. The mean H_2S emission rate of 0.15 g/pig-day did not change with the treatment. No current conclusive results on odor emissions have been published on this type of system.

Miner (Miner 1995) pointed it out that long-term use of chemical additives may require large amounts and frequent applications, making their continual use expensive and potentially damaging to the environment (soil, surface water and groundwater). However, chemical additives may be effective at controlling odor and gas emission during agitation and pumping of manure storage facilities. Researchers at the University of Minnesota (Clanton unpubl.) and at University of Kentucky (Turner unpubl.) are currently testing various chemicals that are capable of reacting with sulfides, thus minimizing hydrogen sulfide emission during agitation and pumping of manure.

Table 18. Effect of land application technique on the reduction of ammonia emissions after spreading cattle and pig slurry on grassland and arable land (adapted from Burton 1997)

Spreading technique	Application on grassland				Application on arable land			
	Trials	Handling rate (gal/ac)	% NH_3 loss[1]	% Reduction on NH_3 emission[2]	Trials	Handling rate (gal/ac)	% NH_3 loss[1]	% Reduction on NH_3 emission[2]
Deep injection (12 in deep)	6	4,000	0.9	98	4	3,400	1.0	98
Shallow injection (3 in deep)	32	2,300	9.4	87	2	2,000	2.8	90
Drag shoe	27	1,500	20	63	5	2,200	9.5	73
Band spreader	3	1,300	43	41	2	2,000	33	31

1 – as a percentage of the NH_3-N in the slurry.
2 – compared to the emission from broadcasting application.

LAND APPLICATION

Land application of slurry manure is one of the most significant sources of odor complaints (Ministry of Agriculture 1992). Odors can be smelled a long distance from the field, depending on the weather, method of spreading, application rates and other more specific conditions.

Land application of manure to cropland is a critical factor in 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 operation. This odor may last for a few hours to as much as two weeks depending on weather conditions. Manure that is applied underneath the soil surface (injected) or covered with soil immediately after spreading (incorporation) nearly eliminates manure odor. This is because the odorous gases must travel through a soil layer before being emitted into the atmosphere. This soil layer acts as both a trap for odorous gases and a treatment system, changing odorous gases into less odorous gases through a microbial process. Manure injection or incorporation also reduces manure nitrogen losses to the atmosphere through ammonia volatilization.

Therefore, in order to minimize the risk of pollution and generation of odor, two general requirements must be observed (Kack and others 1994): (i) faster penetration of slurry into the soil after spreading; and (ii) high spreading accuracy. Various types of equipment have been developed in the last few years in order to comply as much as possible with the above requirements. Nevertheless, broadcasting liquid and solid manure followed by immediate incorporation is still very popular among farmers both in the US and Europe, compared to direct injection of manure, mainly because of energy requirements.

Band spreaders are becoming popular in Europe as regulations on odor and ammonia emissions are becoming stricter. Band spreaders discharge slurry at ground level through a series of trailing pipes. Odor measurements show a reduction of 55 to 60% compared with conventional broadcasting with splash plate spreaders (Ministry of Agriculture 1992). After application, the slurry is rapidly incorporated into the soil in order to minimize odor and ammonia emissions.

Injection techniques (shallow and deep injection) are very effective for minimizing ammonia emissions during manure spreading on land (about 85% less odor than from conventional spreaders – (Ministry of Agriculture 1992)). The equipment is very expensive and it is likely that a farmer will contract with a professional applicator in order to inject manure. The technique is generally not suitable for soils with more than 20% clay content, stony soils and hilly terrain (Frost 1994). A new technique for injecting slurry into soils, especially on grasslands, has been recently developed in Norway (Morken and Sakshaug 1997). The Direct Ground Injection - DGI® concept involves slurry injection under high pressure (5 to 8 bar) directly into the soil. After being pressurized the slurry is distributed to nozzles. The nozzles jet out the slurry in pulses forceful enough to inject the slurry into the ground in elongated, discontinuous cavities at depths between 5 and 10 cm. Trials conducted so far indicate a significant reduction in ammonia emissions (between 80 to 90%) compared to band spreaders.

Various researchers have evaluated the effect of different equipment for land application of manure on the reduction of ammonia emission. Burton (Burton 1997) has compiled much of the information that was available in Europe between 1992 and 1997 (Table 18).

