Approved: February 17, 1998
Date

MINUTES OF THE HOUSE COMMITTEE ON AGRICULTURE.

The meeting was called to order by Chairperson Joann Flower at 9:00 a.m. on February 9, 1998, in Room 423-S of the Capitol.

All members were present except: Representative Henry - excused
Representative Lloyd - excused

Committee staff present: Raney Gilliland, Legislative Research Department
Gordon Self, Revisor of Statutes
Kay Scarlett, Committee Secretary

Conferees appearing before the committee:
James Zahn, PhD, Department of Microbiology, Immunology, and Preventive Medicine, Iowa State University

Others attending: See attached list

Chairperson Flower asked committee members to review the minutes of January 29 and 30. If there were corrections or additions, members were asked to contact the committee secretary before 5:00 p.m.or they will stand approved as presented.

Dr. James Zahn, Department of Microbiology, Immunology, and Preventive Medicine, at Iowa State University, reported on odor research and environmental issues concerning concentrated animal feeding operations. (Attachment 1) He stated that there is little consensus among researchers, producers, and regulators concerning the extent or types of emissions that are responsible for odor and how these emissions can be reduced or controlled. He reported that EPA uses six criteria pollutants as indicators of air quality: ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, and lead. He questioned whether EPA criteria pollutants are suitable indicators of air quality for confined animal feeding operations and agriculture in general.

He stated that unlike many commercial and industrial airborne pollutants which are regulated by the Clean Air and Water Act, there are few specific state or national air quality guidelines that regulate livestock waste emissions from animal production facilities. He identified six compounds that are of concern to human health which are associated with swine production: ammonia, carbon dioxide, hydrogen sulfide, methane, volatile organic compounds, and particulate matter. He explained that all odors and emissions from swine production are chemical in nature. He discussed various factors that influence odor generation and transport including source concentration, surface area, net radiation, air temperature, wind velocity, relative humidity, solution pH, and surface composition and homogeneity.

Dr. Zahn explained that the most critical point in controlling odor emissions from swine production is regulating the volatilization rate of volatile organic compounds from the stored waste system. He said that the sources of odor from livestock waste can be categorized as odors from confinements, waste storage, and land application. He discussed critical control points for odor reduction which focus on production areas that can be modified by the producer: 1) site selection or evaluation; 2) animal confinement area, including cleanliness, reduction in feed and water losses, and dietary manipulation; 3) waste storage or processing; and 4) land application of manure. He discussed selected odor reduction strategies for waste storage and processing including biofiltration, permeable floating biocovers, and anaerobic photosynthetic bacteria.

Dr. Zahn said that the report by the National Environmental Dialogue on Pork Production focused primarily on water quality and proper management. He indicated that the air quality recommendations consisted primarily of setbacks for location of new or expanded lagoons or other manure storage structures, as well as setbacks for land application of the manure.

As the impact of livestock waste emissions on neighboring residences and businesses has sparked intense controversy over health and environmental issues associated with livestock production, Dr. Zahn said their research has focused primarily on off-site pollution affecting those living near confined animal facilities. He stated that cause and effect must be proven in order to pass laws in the area of odor pollutants. He emphasized that the focus must be on the reduction of chemical causes of odors first, as there cannot be a solution to odor until it is known what causes the odor.

The meeting adjourned at 10:33 a.m. The next meeting is scheduled for February 10, 1998.

HOUSE AGRICULTURE COMMITTEE GUEST LIST

DATE: February 9, 1998

NAME	REPRESENTING
Mike Jensen	Ks Pork Council
Doug Wareham	Ks. Grain & Feed Assn. Ks. Fertilizer & Chemical Assn.
Diane Gruver	Ks Coop Council
Carole Jordan	KDA
Chris Wilson	KS Dairy Ass'n

Report on Odor Research and Environmental Issues Concerning Concentrated Animal Feeding Operations

Legislative Session on the Environment and Agriculture, February 9, 1998, State Capitol, Topeka, KS

James Zahn*, Ph.D.

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House Agriculture Committee

February 9, 1998
Attachment 1

Air Quality Regulations

Report on Odor Research and Environmental Issues Concerning Concentrated Animal Feeding Operations

Indicators of Air Quality in the U.S.

- EPA uses 6 "criteria pollutants" as indicators of air quality:
  - For each pollutant, the EPA has designated a maximum concentration above which adverse effects on human health occur.
  - These threshold concentrations are called National Ambient Air Quality Standards (NAAQS).

US-EPA Criteria Pollutants

- Ozone - photochemical oxidant and major component of smog
- Carbon Monoxide - odorous, colorless gas produced from incomplete burning of carbon in fuels.
- Nitrogen Dioxide - brownish, highly reactive gas that is an important precursor to ozone and acid rain. Respiratory problems.
- Sulfur Dioxide - primary contributor to acid deposition and acid rain. Respiratory problems.
- Particulate Matter - chemical and mechanical sources. Respiratory problems.
- Lead - inhalation and ingestion pathways. Multiple negative health impacts.

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National Ambient Air Quality Standards

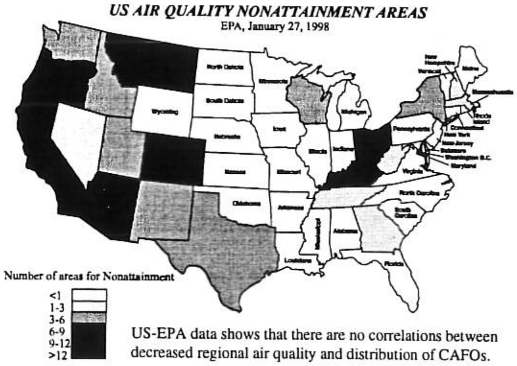
- Ozone - 1 hr. average set at 0.12 ppm; 8 hr. average set at 0.08 ppm.
- Carbon Monoxide - 9 ppm 8 hr. nonoverlapping average not to be exceeded more than once per year. 1 hr. average set at 35 ppm.
- Nitrogen Dioxide - Annual arithmetic mean 0.053 ppm.
- Sulfur Dioxide - Annual arithmetic mean 0.03 ppm; 24 hr. level of 0.14 ppm; 3 hr. level of 0.50 ppm.
- Particulate Matter - Annual arithmetic mean 50 ug/m3; 24 hr. level of 150 ug/m3 not to be exceeded more than once per year.
- Lead - Quarterly average 1.5 ug/m^3

Nonattainment Areas

- US-EPA monitors criteria pollutants at multiple sites in each state to evaluate air quality.
- Areas of the country where air pollution levels persistently exceed the standards may be designated "nonattainment".
  - Normally EPA takes this action only after air quality standards have been exceeded for several consecutive years.

US AIR QUALITY NONATTAINMENT AREAS

EPA, January 27, 1998



US-EPA data shows that there are no correlations between decreased regional air quality and distribution of CAFOs.

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Concentrated Animal Feeding Operations - The "Factory" Analogy

- Are US-EPA criteria pollutants suitable indicators of air quality for CAFOs and agriculture in general?
- A number of air pollutants identified from CAFOs are cited on the Clean Air Act "Hazardous Air Pollutant" list.
- How are these hazardous air pollutants currently regulated?

Title V Permit Program - The Farm as a Major Point Source

- Title V permit program for "major source" commercial/industrial point sources.
- Criteria to be designated as a major source:
  - 100 tons (74,600 kg)/yr of VOCs, carbon monoxide, lead, sulfur dioxide, nitrogen dioxide, or particulate matter.
  - 10 tons (7,460 kg)/yr of any hazardous substance, or 25 tons/yr of any combination of hazardous air pollutants.

Maximum Annual Gas Fluxes from Swine Facilities (Zahn et al., J. Environ. Qual., 1998)

- Hazardous Air Pollutants:
  - Hydrogen Sulfide = 30 g/animal-yr
  - Hazardous VOC = 3 g/animal-yr
- Air Pollutants:
  - Ammonia = 6000 g/animal-yr
  - Methane = 4300 g/animal-yr
  - Total VOC = 9 g/animal-yr
  - Particulate matter = ?

Predicted Animal Population Required for Regulation by the Title V Program

- Hazardous air pollutants (7,460 kg/yr)
  - Hydrogen sulfide:
    7,460kg / 0.03 (kg H2S/animal-yr)
    = 248,000 finish pigs-yr
  - *Total VOC: * = hazardous + non-hazardous
    7,460kg / 0.009 (kg VOC/animal-yr)
    = 828,000 finish pigs-yr
- Air pollutants (74,600 kg/yr)
  - **Cumulative (H2S, VOC, NH3): ** = lagoon only
    74,600kg / 6.039 (kg gas/animal-yr)
    = 12,353 finish pigs-yr

Air Quality Recommendations of the National Environmental Dialogue on Pork Production

Report on Odor Research and Environmental Issues Concerning Concentrated Animal Feeding Operations

NEDPP Air Quality Recommendations

from "A Summary of the Comprehensive Environmental Framework for Pork Production Operations", Q & A, p. 12.

- Setbacks for location of new or expanded lagoons or other manure storage structures.
  - Use of innovative source reduction methods.
- Setbacks for land application of manure which vary in distance depending on:
  - Use of injection or other soil incorporation method.
  - Use of innovative treatment or land application best management practices are used.

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NEDPP Air Quality Recommendations

from "A Summary of the Comprehensive Environmental Framework for Pork Production Operations".

- 13 point comprehensive summary with focus on water quality and proper management.
- Additional research to be conducted on certain environmental and public health questions which the Dialogue participants believe have not yet been answered.

BACKGROUND

Air Quality Problems Associated with Swine Production

The release of gaseous emissions from swine production facilities represents a significant economical and environmental problem facing modern agriculture (Letson and Gollehon, 1996 and Anthan, 1996). Until just recently, progress in assessing the effects of airborne livestock waste emissions on human and environmental health has not been an area of priority in state and federal agricultural research efforts (Gerrits, 1997). Consequently, there is little consensus among researchers, producers, and regulators concerning the extent of emissions (i.e., air concentrations), the types of emissions that are responsible for decreased air quality, and how these emissions can be reduced or controlled. This has forced the livestock and pork industry to rely largely on the dilution of livestock emissions into the atmosphere as an accepted, and most prevalent means of emission and odor control. The impact of livestock waste emissions on neighboring residences and businesses has sparked intense controversy over health and environmental issues associated with livestock production.

