

# Lesson 43



## Emission Control Strategies for Manure Storage Facilities

By Larry Jacobson, University of Minnesota; Jeff Lorimor, Iowa State University; Jose Bicudo, University of Kentucky; and David Schmidt, University of Minnesota

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### Intended Outcomes

The participants will

- Understand odor emission potential from manure storage facility sources.
- Determine the best technology for controlling odor/gases from their manure storage facility based on
  - Effectiveness.
  - Cost.

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### Activities

- Lecture with slides and video
- Show products/demonstrations
- Develop checklist of technologies

### PROJECT STATEMENT

This educational program, Livestock and Poultry Environmental Stewardship, consists of lessons arranged into the following six modules:

- Introduction
- Animal Dietary Strategies
- Manure Storage and Treatment
- Land Application and Nutrient Management
- Outdoor Air Quality
- Related Issues

**Note:** Page numbers highlighted in green are linked to corresponding text.



## Introduction

Manure storage facilities can be a significant source of on-farm odors. Not only are storages the most “apparent” odor source on many farms (especially if there are no visual barriers from neighbors or passersby), but open storage systems are the most susceptible to seasonal effects as well as day-to-day weather changes.

Since many people know that the odors coming from animal farms originate with the manure, it is natural for them to focus on the manure storage facility and assume that it is the main (some may think only) source of odors from the production site. This attitude can be reinforced by the “visual” observance of the manure storage if it is located on a site that can be easily observed by passersby or visitors. To better understand the odor risks associated with your own manure storage or lagoon, a manure storage self-assessment tool (see Appendix A) is provided to assist you in a review. A similar tool is provided at the end of Lesson 42, Controlling Dust and Odor from Open Lot Livestock Facilities, that addresses odor issues associated with open lot runoff control holding ponds. A number of technologies can reduce the odor and gas emissions from storages. This lesson will discuss them, their advantages, and their disadvantages.

## Covers

A logical method to reduce the odors being emitted from open manure storage facilities is to contain the odors and gases inside an impermeable cover or place some type of floating cover on the surface of the manure. By covering an outside manure storage pit or tank, the mass transfer of hydrogen sulfide and other volatile organic compounds from the liquid to the gas phase is reduced. Covers cause reduced ventilation over the manure, and liquid turbulence is minimized.

### Rigid and flexible covers

A concrete or wood lid can reduce odor release from an outside concrete pit until the storage is agitated and emptied (Figure 43-1). Other options for the containment of odorous gases include lightweight roofs (fiberglass, aluminum, etc.) and flexible plastic membranes. Figure 43-1 shows the two different types of rigid covers used for odor containment. Rigid covers are usually more expensive than other types of covers, but they may last longer (10-15 years, depending on the material). It has been estimated that a

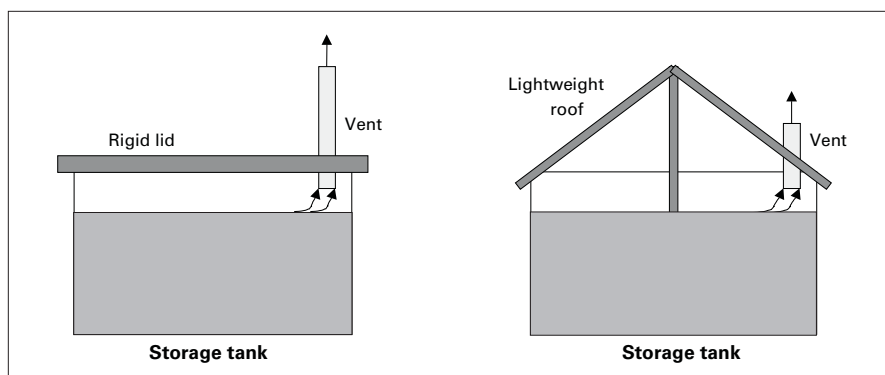


Figure 43-1. Rigid covers used for odor containment.

Since many people know that the odors coming from animal farms originate with the manure, it is natural for them to focus on the manure storage...

Covers cause reduced ventilation over the manure, and liquid turbulence is minimized.

The odor and gas emission reduction efficiencies of permanent...cover[s] can be as high as 80%...[to] over 95%... .

Adding a cover to the manure surface reduces the transfer of hydrogen sulfide ( $H_2S$ ) 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.

concrete cover for a 200-sow farrow-to-finish pig operation might cost as much as \$50,000, but depending on the type of material used, this cost can be significantly reduced. Noncorrosive materials must be used, or the cover life will be very short.

Another type of cover used to contain odors from an outdoor concrete pit is an inflatable cover (Figure 43-2). The cost of an inflated cover varies between \$90 and \$100 per linear foot of diameter. The life expectancy is about 10 years.

In this system, a tarp is attached and sealed as tightly as possible to the tank's perimeter. 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  $H_2O$ ). It has been observed that at an operating pressure of 0.4 in  $H_2O$  the air leakage was 125 cfm ( $ft^3/min$ ). This leakage is approximately equivalent to the rate of a bathroom exhaust fan. For agitation and pumping, the structure is deflated, allowing the tarp to lay over the radiating straps. Access doors are then opened to introduce pumping equipment.