Phillips et al.(Phillips and others 1990) compared different spreading techniques for odor emission reduction. Compared with that of a conventional vacuum tanker (broadcasting), a deep injector, a shallow injector, and a band spreader reduced odor emission immediately after application by 83, 70 and 38%, respectively.

Pain et al. (Pain and others 1991) conducted several experiments with three different incorporation methods (plough, rotary harrow and rigid tines) with different delay times before incorporation (*i.e*. the time between land spreading and incorporation of manure into the soil – at 0, 3 and 6 hours). Their results showed that only plowing immediately after spreading gave a significant reduction in odor emission. Compared with the control, immediate plowing gave a 52% reduction and rotary harrow a 20% reduction. No reduction was achieved with the rigid tines, or when incorporation was delayed 3 or 6 hours.

The effectiveness of a range of methods for reducing odor emission after slurry spreading was evaluated by Pain et al. (Pain and others 1990; Pain and others 1990; Pain and others 1991). Spreading aerobically treated slurry (continuous aeration for 4 days and dissolved oxygen values between 1 and 2 mg/l) resulted in 86% reduction in odor (Pain and others 1990). Anaerobic digestion (retention time between 8 and 10 days, and temperature of 95 ^{o}F) reduced odor emissions during spreading by 84% (Pain and others 1990). In both cases reductions were compared with spreading slurry with a vacuum tanker. Odor emission was still significantly lower for digested slurry following storage for two weeks (Pain and others 1991).

Morken (Morken 1992) has reported on the effect of application techniques and type of slurry on ammonia losses after application to grassland. He found that shallow injection could reduce ammonia losses between 17 and 40%, depending on weather conditions and on the chemical composition of the slurry used. He also compared ammonia emissions from surface applied slurry using different types of slurry: urine drained-off from gutters, separated liquid slurry, slurry diluted with water (1:1), aerated slurry, and slurry mixed with bentonite. Ammonia losses due to urine application were less than 15%. Application of diluted slurry and bentonite-treated slurry resulted in 20 to 30% ammonia losses. Emission figures after spreading untreated and aerated slurry were in the range of 70 to 85%.

Chadwick et al. (Chadwick and others 1998) measured nitrogen losses and methane emission after application of excessive volumes of swine manure in a soil filter system (Solepur process – (Martinez 1997)). About 10,000 gal/ac of swine manure was applied in the Fall and 24,000 gal/ac in the Summer. Manure was applied using a tow hose system connected to a 130-ft wide spray boom. The total amount of nitrogen applied was 585 lb N/ac in the summer and 1,050 lb N/ac in the fall (excessive application rates). Between 6 and 31% of the total N applied was lost through ammonia volatilization following fall and summer applications, respectively. These losses are within the reported range following surface broadcasting of pig slurries at agronomic rates (see Table 18 for comparison). Emissions of N_2O were very high following the application in the fall, representing 23% of the total N applied. Methane emissions following slurry applications were between 0.04 and 0.12% of the total carbon added.

Dilution of liquid manure prior to land application is a traditional technique in regions with high rainfall that results in reduction of ammonia emissions. Water addition in the proportion 3:1 reduced NH_3 loss by 20 to 80% compared to undiluted slurry (Burton 1997).

Safley et al. (Safley and others 1992) reported on loss of nitrogen during irrigation of swine anaerobic lagoon liquid (which is relatively dilute as compared to untreated manure). TKN losses occurring during sprinkler irrigation using a center pivot were found to range from 15 to 43%. Of this amount 54 to 100% was accounted for in volumetric losses (evaporation and drift). Ammonia losses were found to range from 14 to 37%. These losses are comparable to losses found when untreated pig slurry is applied with band spreaders or drag shoes (see Table 3 above). However, they are much lower than ammonia losses reported by other researchers who have surface-applied untreated cattle or swine manure to soil or grassland (Hoff and others 1981; Lockyer and others 1989; Pain and others 1989).

Acidification of liquid manure during storage or in the slurry tanker just before spreading results in significant reductions of ammonia and nitrous oxide emissions as a low pH inhibits NH_3 volatilization during and after land application (Burton 1997; Berg and Hornig 1997). Lenehan et al. (Lenehan and others 1994) reported on equipment design for on-tanker acidification system for slurry treatment prior to land application. Carton et al. (Carton and others 1996) analyzed the effect of cattle slurry acidified with nitric acid on nitrogen efficiency for grass silage production. The slurry was acidified with nitric acid to pH 5.5 and was either broadcasted or band-spread. The average efficiency values for N offtake (Eff-N%) relative to inorganic N fertilizer (over all sites and cuts) with acidified cattle slurry were between 81 and 85%. Untreated slurry gave Eff-N% values between 37 and 59%. It was concluded that unfavorable economic and safety aspects would make acidification with nitric acid unlikely to be adopted in agricultural practice.