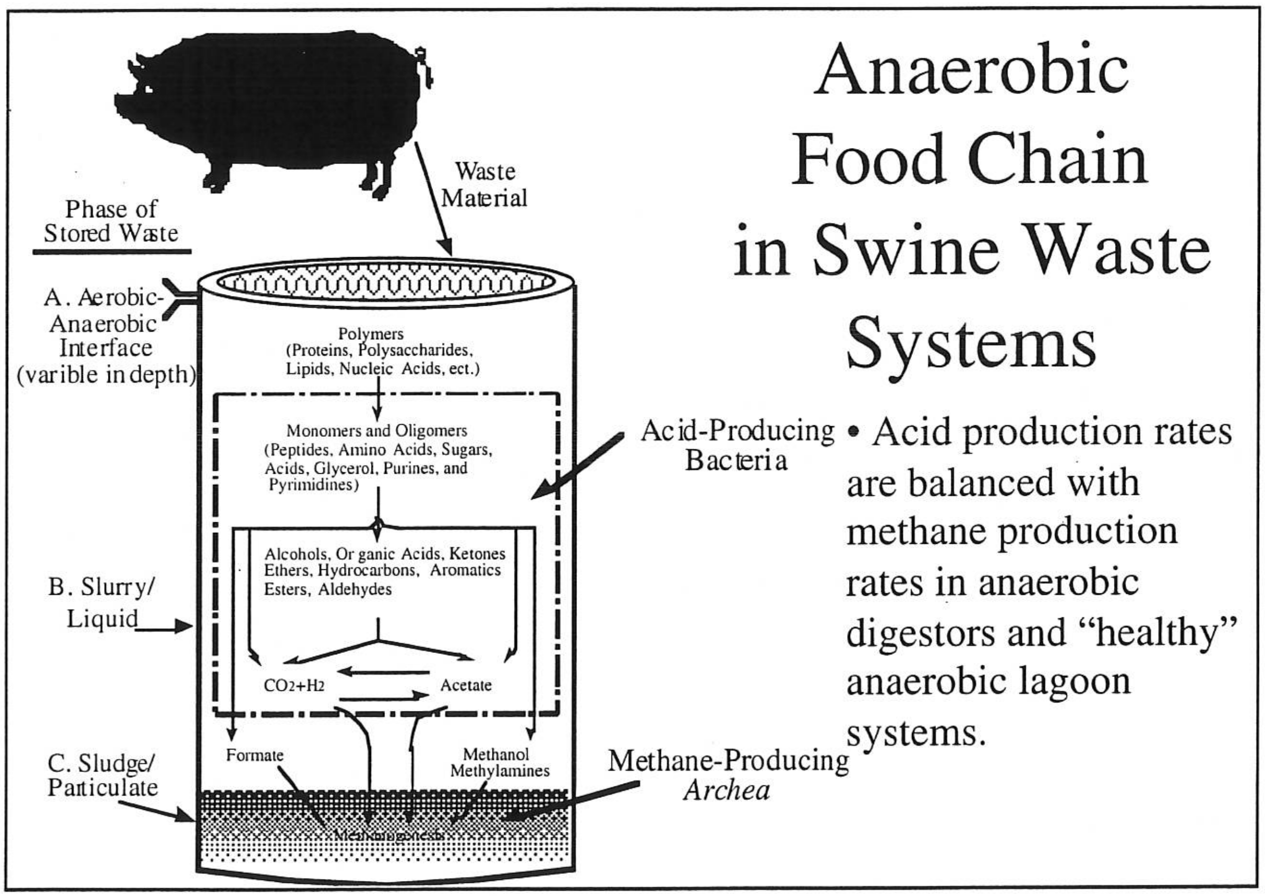
Odor and airborne emissions currently represent a major obstacle in the expansion of swine production facilities throughout the United States to meet the increasing demand for pork products (NPPC, 1997). Emission regulations establishing a maximum acceptable emission rate for individual pollutants released from a source are currently under debate for production agriculture in several regions throughout the U.S. In order to meet increasingly stringent air quality demands, individual producers within the pork industry will be obligated to adopt technologies and changes in production design which minimize the concentration of pollutants present in the emission streams from these facilities.

Biology of the Waste Management System

Most anaerobic liquid/slurry systems are designed to maximize the release of gases into the atmosphere. Within these systems, the anaerobic food chain, composed of a diverse group of obligate and faculatatively anaerobic organisms decompose complex biological wastes to the major endproducts, methane (CH_4), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and ammonia (NH_3). Since no particular group of organisms can decompose complex organic wastes into terminal endproducts individually, there exists a complex interdependence between groups of organisms for efficient and complete processing of complex wastes.

When the interdependence between these groups of organisms is disrupted by environmental parameters within the stored waste (i.e., loading rate, pH, and temperature), unprocessed intermediates from complex biological wastes accumulate, often at high concentrations within the anaerobic waste storage system (Hill and Bolte, 1989). These unprocessed intermediates, which include many types of volatile organic compounds (VOCs), are then available to volatilize from the system and add to the total system emissions.

Figure 1. Anaerobic food chain in animal waste management systems. Adapted from Zahn et al., 1997.



Classes of Swine Waste Emissions that Impact Air Quality

In addition to the major terminal endproducts of anaerobic decomposition (methane (CH_4), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and ammonia (NH_3)), a large amount of particulate matter and volatile organic compounds are released into the atmosphere from animal production facilities. Particulate material consists of minute particles of non-homogenous organic and inorganic material that often travel in airborne emission streams. Of particular health concern are particles in the size range of 0.5 and 5.0 μm. Particles within this size range are termed "respirable", since they are capable of being inhaled and deposited in the lower respiratory system. Particles below the size range of 0.5 μm tend to be exhaled without deposition while particles above the size of 5.0 μm are trapped in the upper respiratory system before they can enter the lungs. The U.S. Environmental Protection Agency has noted that the characteristics, sources, and potential health effects of larger "course" particles (2.5 to 10 μm) and smaller "fine" particles (< 2.5 μm) are very different. Course particles are mechanically-generated and can originate from several different types of sources in animal production including skin, feed, soil, animal activity, and feces. Fine particles are generated exclusively from chemical reaction of reactive gases, mainly hydrogen sulfide, ammonia, and VOCs, emitted directly from animals and animal waste stores. Course particles in the respirable range of 2.5 to 5 μm are generally regarded as a health nuisance, since they may aggravate existing health problems such as asthma. In contrast, fine particles are much more likely to contribute to chronic adverse health effects such as premature mortality and hospital admissions, since fine particles in the respirable range of 0.5 to 2.5 μm penetrate deeply into the lungs (U.S. EPA, 1997).

Unlike many commercial and industrial airborne pollutants, which are regulated by the Clean Air and Water Act, there are few specific state or national air quality guidelines (PM 2.5 and Minnesota hydrogen sulfide emission regulations) that regulate livestock waste emissions from animal production facilities. Nevertheless, various governmental agencies have published voluntary threshold limit values (TLV) that establish concentration limits in the work environment to maintain worker health.

FIGURE 2. Gaseous compounds of concern to human health associated with swine production. Time Weighted Average - (TWA) - This is the time-weighted average concentration for a normal 8 hour workday or 40-hour work week, to which all workers may normally be exposed day after day, with no adverse affect.
Short Term Exposure Limit - (STEL) - This is the maximum concentration to which workers can be exposed for a period up to 15 minutes continuously without suffering from irritation, chronic or irreversible tissue damage or change, or impaired work efficiency.

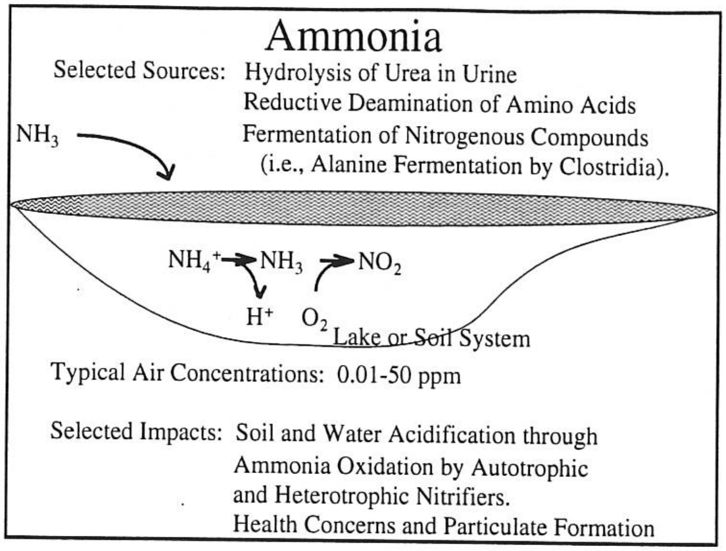
Gaseous Compounds of Concern to Human Health Associated With Swine Production

Gas	Specific Gravity	Odor	Exposure Limit mg/m³ and (ppm) TWA	STEL	Class	Chemical Reactivity
1. Ammonia	0.6	Sharp, Pungent	18 (25)	27 (35)	Irritant	High
2. Carbon Dioxide	1.5	None	9000 (5000)	54000 (30000)	Asphyxiant	Low
3. Hydrogen Sulfide	1.2	Rotten Egg, Nauseating	14 (10)	21 (15)	Odorant Poison	Extremely High
4. Methane	0.5	None		-	Asphyxiant	Low
5. Volatile Organic Compounds	-	Fecal, Stench to Odorless	1 - Non-Toxic (0.5 - NT)	38 - Non-Toxic (10 - NT)	Odorant Poison	Low to Moderate
6. Particulate (Respirable)	-	n/a	3	5	Irritant	Low

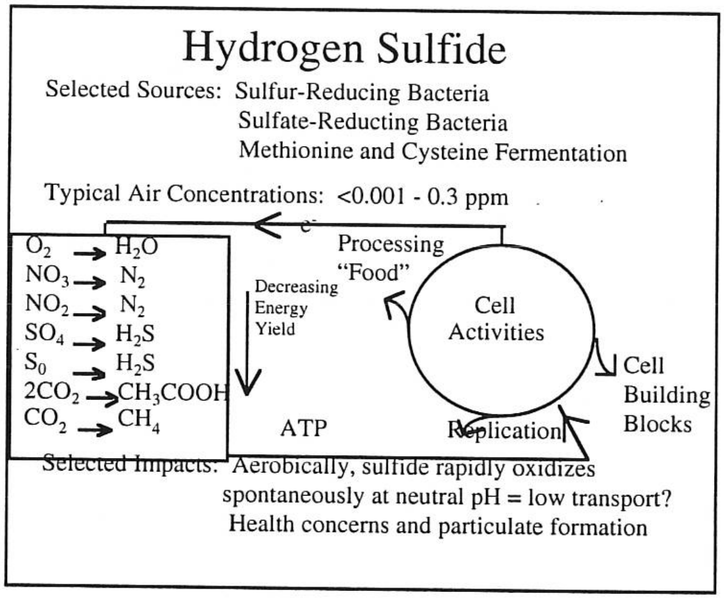
Source: Recommendations by the American Conference of Governmental Industrial Hygienists (1996).
TWA = Time Weighted Average = Normal work exposure without adverse affect.
STEL = Short-Term Exposure Limit = Short-term exposure without irritation or or chronic irreversible tissue damage.
Respirable Particle = Particle size range = 0.5 to 5.0 µm.

Many airborne emissions that are present in emission streams from swine production have established TWA and STEL limits and therefore, health impacts can be addressed by maintaining airborne concentrations below these recommendations. One noticeable exception to this generalization exists for the class of emissions designated as volatile organic emissions. Recommendations for permissible exposure levels for VOCs are based on volatile organic chemicals with common usage in industrial and commercial settings. In many cases, some VOCs emitted from waste decomposition are uniquely found only in animal waste management systems. The effects that these compounds may have on human health are largely unknown.