The odor and gas emission reduction efficiencies of permanent roofs constructed of wood or concrete and of an inflated cover can be as high as 80%. Rigid roofs reduced ammonia losses by 80% in one study, and using an inflated cover, reduced ammonia and hydrogen sulfide emission rates over 95% in another study.

### 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.

Adding a cover to the manure surface reduces the transfer of hydrogen sulfide ( $H_2S$ ) 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. The interface between the gas and the liquid constitutes a resistance or barrier to gas and odor transfer.

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 may be aerobically broken down before they are released to the atmosphere. Impermeable floating material allows odorous compounds to escape through leaks at joints and near the tank walls (Figure 43-3).

Recent work by University of Minnesota researchers indicated that 4-inch, 8-inch, and 12-inch layers of straw alone reduced odors 60%, 80%, and 85%, respectively (Figure 43-4).

Both barley and wheat straw can be used as organic floating covers. The straw is applied to manure storage tanks using a straw chopping/blowing machine. How long these covers will last plus the cost and labor to install and maintain them are also very important issues. One German study estimated the useful life of a straw cover to be 6 months. Others have indicated that a 2- or 3-inch layer of straw will only last for several weeks. Canadian researchers found that a six-inch depth of barley straw lasted the full season (3–5 months) with some reapplications of straw to small areas of the storage

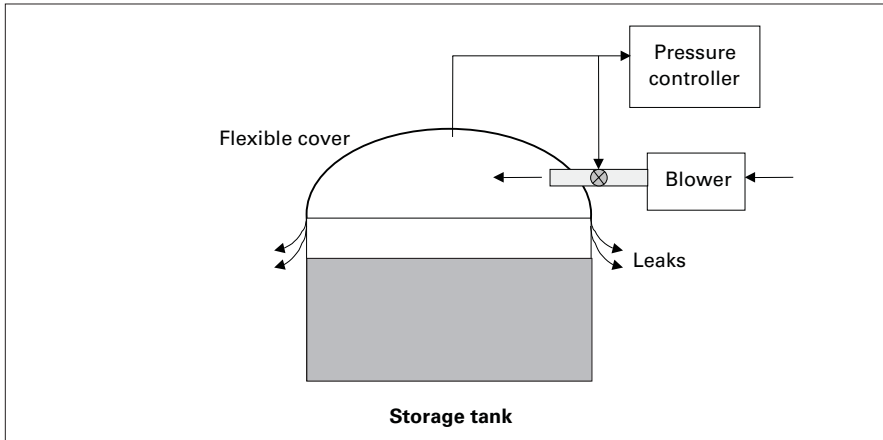


Figure 43-2. Flexible plastic inflated cover and control systems.

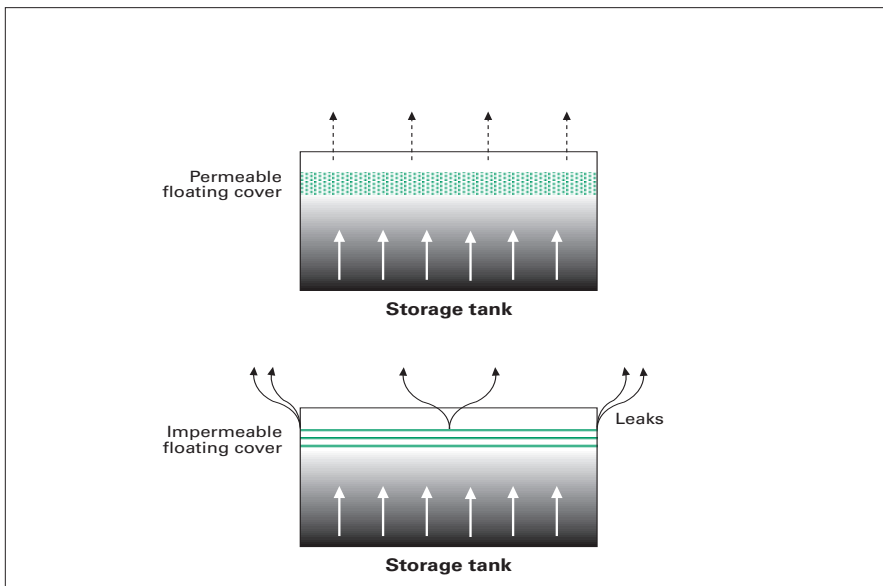


Figure 43-3. Schematics of odor reduction using permeable and impermeable floating covers.