Misselbrook et al. (Misselbrook and others 1997a) presented results related to control by dietary manipulation of emissions from pig slurry following land spreading. Slurries collected from 2 groups of finishing pigs, fed either a standard commercial diet (CD) or a reduced crude protein diet (RD), were spread in early spring on grass/clover swards at 5,350 gal/acre. Slurry from the reduced crude protein fed pigs had a lower ammoniacal-N, total-N and volatile fatty acid content, lower pH and a higher dry matter than slurry from the pigs on the standard diet. Following land application, ammonia volatilization over the first five days were 60% less from RD slurry. Denitrification losses over 51 days were 73% less from RD slurry. Nitrous oxide emissions were similar for the two slurries applied. Methane emissions were also lower from RD slurry.

Currently there is very little work being done in regard to the measurement of odor and gaseous emissions from land application of animal and poultry manure in the United States and there is apparently no experimental data available. Only initial work with passive samplers have been reported by Zupanci et al. (Zupanci and others 1998) in a study for the determination of ammonia flux from swine effluent applications in the southern great plains.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

A suggested future research area is the quantification of airborne contaminant emissions from animal production systems. During the past 20 to 30 years there have been many studies to determine the indoor air quality of animal facilities, but mainly only contaminant concentrations have been measured and reported. Only recently (the last five to ten years) have ventilation or airflow rates also been measured so that actual emission levels of gases, dust, and pathogens can be determined. These studies need to be expanded to outdoor or ambient air, especially for odor and gases. Emission levels as a function of species, operation size (animal units), and housing systems need to be more accurately determined so decision makers, producers, and the public can identify and prioritize contaminants that are causing the problems. This will allow industry and government to target specific contaminants so future production systems will minimize air quality impacts that have the greatest effect on the environment and humans.

The health risks associated with animal production systems is an important area for further research. Additional research is primarily needed for human health issues dealing with outdoor or ambient air levels adjacent to animal production sites, rather than the indoor air human (worker) health issues, for which there is sizeable body of information. However, both indoor and outdoor health issues are critical to the viability of animal agriculture in Minnesota for neighbors, producers, and others working in and around animal facilities.

The modeling of air contaminant emissions from animal production systems is a current topic of study in the research community and this needs to continue. Models currently used to predict odor and gas plumes from animal production sites were developed for other industrial point source emissions that have some distinct differences from current agricultural applications, thus, the models need to be validated by in-field measurements. These measurements are difficult to make but need to be done to increase the confidence and believability of models to predict air contaminant plume movement and concentration. This will require increased sophistication of in-field measuring equipment to record air contaminant levels, which are generally at very low concentrations and are highly variable due to weather conditions.

Mitigation and control technologies for air contaminant emissions from animal production systems are an active area of research. This needs to continue since the criteria or constraints for agriculture are considerably different from other industries. One major difference is the need for systems that have both low initial and operating costs in order to be economically viable. In addition labor requirements to operate the control technology need to be low because of the limited availability of skilled individuals to management complex systems. This remains a challenge to engineers and researchers developing systems to mitigate air quality concerns.

SUMMARY OF MAJOR CURRENT OR ONGOING RESEARCH

Title: Odor and Gas Emission Reduction form using Four Separate Control Technologies in Deep Pitted Curtain-sided Pig Finishing Buildings

Objective: Evaluate the effectiveness and economics of four new low cost odor control technologies for deep pitted curtain sided pig finishing barns.

Organization – Investigators: U of M - Larry Jacobson and Philip Goodrich

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $68,000

Title: Biocover Longevity and Crust Formation

Objective: Evaluate the long term effectiveness of geotextile covers for manure storage structures and determine critical parameters for the establishment and preservation of natural crusts.

Organization – Investigators: U of M - Charles Clanton

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $115,000

Title: Chemical Addition for Hydrogen Sulfide

Objective: Determine dosage rates, effectiveness, economics, and management criteria of several chemical additives to control hydrogen sulfide emissions from manure storages during agitation and pumping.