In addition to human health concerns, emissions from livestock waste decomposition have been proposed to alter the environment in several ways:



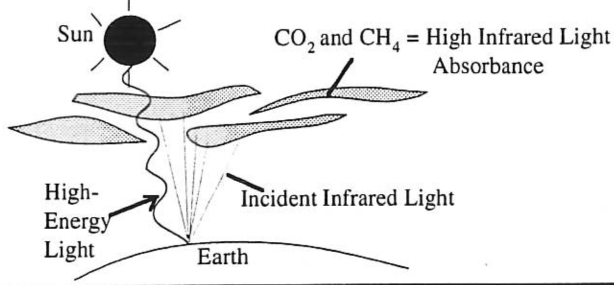
Ammonia - Ammonia is the most abundant alkaline component in the atmosphere. Because it is a weak base (0.1 M solution of [NH_3] has a pH of 11), ammonia plays a major role in neutralization of sulfur dioxide and nitrogen oxides in the atmosphere (Harper and Sharpe, 1996). Acid/base neutralization results in the formation of salts which contributes to particulate matter concentration in the atmosphere. Under aerobic conditions in the soil and aquatic environments, ammonia is oxidized by autotrophic and heterotrophic nitrifying bacteria into nitrite (NO_2). The biological process of ammonia oxidation (nitrification) increases the acidity of the soil and water environment were the reaction takes place. Soil acidification has been associated with crop stress, plant nutrient imbalances, and decrease in soil fertility (Vander Molen, et al., 1990).



Hydrogen sulfide - Hydrogen sulfide is a weak polyprotic acid that spontaneously oxidizes under aerobic conditions at neutral pH ($pK_{a1} = 7.04$; $pK_{a2} = 12.92$). Hydrogen sulfide reacts with bases to form salts. The neutralization reaction produces particulate matter in the atmosphere which is capable of movement in air currents.

Carbon Dioxide and Methane

	Carbon Dioxide	Methane
Selected Sources:	Anaerobic Respiration Fermentation Methanogenesis	Methanogenesis
Typical Air Concentrations:	320 - 5000 ppm	2 - 60 ppm
Selected Impacts:	Global Warming Asphyxiant	Global Warming Asphyxiant



Methane and Carbon Dioxide - These highly stable gases strongly absorb in the infrared range of the electromagnetic spectrum and therefore, efficiently convert infrared energy to heat energy. The "Greenhouse Effect" suggests that the steadily increasing concentrations of methane and carbon dioxide in the upper atmosphere will cause an increase in global temperatures which will result in the melting of the global icecaps and disruption of global ecosystems.

Volatile Organic Compounds

- Selected Sources: Anaerobic Respiration
  Fermentation
  -Terminal End-Products
  -Intermediates
- Typical Air Concentration (total): <0.02 - 10 mg/m^3
- Selected Impacts: Health? (Fat and Water Soluble)
  Particulate Formation
  Odor

Volatile Organic Compounds - Industrial and occupational health organizations have recognized, for a number of years, the severe impact that these compounds have on worker health and productivity. Current studies (Zahn et al., 1997) show that the air concentration of VOCs at swine production facilities is often one order of magnitude below TWA and STEL recommendations. Environmental impacts of VOCs from swine production are largely unknown.

Particulate Matter

•Minute particles of non-homogenous organic and inorganic material

•Selected Sources:

Physical/Biological Sources

- Feed, Skin, Soil, Feces

Chemical Sources

- Reactive gases (acid-base neutralization reactions which form salts in the air)

•Typical Air Concentration (total): <1 - 400 mg/m^3

•Selected Impacts:

Health Hazard

- Respirable Particles (size range 0.5 to 5μm) get trapped in lungs.

Odor?

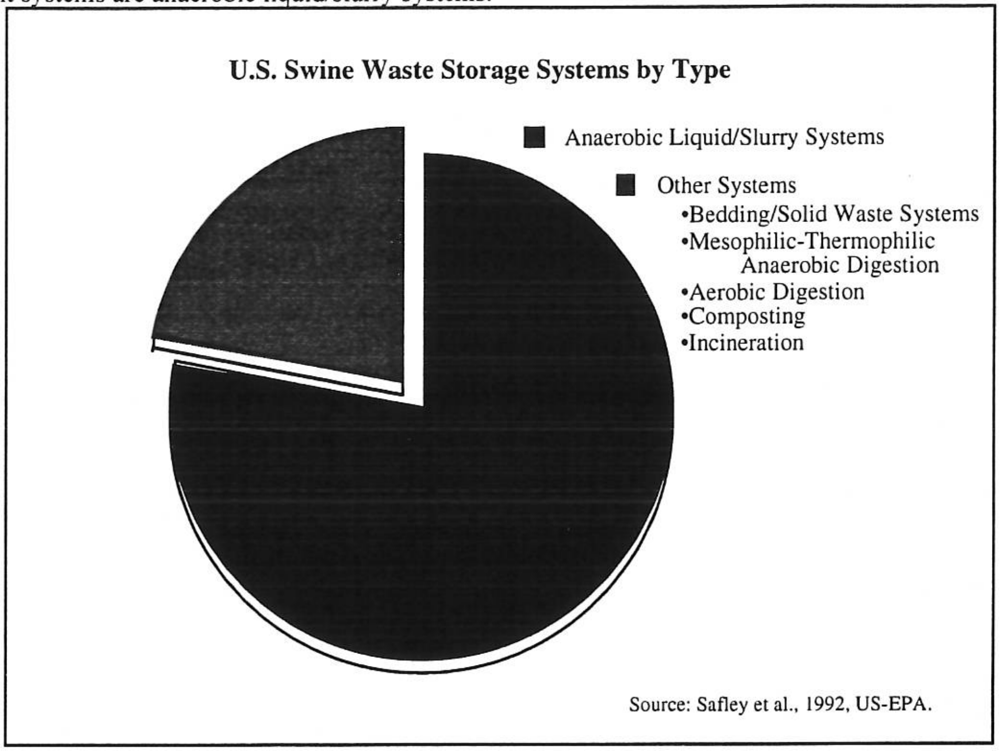
-Odorant molecules may travel on particulate matter.

Particulate Matter - In addition to gases, particulate material consisting of minute particles of non-homogenous organic and inorganic material often travel in emission streams from swine waste storage and animal production facilities. Of particular health concern are particles in the size range of 0.5 and 5.0 μm. Particles within this size range are termed "respirable", since they are capable of being inhaled and deposited in the lower respiratory system. Particles below the size range of 0.5 μm tend to be exhaled without deposition while particles above the size of 5.0 μm are trapped in the upper respiratory system before they can enter the lungs.

How Production System Type Influences Air Quality and Odor Production

The first step in air quality maintenance associated with livestock production is the definition of sources responsible for the emission. The failure of the swine industry to adopt specific waste management guidelines has resulted in the great diversification of anaerobic strategies to store and treat manure (Zahn et al., 1997). As a whole, more than 75% of the swine production systems in United States store and process swine wastes anaerobically (Safley et al., 1992) due to the greater economical feasibility (Sievers and Iannotti, 1982) and the extremely high biological oxygen demand (Sievers and Iannotti, 1982 and Kobayashi and Kobayashi, 1995).

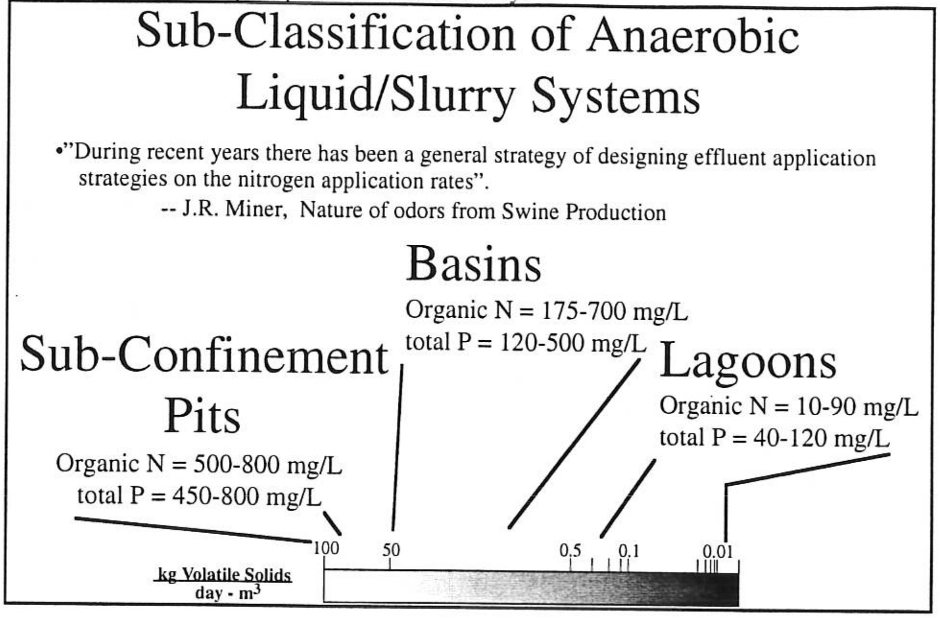
FIGURE 3. Classification of United States swine waste storage systems by type. More the 75% of swine waste management systems are anaerobic liquid/slurry systems.



Because of the popularity of these systems in modern swine production, the following analysis is focused exclusively on air quality problems associated with anaerobic liquid/slurry systems. Anaerobic liquid/slurry systems can be further divided into several subcategories based on the extent of loading. System loading is often measured in units of volatile solid input per day per unit volume (cubic meter). Volatile solids represent the fraction of mainly organic material present in dried waste (103° C) that can be converted directly to gases such as SO_4, CO_2, N_2 at elevated temperatures (550° C). The amount of volatile solids in the sample is determined by subtracting the weight of the sample after ashing (550° C) from the initial dry (103° C) sample weight.

A comparison of waste input (volatile solids) relative to storage capacity for three common waste storage/treatment systems is shown below. These systems (lagoons, deep basins, and sub-confinement pits) have been cited as the most common waste management systems currently utilized by the swine industry (Zahn, et al., 1997).

FIGURE 4. Subclassification of Anaerobic liquid/slurry systems based on input of volatile solids versus storage volume, organic nitrogen, and total phosphorus in stored slurry.



Although there are several considerations in the adoption of a particular anaerobic liquid/slurry storage strategy for management of swine wastes, nutrient utilization and climate has arguably been the most significant factors in system selection (Miner, 1995). From an analysis of current waste management systems in use today it has been noted that "during recent years there has been a general strategy of designing effluent application strategies on nitrogen application rates," (Miner, 1995). Since animal waste is regulated according to zero discharge laws, there are currently no incentives or provisions for wastewater purification. Therefore, swine and other animal wastes are invariably returned back to grazing or crop production land as a final disposal or nutrient utilization site.