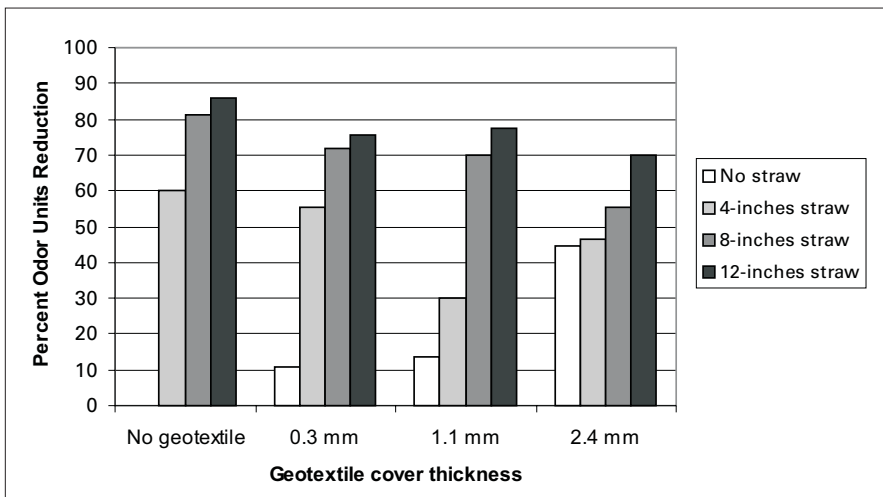


Figure 43-4. Percentage odor units reduction of varying levels of floating straw on liquid manure.

Recent work by University of Minnesota researchers indicated that 4-inch, 8-inch, and 12-inch layers of straw alone reduced odors 60%, 80%, and 85%, respectively...

Both barley and wheat straw can be used as organic floating covers.

**Other floating permeable covers, such as geotextile materials, may provide a better solution than straw for certain types of storage basins... .**

**Covers can significantly reduce odors from open manure storage facilities... .**

facility. University of Minnesota research found that one application of either 12-inch barley or 12-inch wheat straw covers floated for 2 months up to 4 months in pig manure earthen basins. A single, large round straw bale (6 ft in diameter) covered about 500 ft<sup>2</sup> of storage area (100 bales/acre), and the cost for purchasing the straw varied from 5 to 10 cents per ft<sup>2</sup>. Application costs for straw are not well established but may cost 2 or 3 cents per ft<sup>2</sup> of storage area.

Other floating permeable covers, such as geotextile materials, may provide a better solution than straw for certain type of storage basins that are not annually agitated and pumped, even though they have a somewhat higher initial cost. A geotextile membrane is self-floating and grows a biofilm that might self-seal when in contact with manure. As [Figure 43-4](#) shows, a geotextile cover alone had only a slight effect on odor emissions. Odor reductions varied between 10% to 45%, depending on geotextile thickness. Putting straw on top of the geotextile covers resulted, in general, in lower percent reductions of odor emissions than with straw alone. There is anecdotal evidence, from actual farm sites where a geotextile was installed, that this type of material can significantly reduce odor and other gaseous emissions from manure storage facilities. Geotextile covers have been estimated to cost between 25 to 40 cents per ft<sup>2</sup>, which includes both the initial and application costs. The life expectancy is between 3 and 5 years.

Air-filled clay balls have also been used as a floating cover for outdoor manure storage facilities. One study 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. Research at Iowa State University obtained over 90% odor reduction and between 65% and 95% NH<sub>3</sub> reduction by covering swine manure with 1.5 inches of Leca®. A University of Minnesota study found between 56% and 62% odor reduction and between 64% and 84% H<sub>2</sub>S reduction using Macrolite® clay balls (8 inch). Clay balls cost between \$2 to \$5 per ft<sup>2</sup>.

### Summary

Covers can significantly reduce odors from open manure storage facilities, as determined from both practical farm experience and controlled experiments. The main challenge in using this technology is to make it economical by reducing both initial and operating costs, plus minimize maintenance. Covers that have regular or even moderate labor requirements are at a definite disadvantage as compared to those that need little or no maintenance. Selecting the appropriate type of cover and/or materials depends on such items as the type and size of manure storage system, the type of manure treatment system (if any), the frequency of pumping, the amount and quality of labor available, and the cost. Research continues to evaluate and develop other cover materials that will be more effective and economical for livestock producers.

## Liquid/Solid Separation

### Sedimentation or gravity

Liquid/solid separation is sometimes used to reduce the loading on anaerobic lagoons and thus reduce odors. Sedimentation is the separation from water, by gravitational settling, of suspended particles that are heavier than water. The terms “sedimentation” and “settling” are used interchangeably. The three main types of settling patterns, each exhibiting varying forms of stratification (Robertson 1977), are illustrated in [Figure 43-5](#).



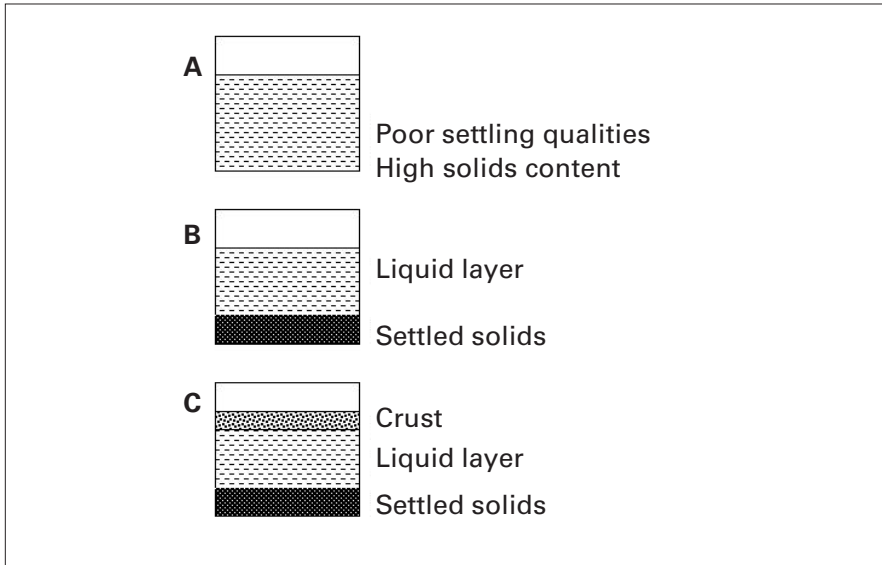


Figure 43-5. Manure settling patterns.