Organization – Investigators: U of M - Charles Clanton

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $27,000

Title: Biofilters —Factors Affecting Long Term Efficiency

Objectives: Evaluate the effectiveness of different biofilter mixtures on long term odor control, pressure drop in the filter bed, and nitrogen removal.

Organization – Investigators: U of M - Kevin Janni

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $60,000

Title: Dietary Manipulations on Swine Manure Characteristics

Objective: Determine the effect of various dietary factors in the diets of growing-finishing pigs and dairy heifers and their potential impact on manure characteristics that affect odor emissions.

Organization – Investigators: U of M - Samuel Baidoo

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $100,000

Title: Solids-Liquid Separation for Controlling Odor and Improving Manure Handling

Objective: Determine the relationship of manure slurry particle size on odor emissions and assess various separation and handling systems for swine and dairy manure.

Organization – Investigators: U of M - Jun Zhu

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $70,000

Title: Development of a Standardized Method for Odor Quantification from Livestock Production Facilities: Stage II, Field Testing

Objective: Develop a standardized method to quantify odor using indicator gases.

Organization - Investigator: Iowa State University – Alan DiSpirito

Funding Agency – ID : National Pork Producers Council – 99-056

Amount - $24,420

Title: Health Significance of Airborne Particles at Pork Production Facilities

Objective: Determine the health significance of airborne particles emitted from pork production facilities.

Organization – Investigator; North Carolina State University – Robert Bottcher

Funding Agency - ID; National Pork Producers Council - 99-116

Amount - $50,000

Title: Odor, Ammonia and Hydrogen Sulfide Emission Factors for Grow-Finish Buildings

Objective: Determine the odor, hydrogen sulfide and ammonia emissions from a grow finish swine building.

Organization – Investigator; Purdue Research Foundation - Albert Heber

Funding Agency – ID; National Pork Producers Council - 99-122

Amount - $28,907

Title: Reduction of Odorous Compounds in Pig Manure through Specific Dietary Manipulation – A Practical Field Study

Objective: Determine the effectiveness of swine diet manipulation on odor reduction.

Organization – Investigator; Purdue Research Foundation - Alan Sutton

Funding Agency – ID; National Pork Producers Council - 99-103

Amount - $36,705

Title: Ammonia Emission in a Room For Weaned Piglets with a sloped pit wall

Objective: Determine the effectiveness of a new manure pit design on ammonia emissions.

Organization – Investigator: Research Institute for Pig Husbandry, Netherlands - A.J.A.M. van Zeeland and G.M. den Brok

Funding Agency - ID - Ministry of Agriculture (Netherlands) - Report P4.31

Title: Ammonia Emission in Farrowing Rooms with Manure Trays

Objective: Determine the effectiveness of a new manure handling method on ammonia emissions.

Organization – Investigator: Research Institute for Pig Husbandry, Netherlands -
A.J.A.M. van Zeeland and N. Verdoes

Funding Agency - ID - Ministry of Agriculture (Netherlands) - Report P1.201

Title: Evaluation of New Nutritional Technologies for Situation Dependent Diet Formulation in Swine.

Objective: Evaluate the effect of dietary changes to reduce nutrient excretion and odor emissions.

Organization – Investigator; Minnesota Agricultural Experiment Station (MAES) – Jerry Shurson, Animal Science Department

Funding Agency – ID - U of M, AES – 16-064

Title: Animal Manure and Waste Utilization, Treatment, and Nuisance Avoidance for a Sustainable Agriculture

Objective: Develop and refine methodology, technology and management practices to reduce odors, gases, airborne microflora, particulate matter and other airborne emissions in animal production systems.

Organization – Investigator; Minnesota Agricultural Experiment Station (MAES) – Larry Jacobson, Uof M, Biosystem and Agricultural Engineering Dept.

Funding Agency – ID - U of M, AES – 12-082

Title: Stakeholders Feedlot Air Emission Data Collection Project

Objective: Evaluate emission and dispersion of odor, ammonia, and hydrogen sulfide from livestock and poultry facilities.

Organization – University of Minnesota, National Pork Producers, Minnesota Deparment of Agriculture, Minnesota Pollution Control Agency, and Minnesota Livestock and Poultry Producer Groups.

Funding Agencies – National Pork Producers Council, Minnesota Pork Producers Association, Minnesota Department of Agriculture, MN Pollution Control Agency

Duration of Study: July 1999 to July 2002

Amount - $14,000

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