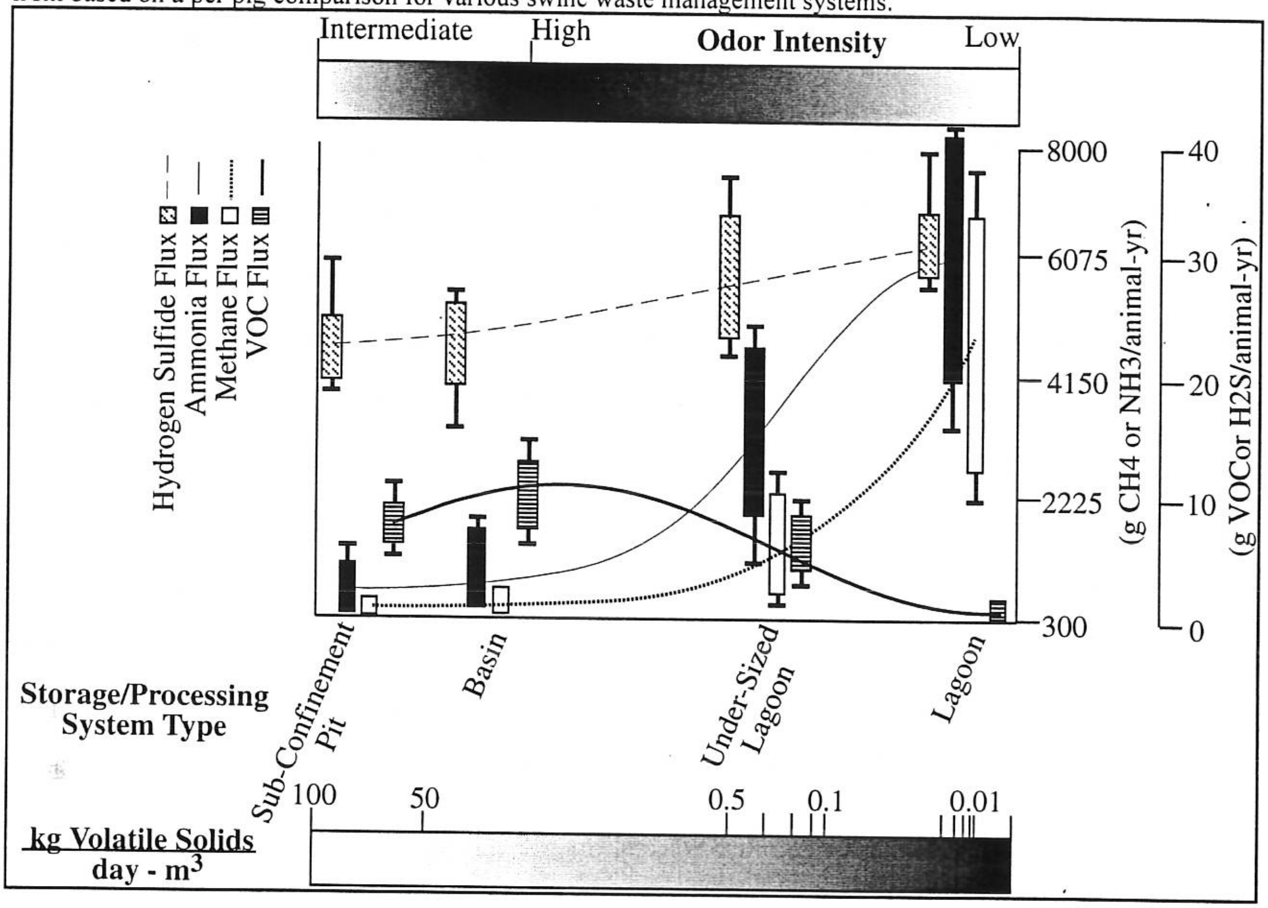
In situations where crop production is of limited significance to the operation or in the case where there is insufficient grazing or crop land to apply swine wastes, lagoons are often employed to reduce the amount of total nitrogen present in the waste material to allow for higher application rates. With lagoons, animal wastes containing organic forms of nitrogen are efficiently processed in a biologically-active system to ammonia that subsequently, can be released into the atmosphere. Harper and Sharp (1996) recently noted that less than 1% of the total nitrogen input into lagoon systems is available for nutrient utilization by crops after processing in this type of waste management system. On the other hand, if there is economic interest in crop production or sufficient grazing or crop land to apply swine wastes, high-load (kg volatile solids/animal-m^3) waste storage systems exhibiting extremely low biological activity are often preferred to keep nitrogen in an organic form (i.e., amino acid and other non-ammonia forms of nitrogen) which is more resistant to volatilization. In pit systems, typically more that 40% of the nitrogen input is available for nutrient utilization by crops, since nitrogen is retained in a highly stable organic form (Miner and Smith, 1975).

Selection of Waste Management System Based on Emission and Odor Potential

Recent environmental assessments have suggested that high volume manure management systems have a higher potential to change the quality of surface and ground water due to the large volumes contained within these systems and the fact that many of these systems rely on earthen liners for retention of wastes. This viewpoint, coupled with the revitalization of interest in maximizing the economic value of swine manure as a value-added nutrient for crops has recently re-directed the construction of new swine production, especially in the Midwest, toward the use of high-load waste management systems that utilize below-ground concrete-lined or above-ground steel manure storage systems. Unfortunately, there has been an obvious lack of information available to producers and researchers that addresses how these various manure management systems compare in generation of airborne emissions and odor.

Recent studies have shown that VOC flux rate from swine production facilities are inversely correlated with methane, ammonia, hydrogen sulfide flux rates. Waste management systems with high loading rates and relatively low biological activity demonstrated lower ammonia and methane flux rates than systems with low loading rates and relatively greater biological activity. Additionally, systems with high loading criteria showed an average 10-fold increase in total volatile organic emissions as compared to lagoon systems. Therefore, systems employing low loading rates should be more concerned with release of methane and ammonia into the atmosphere while systems employing high loading rates should be focused on the reduction of VOC emissions. The flux of hydrogen sulfide from these systems differs only slightly with respect to waste management system employed. Reduction of hydrogen sulfide emissions is of universal concern with all types of anaerobic liquid/slurry waste management systems evaluated.

FIGURE 5. Annual estimated flux of ammonia, methane, hydrogen sulfide, and volatile organic compounds from based on a per pig comparison for various swine waste management systems.



What is the underlying cause for these differences in emission parameters? As mentioned previously, decomposition of manure under anaerobic conditions is catalyzed by many groups of microorganisms composing the anaerobic food chain. Under anaerobic conditions, these organisms decompose complex biological wastes to the major endproducts, methane (CH_4), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and ammonia (NH_3). Since no particular group of organisms can decompose complex organic wastes into terminal endproducts individually, there exists a complex interdependence between groups of organisms for efficient and complete processing of complex wastes. The environment in high load waste management systems favors incomplete processing of biological wastes because these conditions strongly inhibit the activity of many bacterial populations performing acid-producing reactions and most

Archea populations performing methane-producing reactions. As a result, fermentation products of partially-decomposed waste accumulate within the waste storage system environment and are available to volatilize into the atmosphere. Nearly all of these intermediate compounds generated in incomplete processing of waste have been identified as organic in nature. On the other hand, lagoons and other systems employing low loading rates, have a well functioning anaerobic food chain because the conditions in these systems promote greater microbial diversity and more complete processing of wastes to the endproducts, methane (CH_4), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and ammonia (NH_3).

The Relationship Between Emission Chemistry and Swine Waste Odor

The perception of odor begins with the impingement of airborne chemical compounds on olfactory receptors in the olfactory area of the nasal cavity. All odors that are perceived by the human olfactory system are due to the presence of volatile organic or inorganic compounds in the air that is inhaled. Although there are six different classes of gases released from the anaerobic decomposition of animal wastes, only ammonia, hydrogen sulfide, and volatile organic compounds have odor threshold values low enough to potentially contribute to odor. Since it is both expensive and impractical to use human sensory evaluation for studies requiring large sample numbers, there has been considerable interest in designating select gases in emission streams as indicators of odor concentration. Several recent investigations have focused on establishing a relationship between chemical concentration and odor concentration (Hobbs et al. 1995, Jacobson et al. 1997(a), Jacobson et al. 1997(b), Obrock-Hegel 1997, Pain et al. 1990). Obrock-Hegel (1997), found that nutritional manipulation of amino acid intake reduced ammonia, cresols, and indoles measured in air samples from production environments; however, no reduction in odor concentration was observed between control and treatment samples. Schulte et al. (1985) and Hobbs et al. (1995), linked high levels of ammonia to odor. However, the latter authors noted that this relationship could not be universally applied to all farms, especially when they differed in waste management system utilized. The use of air concentrations of hydrogen sulfide as an indicator of odor concentration has also proven to be a formidable challenge. Jacobson et al., 1997 evaluated odor and hydrogen sulfide concentration for approximately 60 different pig, dairy, beef, and poultry manure storage units on farms in Minnesota. No correlation was observed between hydrogen sulfide and odor concentration for waste storages based on a species comparison, for production system grouped according to waste management system type (pit, basin, lagoon) nor independent of species and system type.

Similar to hydrogen sulfide and ammonia, several volatile organic compounds emitted from swine waste decomposition have extremely low odor thresholds . Low odor thresholds, coupled with the fact that many organic compounds show much greater chemical stability in the atmosphere than either hydrogen sulfide or ammonia, suggest that volatile organic compounds may largely be responsible for livestock odor. Figure 6 shows the relationship between concentration of VOCs in air from 30 swine farms and odor intensity measured by direct scaling using a standard of defined magnitude. These results indicate that volatile organic compounds are strongly associated with swine waste odors perceived by the human senses and that the air concentration of these compounds may be employed to predict odor intensity.

Figure 6. Total concentration of indicator volatile organic compounds present in the air *versus* odor intensity measured by the direct scaling technique using a standard of defined odor magnitude. Chemical composition for representative samples from each of the four subsets are shown below in Table 1

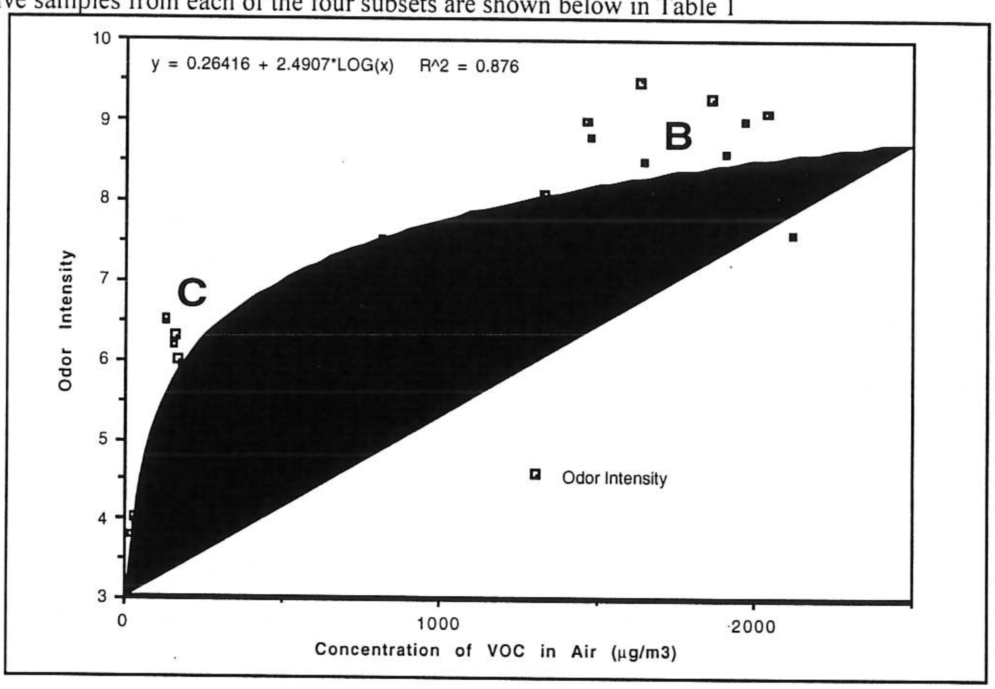


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Table 1. Representative chemical breakdown for clusters of data points in Figure 6. Individual volatile organic compounds contributing to the total volatile organic emissions from swine production facilities differing in waste management system.