Type A settling usually occurs in manure containing a high percentage of suspended solids (approximately 10% or more), including extraneous bedding material and food residues. Manure from swine houses using wet/dry feeders will exhibit Type A settling. Type B is commonly found in the storage of swine manure with a high proportion of solid particles with a specific gravity greater than one and low total solids (TS) content (< 7%). Type C is found in cattle manure. The crust formation is caused by the presence of food residues and solid particles with a specific gravity less than one.

Most readily settleable solids in livestock manure settle in about 30 minutes or less although some additional settling occurs for hours. Gravity settling in basins or tanks may remove up to 50% of solids. Some organic matter and nutrients are also removed from the liquid fraction (Table 43-1).

Frequency of maintenance and cleanout (solids removal) greatly influences the efficiency of gravity-settling processes. Cleaning the basin after every major runoff event will improve its treatment efficiency, reduce odors, and restore the basin capacity. Basin and tank capacities are determined by knowing the settling velocities of solid particles and peak flow wastewater retention time. The solids storage volume required depends on the solids removal rate from the lot, lot size, and time between cleanouts.

Most readily settleable solids in livestock manure settle in about 30 minutes... .

Table 43-1. Settling basin performance (results in wet basis).

Manure	Input Solids, %	% Removal from Liquid					Reference
		Solids	COD	TKN	N-org	TP	
Flushed dairy	3.83	55 (VS)	61	-	26	28	Chastain et al. 1999
Dairy	1.1	65	-	40	-	-	Powers et al. 1995
Poultry, beef, dairy, swine, horse	-1	45-76 <sup>a</sup>	28-67 <sup>a</sup>	-	-	-	Moore et al. 1975
Feedlot runoff	1-3	40-64	-	84	-	80	Lorimor et al. 1995
Flushed swine	0.2	12	-	33	-	22	Westerman 1997
Feedlot runoff	1-3	13	-	0.7	-	0.3	Lorimor et al. 1995

<sup>a</sup> 10-minute settling time

Performance data of mechanical separators vary widely...

Mechanical separators also remove some of the volatile solids (VS) and chemical oxygen demand (COD) from the manure and thus can potentially reduce odor.

### Mechanical

Mechanical separators of animal waste include screens (inclined screens, rotating screens, vibrating screens), belt and screw presses, and centrifuges. Such equipment has long been used in both municipal and industrial wastewater operations but has not been commonly used for livestock wastes. However, in regions of concentrated confined animal production, there is more interest in and pressure to remove nutrients from the liquid stream and transport them from the farm.

Performance data of mechanical separators vary widely not only because of the different testing and reporting procedures, but also because the characteristics of the manure used were sometimes different (Zhang and Westerman 1997a). Total solids (TS) in separated material vary from as low as 5% with a stationary screen up to 30% or 35% with centrifuges. Separation efficiencies for TS can vary from less than 10% to about 60%. Mechanical separators also remove some of the volatile solids (VS) and chemical oxygen demand (COD) from the manure and thus can potentially reduce odor. Chastain et al. 1999 indicated VS and COD removals of up to 65% from flushed dairy manure (TS = 3.83%) with a stationary inclined screen (screen size of 1.6 mm). Presses and centrifuges are found to have higher separation efficiencies and produce drier solids than screen separators.

Nutrient removal is also related to input solids concentration. Table 43-2 (Converse 1999) gives an estimate of the nutrient concentration in the solid stream as a function of the input solids concentration for a screw press with

**Table 43-2. Approximate percent of nutrients in the solid material as a function of input solids concentration.**

Type of Manure	Screen Size, mm	Input Solids, %	% of Input Nutrient in the Solids Material			
			TKN	NH <sub>4</sub> <sup>+</sup>	TP	K
Dairy	2.4	2	10	1	8	3
		9	36	22	27	22
Swine	0.5	2	5	2	3	2
		5	7	4	5	5

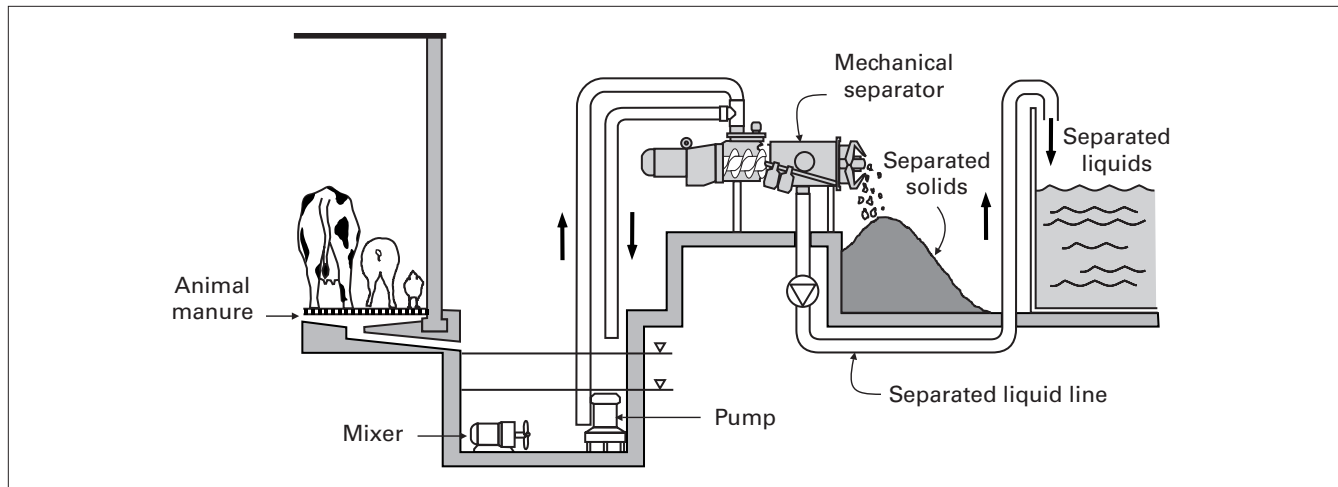


Figure 43-6. Basic arrangement for a mechanical solid-liquid separation system.

different screen sizes. If the input solids to the press were 9%, then approximately 27% of the phosphorus entering the press would end up in the solid material, and 73% would end up in the liquid leaving the press.

Westerman and Bicudo (1998) reported on odor intensity, irritation, and pleasantness from samples taken before and after mechanical separation (screw press) of flushed swine manure. The results presented were means taken from duplicate samples analyzed by eight panelists. They found that there was no significant difference in odor (intensity, irritation, and pleasantness) between flushed wastes and the separated liquid.

Zhang and Westerman (1997a) concluded from a review of previous research results on mechanical separation of animal wastes 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 be designed to remove both coarse material and particles smaller than 0.25 mm to significantly reduce both odor generation and nutrient contents.

Separated solids must be further processed if they will be transported off farm for use as feed or fertilizer. Due to the still high moisture content (usually between 70–85%), solids must undergo some type of drying, either mechanical or natural, before they can be used. Storage, handling, and spreading techniques for both liquid and solid manure are required if the solids are separated. Higher investments for equipment must be made for operation and maintenance, and more management skills are needed.

## Biological Processes

Biological treatment of manure is not a new phenomenon. Manure that is stored in earthen basins, pits, or tanks or is spread on land undergoes biological degradation. In these cases, the processes involved are relatively uncontrolled and may take a long time. Biological treatment systems or technologies can help accelerate the natural process and can be, for most of the cases, well controlled.

The main applications of these systems in the agricultural area are (a) stabilization of manure; (b) removal of odor; (c) removal of organic matter; (d) nitrification; and (e) removal of nutrients.

### Aerobic treatment

Complete aerobic treatment eliminates manure odors. Aerobic treatment is usually only suitable for separated slurry or dilute effluents. Solids in manure increase the amount of oxygen needed and also increase the energy needed for mixing. 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 1997b), lower levels of aeration have been recommended for partial odor control. [Figure 43-7](#) shows a diagram of a typical aerobic treatment system.