Peak # and retention time (min.)	Organic compound†	Swine waste storage system or production site (Analyte air concentration (μg/m³)‡ and Percent total peak area (%)§)			
		A¶	B	C	D
1 (4.8)	Dimethyl disulfide	12 (1.3)	nd	17 (6.8)	nd
2 (6.1)	2-Butanol	8 (0.8)	nd	19 (7.5)	nd
3 (7.5)	Dimethyl trisulfide	nd	nd	13 (5.2)	nd
4 (8.6)	Unknown	nd	nd	8 (2.9)	nd
5 (10.6)	Acetic acid	281 (15.2)	262 (7.6)	11 (2.7)	2 (2.3)
6 (11.9)	Propionic acid	126 (11.1)	50 (2.3)	5 (1.9)	4 (8.2)
7 (12.4)	Isobutyric acid	23 (2.5)	107 (11.4)	6 (2.2)	nd
8 (13.3)	Butyric acid	142 (15)	586 (32)	13 (5.1)	5 (12.9)
9 (14.0)	Isovaleric acid	73 (8.3)	98 (6)	3 (1.2)	nd
10 (15.0)	n-Valeric acid	43 (4.9)	360 (27)	5 (2.0)	1 (0.7)
11 (15.7)	Isocaproic acid	nd	10 (0.5)	nd	nd
12 (16.0)	n-Caproic acid	nd	105 (7.4)	nd	nd
13 (16.1)	Unknown	11 (1.2)	nd	nd	nd
14 (16.6)	Heptanoic acid	nd	8 (0.3)	nd	nd
15 (17.2)	Benzyl alcohol	nd	nd	2 (1.2)	nd
16 (18.8)	Phenol	9 (1.5)	24 (1.6)	8 (6.9)	3 (9.9)
17 (19.7)	4-Methyl phenol	85 (19.6)	32 (2.7)	9 (7.5)	3 (17.8)
18 (20.9)	4-Ethyl phenol	3 (0.7)	2 (0.2)	4 (3.3)	1 (6)
19 (21.9)	2-Amino acetophenone	nd	nd	nd	0.2 (0.4)
20 (23.4)	Indole	nd	1.1 (0.2)	0.8 (0.6)	0.1 (0.5)
21 (23.7)	Hexadecanoic acid	nd	nd	9 (7.8)	5 (33)
22 (24.2)	3-Methyl indole	0.5 (0.2)	1.4 (0.3)	1.3 (1.1)	0.2 (0.7)
Total air concentration of VOCs identified (μg/m³)		817	1647	134	25
Percent of total peak area (%)		82.3	99.5	65.9	92.4

† International Union of Pure and Applied Chemistry (IUPAC) system nomenclature.
‡ Micrograms of substance per cubic meter of air.
§ Percent peak area relative to chromatogram total integrated peak area.
¶ Swine waste storage system or production site; A = Confinement system with subconfinement pit waste storage; B = Outdoor cement-lined basin; C = Outdoor earthen-lined basin/lagoon; D = Lagoon. nd = analyte not detected.

Factors that Influence Odor Generation and Transport

Except for the portion of the volatilization budget that is propagated or enhanced by gas production from biogenic sources (i.e., purging of the manure with gases of biogenic origin such as CH_4, CO_2, H_2S, or N_2), volatilization and atmospheric transport of odors from swine production is a non-biological event. Volatilization is defined as the movement of inorganic and organic compounds present in the liquid phase into the gas phase. Since all odors and emissions from swine production are chemical in nature, movement of inorganic or organic chemical odorants and emissions from liquid or solid form to gaseous form follows basic chemical laws.

Table 2. Partitioning behavior of elements/compounds between aqueous and vapor phases.

Partitioning Behavior		
Element/Compound	**Henry's Law Constant (vapor pres./solubility)**	
Helium	**2700**	"Likes" to be in Air
Nitrogen	**1600**	
Oxygen	**780**	↓
Hydrogen Sulfide	**10**	
Carbon Dioxide	**29**	
Methyl Bromide	**0.006**	"Likes" to be in Water
p-Cresol	**0.00000097**	

Unlike hydrogen sulfide or carbon dioxide, the emission rate of many organic compounds, several of which are strong odorants, will depend more greatly on conditions that alter the solubility or vapor pressure of these types of compounds. Environmental parameters that influence solubility and vapor pressure of organic odorants in solution include:

a) Source Concentration

The number of molecules that leave the surface of a liquid is proportional to the concentration of molecules in the solution. Therefore, the concentration compounds present in the liquid-phase is one of the most important factors effecting odor and emission potential of the system.

b) Surface Area

The number of molecules that leave the surface of a liquid is proportional to the surface area of the liquid. For acetic acid and 4-methyl phenol, two common volatile organic odorants from swine production, a change in the surface area from 18 to 62 cm^2 (3.5-fold increase in surface area) was observed to increase emission of acetic acid by 3.7-fold and emission of 4-methyl phenol by 3.5-fold. Therefore, if the concentration of material in solution remains the same and the surface area increases, emission rate will increase proportionally with the change in surface area.

c) Net Radiation

Outdoor bodies of water such as lagoons and outdoor basins act as massive sinks of energy from the sun. Conversion of light energy to heat energy increases the vapor pressure of chemical components present in the waste material. For acetic, propionic, and butyric acids, a change of 25° C can elevate the vapor pressure nearly one order of magnitude (i.e., from 0.6 kPa to 6kPa) (Gallant and Yaws, 1993). Controlled environment studies evaluating the effect of relative humidity, air temperature, wind velocity, and net radiation have suggested that net radiation is individually the most significant factor in volatilization of organic compounds from stored swine wastes.

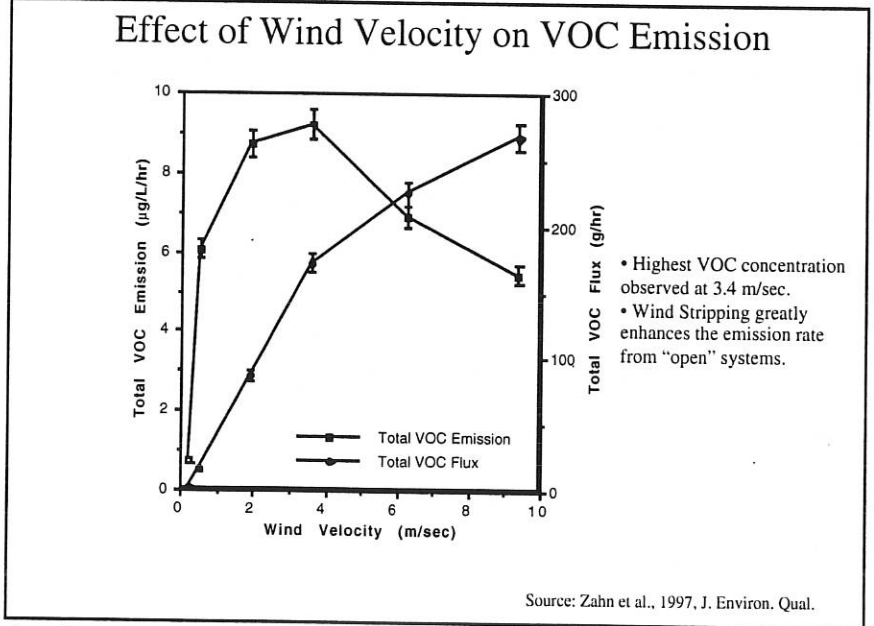
d) Air Temperature

Like net radiation, air temperature strongly influences vapor pressure. As noted previously, a change of 25° C can elevate the vapor pressure nearly one order of magnitude for many organic acids. For acetic acid, a change in air temperature of only 7° C (from 25°C to 32° C), at constant relative humidity, will change the emission rate of this organic compound by nearly 24%.

e) Wind Velocity

High wind velocity over a liquid surface greatly increases the rate at which odorants and other emissions are released from stored waste. This is because: 1) The compounds that volatilize from the system are carried away in air currents at rates that often exceed emission rate and equilibrium between liquid and gas phases is never achieved. Wind velocity directly affects how steep the concentration gradient will be, and the equilibrium status. Under low wind velocity, higher concentrations of volatile compounds accumulate in the boundary layer between the gas and liquid phases which inhibits the volatilization rate. 2) Extremely high wind velocity also physically "strips" compounds from the surface layers of stored waste.

Figure 7. The effect of wind velocity on air concentration and flux rate of volatile organic compounds from an outside swine waste storage. Highest odor occurs at the point of highest air concentration of total volatile organic compounds (approximately 3.4 m/s wind speed).



f) Relative Humidity

Relative humidity has a slight inhibitory effect on the volatilization of compounds from the waste storage system into the atmosphere. For slightly soluble gases such as dimethyl sulfide, methane, and other volatile organic compounds, the aqueous boundary layer (at the solution air interface) retards transport of these compounds into the atmosphere (MacIntyre, 1995). The rate limiting step in the movement of these gases into the atmosphere is then the exchange across the air-water boundary. High relative humidity has been shown to have a stabilizing effect on the air-water boundary while low humidity situations destabilize the boundary. A stabilized boundary will more efficiently retard the movement of these types of emissions across the boundary layer while a destabilized boundary layer will permit increased volatilization.

g) Solution pH

Solution pH alters waste system parameters such as ionization of organic and inorganic acids and bases and chemical/biological transformations occurring within the solution. Like temperature, ionization state of acids and bases in solution greatly alters partial pressure and therefore, release rate from solution. For ammonia (a weak base) the midpoint point (pKa) occurs at a pH of 9.24. At this pH half of the species in solution are in the ammonium-form (NH_4^+) and are resistant to volatilization and the other half are in the ammonia-form (NH_3) and capable of movement into the air. Increasing the acidity (decreased pH) of the waste storage system reduces volatilization losses of ammonia since ammonia in converted to the ammonium-form. For acids, such as the volatile fatty acids, hydrogen sulfide, and other organic sulfides, the opposite behavior is observed. Examples of acids include acetic acid ($pK_a = 4.8$) and hydrogen sulfide ($pK_{a1} = 7.04$, $pK_{a2} = 12.9$).

e) Surface Composition and Homogeneity

The formation of crusts and scum layers on the surface of waste storages effectively reduce transfer of semivolatile and volatile compounds into the atmosphere. These surface layers reduce emission rate through a combination of factors listed above. Manure storage additives often utilize detergents (sodium dodecylsulfate) or other surfactants to decrease surface tension at the liquid surface. These surfactants lower surface tension of a liquid by concentrating at the liquid surface. The reduction of surface tension by the surfactant makes the surface tension of the water comparable to that of light oils which then reduces volatilization of odorants and other emissions from the liquid.

Critical Control Points for Reducing Odor Emissions from Pork Production Facilities

The most critical point in controlling odor emissions from swine production is regulating the volatilization rate of volatile organic compounds from the stored waste system. As noted, 1) source concentration, 2) surface area, 3) net radiation, 4) air temperature, 5) wind velocity, 6) relative humidity, 7) solution pH, and 8) surface composition and homogeneity influence the emission rate of odor from a source. Once emissions from pork production enter the air through the volatilization process, they are subject to transport and dispersion into the atmosphere. The fate of these chemicals following atmospheric release is currently of intense concern to individuals living or working in neighboring residences and businesses situated in the emission stream. Because dispersion mechanisms are inherently inconsistent in nature (because they rely on inconsistent meteorological conditions), a greater emphasis for odor control measures is focused on reducing volatilization rate, and a minor emphasis is focused on mechanisms that maximize atmospheric dilution.