**M**anure that is stored in earthen basins, pits, or tanks...undergoes biological degradation.

**C**omplete aerobic treatment eliminates manure odors.

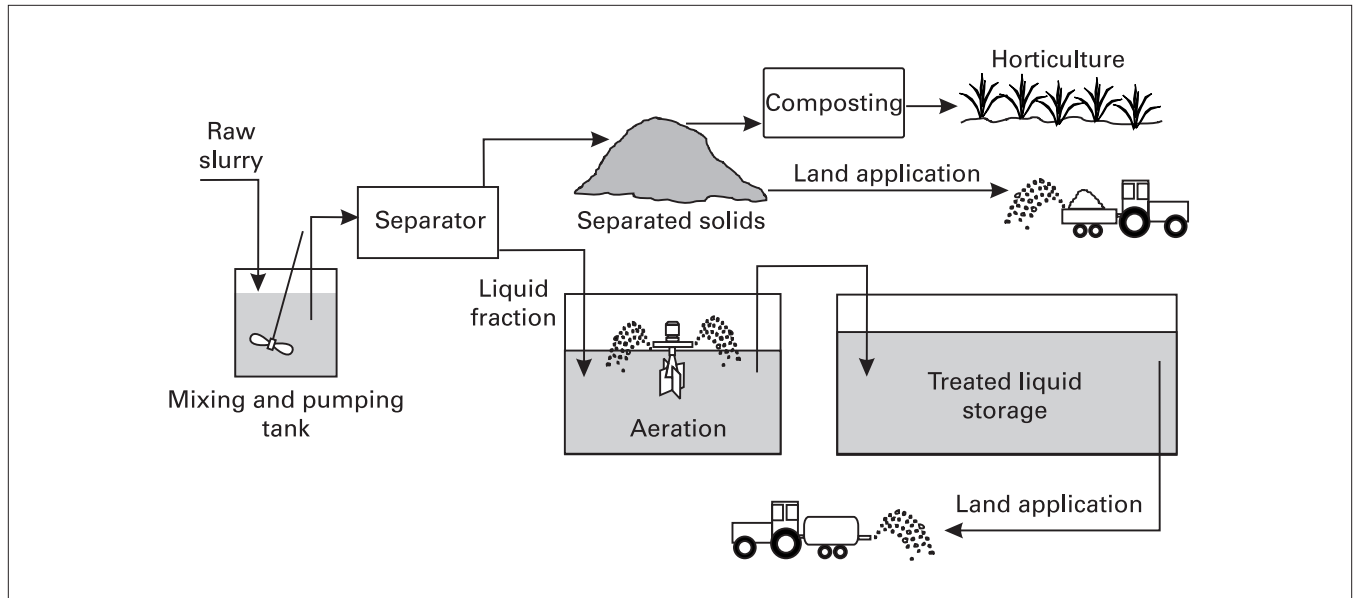


Figure 43-7. Aerobic treatment system.

**The biggest drawbacks to aerated lagoons are**

- (a) the cost of energy to run the aerators;
- (b) biosolids production, which is higher than in anaerobic systems; and
- (c) the potential for release of ammonia if the aeration level is not correct.

A variety of aerobic reactors can be used for odor control. Many batch aeration treatments carried out in farms can be described as batch fed or semi-continuous, if slurry is either added or removed during the process. This tends to be the result of practical needs rather than process requirements (Burton 1992). Batch treatment may require additional storage facilities other than the tank used for aeration. Without additional storage, the aeration vessel has to be large enough to store slurry longer than the specified treatment time. Aeration can be continuous or intermittent and is carried out during the time the tank is filling (up to 6 months). Continuous aeration offers the option of a controlled steady-state process, and the phenomenon of the initial surge in activity is avoided. On the other hand, energy costs will be higher compared to intermittent aeration.

Lagoons can be aerated to control odor. Aerated lagoons (Figure 43-8) are able to reduce odor significantly by avoiding the anaerobic treatment environment that can produce odorous compounds. The biggest drawbacks to aerated lagoons are (a) the cost of energy to run the aerators; (b) biosolids production, which is higher than in anaerobic systems; and (c) the potential for release of ammonia if the aeration level is not correct.

If too little oxygen is put into the system, manure will not be stabilized and the anaerobic conditions that result will lead to additional odors. If too much oxygen is put into the system, ammonia and other gases will be released. Research carried out in the United Kingdom and the Netherlands has shown that nitrous oxide is also released to the atmosphere during combined aerobic/anoxic treatment (Pahl et al. 1998, Willers et al. 1996).

Other aerobic treatment systems include aerated filters with fixed media for maintaining a bacteria biofilm. This type of system has been used to some extent for nitrification of municipal and industrial wastewater, but only a few applications related to livestock manure have been reported to date.

As Table 43-3 shows, several researchers have reported significant odor reduction from manure after aerobic treatment. The costs associated with the operation of such systems are still too high to encourage widespread adoption of the technology by producers.

Burton et al. (1998) have also quantified the effect of treatment duration on odor abatement. No odor regeneration was discerned during the first 28 days after anaerobic storage of pig slurry treated for 2.4 days.

**Composting**

Composting is another type of aerobic treatment that is applicable to solid or semi-solid manure (Figure 43-9). Composting is a 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 and 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 also reduces the volume of material as much as 50% and produces a very uniform, easy-to-handle material. More details on actual composting methods can be found in NRAES 54, On Farm Composting Handbook (NRAES 1992).

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% 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. Efficient composting requires optimum conditions for microbial growth. Composting

**Composting is another type of aerobic treatment that is applicable to solid or semi-solid manure.**



**Figure 43-8. Aerated lagoons treating flushed swine manure.**

**Table 43-3. Odor reduction from manure after aerobic treatment.**

Type of Treatment	Duration of Treatment	Target Aeration Level	Reduction in Odor	Estimated Cost	Reference
Fed-batch, continuous aeration	1.7-6.3 days	less than 1 mg O <sub>2</sub> /L	50%-75%	\$1-\$3 per pig	Burton et al. 1998
Sequencing batch reactor, intermittent aeration	HRT <sup>1</sup> : 5 days SRT <sup>2</sup> : 30 days	6 mg O <sub>2</sub> /L	88%	N/A	Bicudo et al. 1999
Aerated lagoon, continuous aeration	HRT: 2.1 days	5 mg O <sub>2</sub> /L	45%	\$6 per pig	Westerman and Bicudo 1999
Aerated filter	HRT: 16 hours	6-8 mg O <sub>2</sub> /L	64%	\$2 per pig	Westerman et al. 1998

<sup>1</sup>HRT: hydraulic retention time

<sup>2</sup>SRT: solids retention time

Composting can reduce manure volume, stabilize manure nutrients, kill pathogens and weed seeds, and produce a homogeneous non-odorous product.