Sources of odor from livestock waste can be categorized as odors from confinements, waste storages, and land application. The following critical control points for odor reduction focus on production areas that can be modified by the producer:

1. SITE SELECTION OR EVALUATION

Impact on odor: Increased dispersion of odor into the atmosphere reduces odor concentration at a downwind receptor. Atmospheric transport of odor can by reduced by maintaining filtering barriers, such as ground cover or trees, in a downwind direction from the source. Identify possible odor nuisance risks and develop a plan to reduce future conflict.

During transport of pollutants from source to receptor, the mass that is emitted from the source is assumed to remain in the atmosphere with Gaussian plume models. These models predict that use of tree barriers and odor source control are the most important factors in limiting odor dispersion from existing structures (Chastain and Wolak, 1997). It has recently been noted that considerable losses of volatile organic emissions occur at the ground surface through reaction, gravitational settling, or turbulent impaction (Zahn et al., 1997). Therefore, the role that dense tree or vegetative barriers have on reducing atmospheric transport of odors and other emissions from waste storages is underestimated with current models by up to 93% under normal and unstable atmospheric conditions.

2. ANIMAL CONFINEMENT

- **Cleanliness of the Animal Confinement**

Impact on odor: Air exchange rate in buildings and fans is increased by removal of manure and dust accumulation in the flow path of exhaust and inlet air openings. Maintaining constant dunging areas within confined areas in addition to regular removal of manure deposits reduces odor volatilization by minimizing the active surface area.

• **Reduce Feed/Water Losses**

Impact on odor: Higher feeding efficiency reduces the loading rate of waste into the waste management system. A reduction in loading rate results in reduced source concentration of odorants in the waste management system and a lower volatilization rate. Efforts to reduce the spillage of feed and water by inefficient or malfunctioning feeders and waters will reduce system loading rate and odor emission.

• **Dietary Manipulation**

Impact on odor: Improved digestibility and utilization of feed has been shown to reduce excretion volume and the loading rate of the waste management system. A changes in the composition of feed has also been shown to alter gut microflora and the composition of waste products excreted from swine. A change in the composition of waste, such as concentration of a buffering ion (ammonia/ammonium), has been shown directly influence the pH of both excreted and stored animal waste. A reduction in system loading rate will reduce source concentration of odorants available for volatilization. Bulk changes in the pH of the waste storage environment have both beneficial and detrimental affects in the volatilization of odorants from the storage environment.

Minimizing nutrient excesses in diets, improving nutrient digestibility and utilization, and balancing nutrient levels to meet the needs of the pig and microflora in the gut have been approaches proposed to reduce odor production in animal excrement (Sutton et al., 1997). Studies focused on the manipulation of animal diets have focused on reducing crude protein intake (Kay and Lee, 1995; Kay and Lee, 1997), dietary supplementation with synthetic amino acids (Lenis, 1993), and dietary supplementation with fermentable substrates such oligosaccharides and cellulose (Sutton et al., 1997). All of these treatments have shown significant reductions in total nitrogen excretion (near 44%), reduction in the pH of stored waste, presumably due to the loss of the buffering capacity provided by basic components, and reduced emission of ammonia from animal confinements due to both lower solution-phase concentrations of ammonia and reduced volatilization through acidification of the pit environment. Additionally, Kay and Lee (1997) demonstrated that growing and finishing pigs on a low crude protein diet consumed less water and therefore produced approximately 28% less volume of slurry for land application. While control and reduction of ammonia emissions is of concern, especially for European countries (Kay and Lee, 1997), the impact of dietary manipulation on the reduction of odors has currently not been established. Obrock-Hegel 1997, found that nutritional manipulation of amino acid intake reduced ammonia, cresols, and indoles measured in air samples from swine confinements; however, no reduction in odor concentration was observed between control and treatment samples as measured by Dynamic-Forced-Choice Triangle Olfactometry. Sutton et al., (1997) found increased amounts of malodorous sulfide and disulfide compounds in the headspace of manure samples from pigs on reducing crude protein diets, and with reduced crude protein diets supplemented with fermentable substrates. As noted previously, acidification the slurry reduces volatilization of basic compounds such as phenolic compounds, amines, and ammonia but enhances volatilization of acidic components such as volatile fatty acids, hydrogen sulfide, and other organic sulfides. Although there is currently a lack of evidence supporting the idea that reduced crude protein diets, or reduced crude protein diets supplemented with fermentable substrates reduce odor emission, there is no question of the importance of dietary manipulation in future odor research.

3. WASTE STORAGE OR PROCESSING

Impact on odor: Great variability exists in the types of anaerobic liquid/slurry waste management systems available for swine production. However, systems open to environmental exposure all have the capacity to release odor and other gases into the atmosphere. The rate at which odorants and other dissolved gases move into the atmosphere may be regulated by treatments that influence the input of wastes or processing of wastes within the system (source concentration), active surface area of the storage, exposure of the system to sunlight (net radiation), the temperature of air exposed to the system, wind exposure (velocity), exposure of the system to air water vapor (relative humidity), bulk pH of the waste material in solution, and the uniformity of the stored material at the air interface (surface composition and homogeneity). Many of these variables that influence volatilization rate can be altered through various treatment processes discussed below.

4. LAND APPLICATION OF MANURE

Impact on odor: Since animal waste is regulated according to zero discharge laws, there are currently no incentives or provisions for wastewater purification. Therefore, swine and other animal wastes are invariably returned back to grazing or crop production land as a final disposal or nutrient utilization site. Application of manure on crop or grazing land results in environmental pollution through ammonia volatilization, release of inorganic and organic gases including greenhouse gases and nitrate leaching. Agriculture is currently regarded as the largest single nonpoint source of water pollutants, including sediments, salts, fertilizers, pesticides, and manures (National Research Council, 1989). Application of a nutrient-rich, highly anaerobic waste material into the aerobic environment of crop and grazing lands results in an "explosion" of metabolic activity by soil microorganisms. These microorganisms transform components in the manure, including highly odorous compounds such as organic acids, sulfides, cresols, indoles, aminies, and aromatics, to gases such as nitrogen, nitrous oxide, carbon dioxide, methane and also incorporate nutrients (C, H, N, S, and trace elements) into cell biomass. During the transformation process, that may occur over several hours to several days, odorous material in the waste is also capable of entering the atmosphere through volatilization. The rate at which odors move into the atmosphere (volatilization rate) is influenced by application rate (source concentration), active surface area of spreading, exposure of manure to sunlight (net radiation), the temperature of air and soil exposed to manure, wind exposure, and water vapor in the air. Strategies to reduce odor nuisance typically focus on timing the application for periods in the day 1) associated with low outdoor activity of neighbors, 2) choosing daily conditions when the highest volatilization rate occurs so that volatilization losses occur in a narrow "window", 3) minimizing exposure of manure to air during the agitation process or when land applying manure.

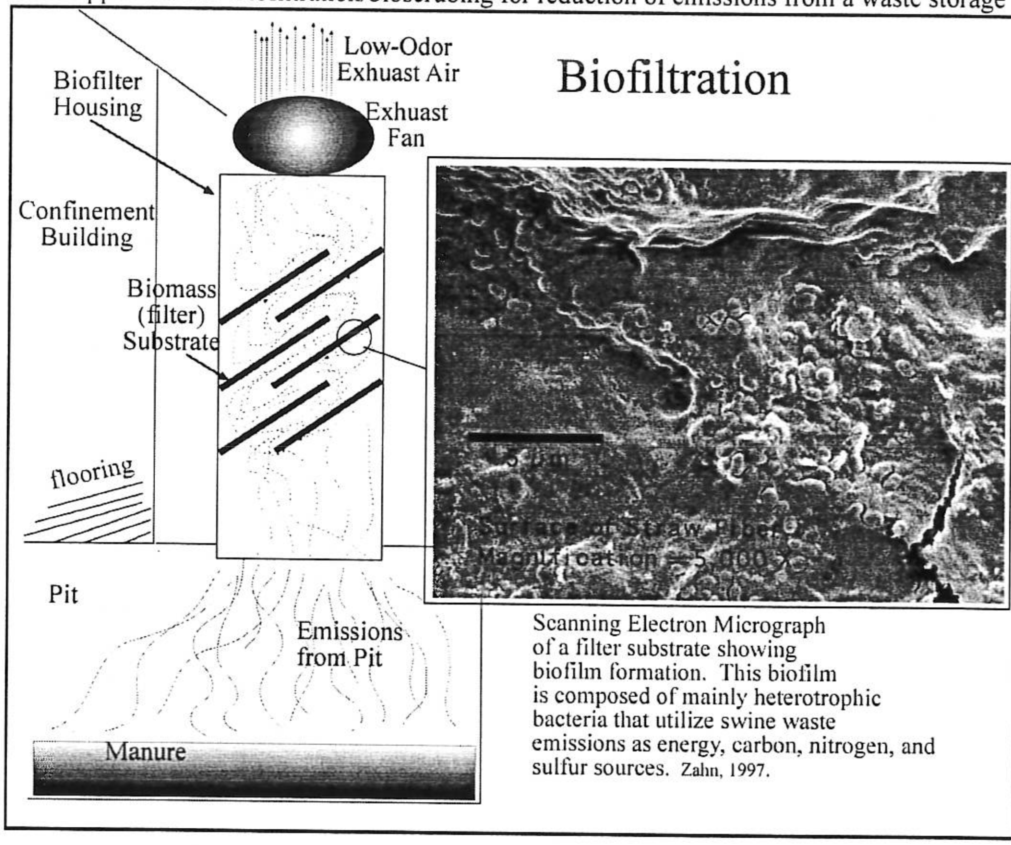
Selected Odor Reduction Stratigies for Waste Storage and Processing

Biofiltration

(Impact: source concentration)

Subconfinement pits, outdoor basins and manure storage tanks provide conditions of high manure loading rates and low surface area. Under conditions of high loading and low surface area, emissions can be treated in a two step process where an aerobic process is decoupled from the highly anaerobic conditions of the waste storage system. Biofiltration, is an aerobic process were emissions from the storage system pass through a porous filter material inhabited by aerobic bacteria which utilize odorant and other chemicals present in the emission stream as carbon, nitrogen, sulfur, and energy sources. Because this treatment method is decoupled from the anaerobic waste, the nutrient value of the manure is not changed and at the same time, air quality of emissions is increased by removal of odors and other chemical compounds.

FIGURE 8. Application of Biofiltration/bioscrubing for reduction of emissions from a waste storage pit.