...sufficiently high initial C:N ratio and drier materials can help minimize odor and gaseous losses from composting operations.



Figure 43-9. Windrow composting operation at a dairy farm.

requires a supply of oxygen, adequate moisture, and a blend of material that meets a specific carbon-to-nitrogen (C:N) ratio. If these parameters are met, carbon dioxide and water will be the primary gas emissions from the process. Composting can reduce manure volume, stabilize manure nutrients, kill pathogens and weed seeds, and produce a homogeneous non-odorous product.

At many composting sites, odors originate with the incoming ingredients, which may have been stored anaerobically 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 operations appear to be most significant in the early stages of the process and during turning. University of Minnesota researchers (Schmidt and Bicudo 2000) have recently reported that odor emissions from a full-scale chicken layer manure composting operation are reduced by 75% after the first two weeks of composting and by 85% after 4 weeks of composting. Hydrogen sulfide emissions were reduced by about 60% after 4 weeks of composting. Management seems to be a key factor in reducing odors and gaseous emissions from composting operations.

Research 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 been added to compost mixtures to minimize ammonia volatilization (Burton 1997).

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, the composting process does not seem to produce significant odor and gas emissions.

### Anaerobic treatment

**Anaerobic lagoon.** Anaerobic treatment of manure takes place in the absence of oxygen. The most common type of anaerobic digestion system used for livestock manure, which also combines storage, is the anaerobic lagoon. Design and management are key factors in maintaining acceptable odor levels from lagoons. Both one- and two-stage lagoon systems are used.



**Figure 43-10. Partial view of an anaerobic lagoon treating swine manure.**

When properly sized and managed, an anaerobic lagoon (Figure 43-10) can be operated with a minimum of disagreeable odor.

Volatile nitrogen gases are natural byproducts of anaerobic decomposition and are released from open lagoon surfaces. When released from a lagoon surface, the relative proportions of these compounds and their impact on the environment are not well documented or understood.

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 during system startup, when the lagoon surface is disturbed during windy conditions; during agitation and pumping for land application; and during spring turnover—defined as very vigorous bacterial activity during the spring due to incomplete metabolism of material during winter. When acid-forming and methane-forming anaerobic bacteria are in balance, an anaerobic lagoon produces minimum odors.

Distinct purple- or pink-colored anaerobic lagoons have been observed to produce less odor (Chen et al. 1997). The color and odor reduction is caused by naturally occurring purple sulfur bacteria, phototrophic organisms that oxidize sulfide under anaerobic conditions. This type of bacteria metabolizes simple organic compounds, reducing the strength of the lagoon wastewater, removing toxic amine compounds, and producing anti-viral substances. When these organisms are dominant, lagoon odor, chemical oxygen demand, ammonium nitrogen, and soluble phosphorus concentrations are reduced. The purple or pink color is a good indicator of a healthy lagoon.

**Anaerobic digesters and filters.** Anaerobic digesters are designed and managed to optimize the bacterial decomposition of organic matter under more controlled conditions than in a lagoon. A complete anaerobic digestion system is shown in Figure 43-11. One of the most common anaerobic reactors used for the treatment of manure is the plug-flow reactor. In this system, manure is added to one end of a tank, allowing the effluent to overflow and be removed from the other end into a storage facility. Effluent solids may be separated from the liquid and composted if there is an interest in doing so.

Other types of anaerobic digesters include complete-mix, contact, and upflow anaerobic sludge blanket digesters. The anaerobic sequencing batch reactor is another alternative for the treatment of animal manures that is being