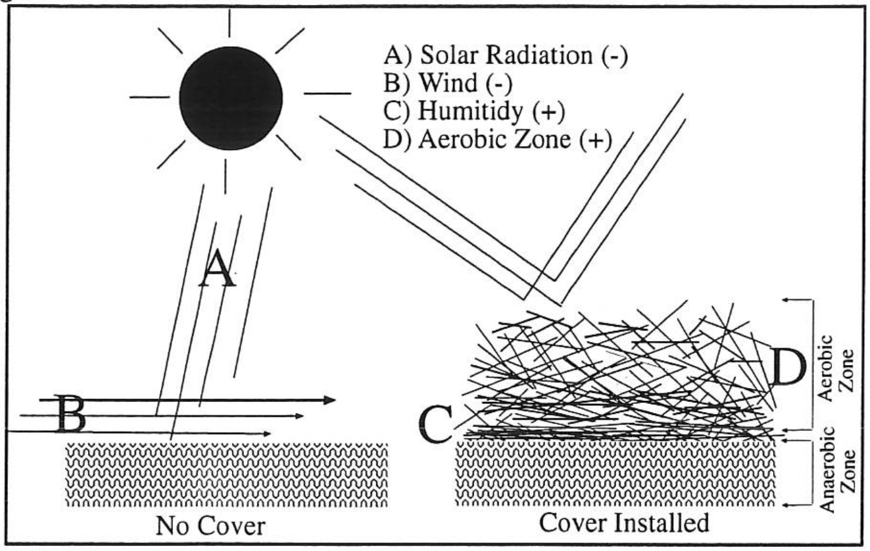
Biofiltration control of pollutants in waste gas streams has been successfully used in Europe to reduce hydrogen sulfide and volatile organic compound emissions released from industrial production and processing (Leson and Winer, 1991; Yang and Allen, 1994). Several groups of aerobic and microaerophilic prokaryotic microorganisms are known to catalyze the degradation of organic and inorganic air pollutants that pass through the biofilter (Leson and Winer, 1991). Optimum performance and loading parameters for biofilters have been correlated to growth and metabolic activity of microorganisms inhabiting the biofilter (Yang and Allen, 1994). Additionally, the supply of oxygen, the waste gas flux rate, and the availability of other nutrients required for growth are also limiting factors in the reduction of organic and inorganic air pollutants passing through the filter material. Biofiltration relies on primarily bacteria and fungi, immobilized on the surface of the filter substrate, that utilize organic emissions in the gas streams as carbon, nitrogen, sulfur, and energy sources. The plethora of bacteria found to inhabit the filter material include genera of the chemolithotrophic bacteria including ammonia-oxidizing bacteria (*Nitrosomonas*), hydrogen sulfide-oxidizing bacteria (*Thiobacillus*), genera of heterotrophic bacteria including methane oxidizing bacteria (*Methylomonas*), cresol-degrading bacteria (*Pseudomonas*), and a diverse number of other hetrotrophic bacteria using carbon compounds as energy sources. In the aerobic environment provided by the filter material, inorganic and organic emissions, including the malodorous swine waste emissions, may be oxidized to provide cellular energy, assimilated into cellular material, or co-metabolized in reactions providing no energy or nutrient value to the organism.

Permeable Floating Covers - Biocovers

(Impact: source concentration, net radiation, surface composition and homogeneity, relative humidity)

The use of floating, porous covers on basin and tank waste storage systems is a successful modification to the idea of biofiltration. The idea for placing floating, porous material on top of manure storage systems to reduce odor is based on an observation that dairy manure storages with floating scum layers had less odor than with a free water surface (Miner, 1995). Floating, porous covers represent an attractive treatment strategy for swine waste emissions, since the processes of anaerobic decomposition that occur in the stored waste and the aerobic treatment of the gaseous pollutants evolved from the anaerobic treatment are decoupled in two separate processes. Because these processes are decoupled, odor reduction is not dependent on reducing the nutrient value of the manure; as is the case with digestive or biological system additives. This odor control strategy also provides the advantage that some porous floating materials can be grown as cover crops at production sites (Freese, 1997) and the technique is amenable to many existing swine production systems.

FIGURE 8. Mechanisms for reducing of volatilization losses from an outdoor waste storage using permeable floating covers or biocovers.



Mechanisms of odor reduction with biocovers:

A) Solar Radiation (+, Positive Correlation to Emission)

Outdoor bodies of water such as lagoons and outdoor basins act as massive sinks of energy from the sun. Conversion of light energy to heat energy increases the vapor pressure of chemical components present in the waste material. For acetic, propionic, and butyric acids, a change of 25° C can elevate the vapor pressure nearly one order of magnitude (i.e., from 0.6 kPa to 6kPa) (Gallant and Yaws, 1993). Covers act as reflective barriers to solar radiation.

B) Wind Velocity (+, Positive Correlation to Emission)

High wind velocity over a liquid surface greatly increases the rate at which odorant and other emission are released from stored waste. This is because: 1) The compounds that volatilize from the system are carried away in air currents at rates that often exceed emission rate, a equilibrium between liquid and gas phases is never achieved. Wind velocity directly affects how steep the concentration gradient will be, and the equilibrium status. Under low wind velocity, higher concentrations of volatile compounds accumulate in the boundary layer between the gas and liquid phases which inhibits the volatilization rate. 2) Extremely high wind velocity also physically "strips" compounds from the surface layers of stored waste. Covers reduce or eliminate the impacts of wind on volatilization.

C) Relative Humidity (-, Negative Correlation to Emission)

Relative humidity has a slight inhibitory effect on the volatilization of compounds from the waste storage system into the atmosphere. For slightly soluble gases such as dimethyl sulfide, methane, and other volatile organic compounds, the aqueous boundary layer (at the solution air interface) retards transport of these compounds into the atmosphere (MacIntyre, 1995). The rate limiting step in the movement of these gases into the atmosphere is then the exchange across the air-water boundary. High relative humidity has been shown to have a stabilizing effect on the air-water boundary while low humidity situations destabilize the boundary. A stabilized boundary will more efficiently retard the movement of these types of emissions across the boundary layer while a destabilized boundary layer will permit increased volatilization. Biocovers establish a high humidity zone that impedes the volatilization process.

D) Aerobic Zone (+, Positive Correlation to Emission)

The filter material establishes an aerobic zone above the stored waste which is highly anaerobic. Emissions from the storage system pass through the porous filter material which becomes inhabited by aerobic bacteria that utilize odorant and other chemicals present in the emission stream as carbon, nitrogen, sulfur, and energy sources. See biofiltration discussion above.

TABLE 3. Cost and other information concerning permeable and impermeable covers for High-Load* systems

Type of Cover	Price	Information
Straw	**1 - 2¢/ square foot**	Can be wheat, oat, flax, barley or brome straw. Barley floats best, then wheat. Apply 8 to 12 inches of straw in June, then reapply 1 inch in August. May have to patch up any spots that sink or drift. Straw chopping/blowing machines rent for $250/day (about $30,000 to buy). Buy weed-free straw. Doesn't appear to plug up injection equipment, even in cold temps. Research shows 80% odor reduction.
Cornstalks	**< 1¢/ square foot**	Iowa State University tested a dry mixture of stalks, leaves and cobs at both 6 and 10 inches deep on two manure tanks. Both covers controlled odor for first six weeks, but thinner layer had higher odor level by 7 weeks. Flies were a problem when the stalks became wet and decayed. Liquid pooled around edges of tanks after a few weeks. Cobs and stalks resisted decay better than leaves. Cheapest cover available.
Plastic*	**40 - 85¢/ square foot**	Permalon floating plastic cover made by Reef Industries in Houston, Texas. Call **800/231-2417**. Designed to capture methane emissions and odor from lagoons. High density polyethylene resists punctures, tears. Lightweight. UV stabilized. Cold crack tested to -60°F. In use on hog farms in Minn., Okla., and N.C. Price depends on complexity of installation (most manure storage units run about $.50/square foot).
Peat Moss	**27¢/ square foot**	Canadian studies show a 4-inch floating mat of peat moss forms intact scum layer on manure basins. Large cell structure lets peat absorb odors like a sponge. Peat adds 2% nitrogen to manure vs. uncovered. For distributors, call the Canadian Peat Moss Association in Alberta at **403/460-8280** or check their Web site: www.peatmoss.com. Peat moss sells for about $7 a bale (7.6 cubic feet).
Foam	**25¢/ square foot**	A floating, permeable foam cover is being studied by ag engineer Ron Miner at Oregon State University. The product reduces the escape of ammonia. Made of thin open-celled polyurethane foam. More permanent than straw cover, and no drifting. Miner is working with a manufacturer, but the product is not yet ready for sale. One concern is with disposal of foam product after use.
Leka rock	**90¢/ square foot**	Iowa State research in 1997 shows best odor reduction with a 2-inch cover of leka rock, compared with straw and cornstalks. Leka rock is a porous material made from lava rock and coated with an impervious material baked on the surface. Often used as a building material. Floats on manure surface. Spreads uniformly due to magnetic property of rock. Must be shipped from Norway at a cost of $5 - $6/cubic foot.

* Covers recommended for covering high-load systems with minimal surface area for the exception of plastic (polyethylene) covers that have been used successfully on storage systems of large surface area.

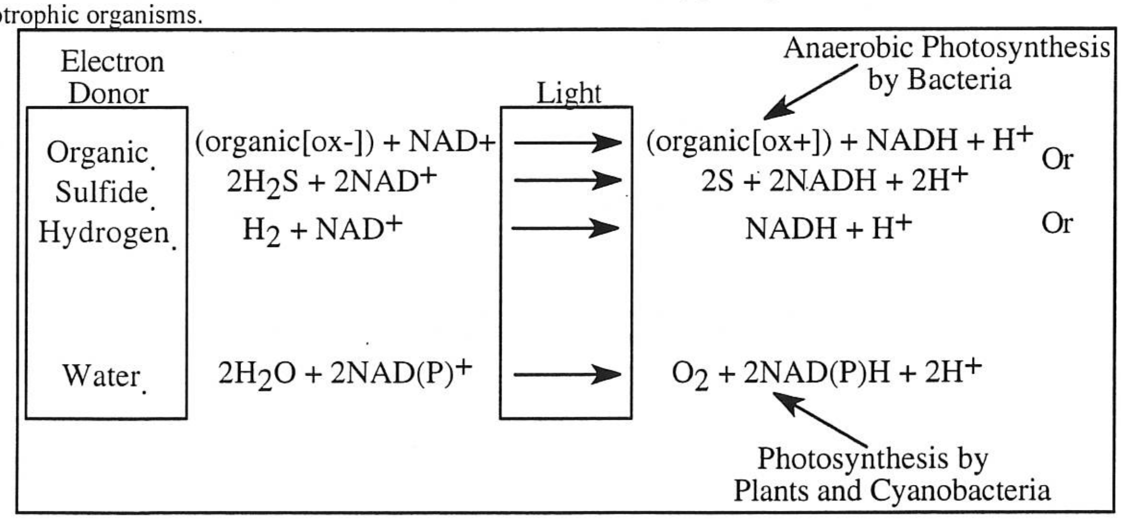
Source: Betsy Freese. Successful Farming Magazine. Sept. 1997.

Anaerobic Photosynthetic Bacteria

(Impact: source concentration)

Photosynthetic bacteria carry out the process of photosynthesis under obligate anaerobic conditions. These requirements for photosynthesis differ greatly from algae and plant species, which require oxygen for energy production and evolve oxygen due to the formation of oxygen through the splitting of water molecules. Instead of splitting water for use as a reductant in photosynthesis, anoxygenic photosynthesis is dependent on substrates such as hydrogen sulfide, hydrogen, and organic compounds such as volatile fatty acids and aromatic compounds to provide the reducing equivalents and carbon (Imhoff, 1995). In many uncovered livestock waste lagoons, purple and green photosynthetic bacteria are found in high concentrations, especially in warm weather (Caumett, 1989). Several investigators have reported temporal changes in the pigmentation of the lagoons from pink to rose to brown. These color changes are the result of changes in temperature and pH of the lagoon resulting in the selection of different species of photosynthetic bacteria. Field reports have indicated a direct relationship exists between decreased odor and blooms of anaerobic photosynthetic bacteria.

FIGURE 9. Basic differences in electron donor utilization and oxygen requirements for eukaryotic and bacterial phototrophic organisms.



In Japan phototrophic bacteria are used in natural purification processes of various types of waste water containing high organic concentrations (Kobayasi and Kobayashi, 1995). Several human waste waster treatment plants are currently being operated using this technology (Kobayashi 1970; Kobayashi and Tchan 1973). The advantages of this system over the more common activated sludge process include: a) dilution is not required, b) no secondary sludge is produced, c) little space is required. In addition, the byproducts (photosynthetic bacteria) of these purification processes are used as aquatic (for brine shrimp) and livestock feed, as well as organic fertilizers (Kobayasi and Kobayashi, 1995).

In the United States, there has been no attempts to construct waste treatment plants for human or animal wastes that utilize phototrophic bacteria. However, indigious blooms of anaerobic photosynthetic bacteria commonly occur in many human and livestock waste lagoons. These blooms are typically associated with a significant reduction in odor emission. Odor reduction is due to a decrease in the source concentration of volatile organic compounds and hydrogen sulfide present in the liquid-phase of the stored waste. The group of purple non-sulfur bacteria are the predominate family of phototrophic bacteria in lagoon systems that are moderately over-loaded with waste material. Purple non-sulfur bacteria have been shown to efficiently degrade highly odorous organic compounds such as organic acids, aromatics (p-cresol), and sulfides including methyl mercaptan, ethyl mercaptan, and propyl mercaptan (Kobayashi and Kobayashi, 1995). Several types of organic compounds and hydrogen sulfide in some cases, serve as the source of cellular reducing power (NADH) for these organisms, while light from the sun provides the energy source.

TABLE 4. Purification of Swine Waste by treatment with photosynthetic bacteria and followed by aeration (from Kobayashi and Kobayashi, 1995).

Property	Original Swine Waste Effluent	After Treatment with Photosynthetic Bacteria (PSB)	Purified Effluent (Aeration Following the PSB Treatment)
• Biological Oxygen Demand (ppm)	6600	380	15
• Chemical Oxygen Demand (ppm)	3364	354	64
• Suspended Solids (ppm)	6540	450	17
• Kjeldahl Nitrogen (ppm) as NH_4^+	915	32.8	7.8
• pH	6.8	7.3	7.1

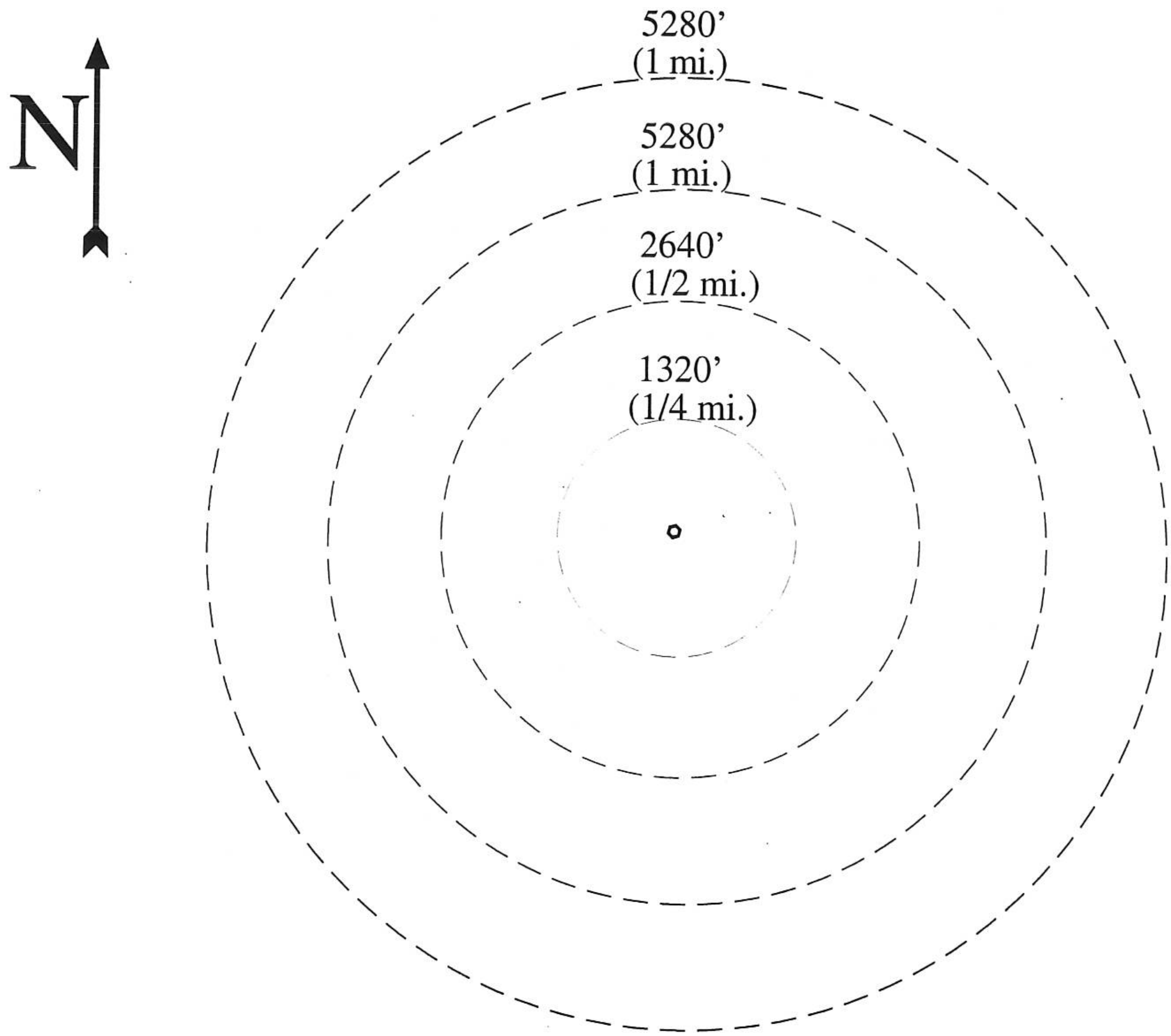
Conditions that promote blooms of anaerobic photosynthetic bacteria in swine waste lagoons are not well understood. In some swine waste lagoon systems, the annual bacterial photosynthetic bloom event has been correlated with a decrease in loading rate, an increase in solution-phase temperature, and finally, an increase in the photoperiod.

Appendix

ODOR NUISANCE RISK ASSESSMENT

SITE DESCRIPTION WORKSHEET

1. Draw an arrow to indicate the dominate wind direction for:
   - summer
   - spring
   - time of year manure is applied to the land
2. Mark location of potential odor sources:
   - livestock confinement(s)
   - manure storage or lagoon(s)
   - land application site
3. Mark location of all neighbors within 1 mile of odor sources.
4. Mark location of public facilities (schools, churches, recreational facilities, etc.)
5. Circle neighbors downwind (prevailing) or those likely to find odors to be a nuisance.



ODOR NUISANCE RISK ASSESSMENT

RISK EVALUATION WORKSHEET

Sources of odor from livestock waste can be categorized as odors from confinements, waste storages, and land application. The following critical control points for odor reduction focus on production areas that can be modified by the producer. The following exercise aids the participant in identifying possible odor nuisance risks and in the development of a management plan to reduce future odor nuisance. Score one point for each criterion you meet or exceed and place a zero on the line for each criterion not meet.

Site Selection or Evaluation: Distance is one of the best odor management tools (Score 6 pts).

_____ Maintain adequate separation distance of the facility.

- 2500 feet minimum for swine facilities or beef feedlots.
- 2000 feet minimum for dairy facilities.
- 1500 feet minimum for poultry facilities.
- Double above separation distances to communities, schools, and recreational areas.
- Double above separation distances for larger-than-average livestock facilities.

_____ Avoid locating facilities upwind of neighbors based on prevailing summer wind direction.
_____ Avoid locating upslope from neighbors in low-lying or valley areas.
_____ Locate manure storage or lagoon near center of cropping area or other remote area instead of near livestock housing.
_____ Establish visual barriers that block line of sight from neighbors and public roads to farm facilities.
_____ Keep facility grounds neat (ex. regular mowing, buildings painted and in good condition, grounds free of equipment and debris).

Animal Housing: Regular manure removal, automatic feeders in good operation, and a dry outdoor lot or confinement area reduce odor nuisances (Score 8 points).

_____ Check feeders/waters daily for optimum performance.
_____ Dust accumulation is kept to a minimum in the flow path of exhaust and inlet air openings into confinement buildings (ex. pressure wash fan housings and/or curtain areas).
_____ Environmental conditions are monitored daily and kept constant in confinement buildings to promote constant (minimal) dunging areas within pens.
_____ Manure deposits are cleaned on a daily basis (continuos mechanical scraping or regular flushing).
_____ No excessive deposits of feed or water occur in animal area.
_____ Keep confinement floors and outdoor lots as dry as possible by:

• Providing unobstructed drainage, especially around waters.
• Preventing upgradient surface water runoff from entering lots.
• Preventing roof water from entering lot.

_____ Frequent cleaning of areas of greatest manure accumulation.

_____ Remove manure accumulation under pen panels or from under fences.

Manure Storage or Processing: Transfer of manure into dedicated storage or processing units reduces active surface area of waste material exposed to the environment and odor production. Chose between storage (ex. pit, basin) or processing (ex. lagoon). (Score 4 points).

Storage: Reducing exposure of storage surfaces to air and sunlight limits odor release.

_____ Encourage crust development on manure storages by:
• Bottom loading storages.
• Minimizing water additions.
• Minimizing surface agitation and breakup of crust.
• Encourage artificial crust formation using crop residue or grass clippings.

_____ Cover storage with plastic covers, crop residues, other organic floating material, or inorganic floating material.

_____ Plant trees or other windbreaks around the storage area.

_____ Consider wind direction before agitation.

Processing: Providing sufficient volume to allow biological activity to degrade odorous compounds reduces odor emissions.

_____ Separation of solids with settling basin or liquid/solid separator.

_____ Construction of a second lagoon operated in parallel with the original lagoon.

_____ Lagoon turns purple by late spring.

_____ Plant trees or other windbreaks around the lagoon.

Land Application: Minimize mixing of air and manure to reduce land application odor problems. (Score 10 points).

Agitation and emptying of storage and land application creates the least nuisance if timed:

_____ between 8 am and 2 pm during warm weather.

_____ to avoid periods when outdoor recreational activities are most likely (evenings, weekends, and holidays).

_____ on hot, sunny days to maximize drying and volatilization of odors.

_____ during dry, windy days to maximize drying and volatilization of odors.

Minimize mixing of air and manure by:

_____ immediate incorporation of manure by injectors or shallow tillage implements mounted on tool bar attached to liquid manure tankers.

_____ same day incorporation of manure by separate tillage operation following manure application.

_____ use of drop hose or other low trajectory spreading equipment.

_____ avoiding manure application through irrigation systems unless treated in properly sized treatment lagoon.

_____ low pressure and drop nozzles on irrigation equipment.

_____ Select appropriate land application site according to wind direction and location of neighbors.

_____ Total Score (28 points)

Scale: 28-26 **Excellent**; 25-22 **Average**; 21-below **Below Average**

ODOR NUISANCE RISK ASSESSMENT

ODOR MANAGEMENT PLAN

Assessment	Odor Sources Animal Confinement	 Manure Storage or Treatment	 Land Application
Areas of Strength			
Areas of Weakness			
Future Goals for Odor Reduction			

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