**When acid-forming and methane-forming anaerobic bacteria are in balance, an anaerobic lagoon produces minimum odors.**

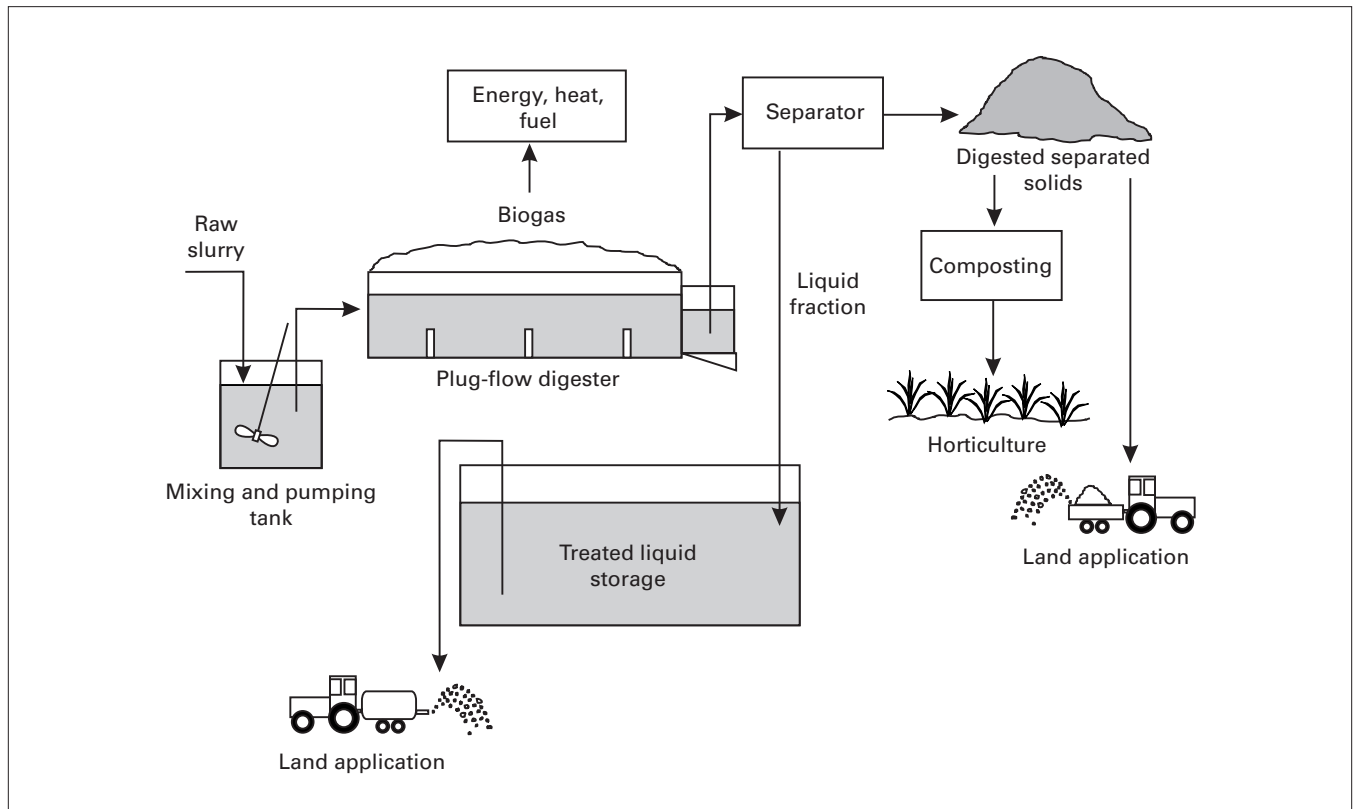


Figure 43-11. A typical anaerobic digestion system showing a plug-flow reactor and optional separation and composting of digested solids.

Usually, anaerobic digesters are operated between 95°F and 100°F.

researched both in Canada and in the United States, mainly at the University of California, Davis, and Iowa State University.

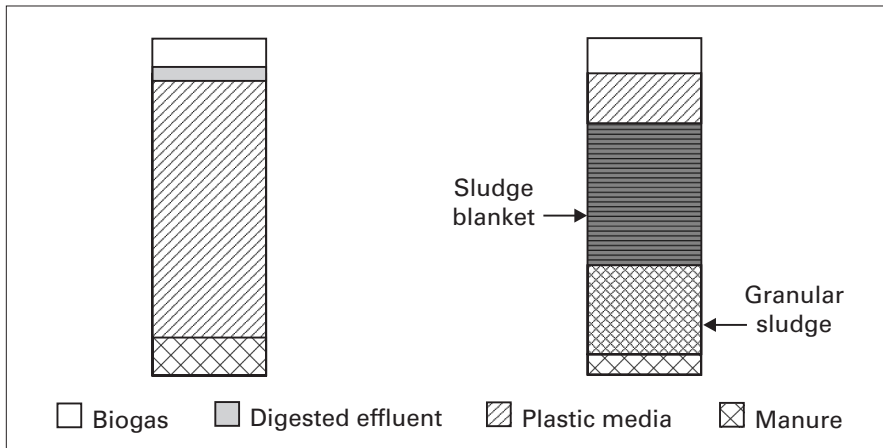
Digesters are more efficient, with better treatment and biogas production, when operated at high temperatures (over 120°F). However, this is not usually cost effective because the energy inputs required to maintain this high temperature are greater than the energy gained in the process.

Usually, anaerobic digesters are operated between 95°F and 100°F. There have also been some successful applications in the 60°F to 75°F operating range, with lower treatment efficiencies offset by higher retention times.

Anaerobic filters have also been used for the treatment of more dilute or pre-screened manure (Sanchez Hernández and Rodriguez 1992). The anaerobic filter is a column filled with various types of solid media (Figure 43-12). The manure flows either up or down through the column, contacting the media, on which anaerobic bacteria grow and are retained. Because the bacteria are retained on the media and not washed off in the effluent, long solids retention time can be achieved with reasonably short hydraulic retention times (HRT). Therefore, the anaerobic filter can be much smaller than other types of digesters with equivalent treatment efficiencies.

According to Lusk (1998), surveyed farmers who have installed and continue to operate digesters are generally satisfied with their investment decisions. Some chose to install digesters for non-economic reasons, primarily to control odor or contain excess nutrient runoff. Although the control of odors by anaerobic digestion has not been the focus of much research, some encouraging results have been published in the last 10 years.





**Figure 43-12. Anaerobic filters used for the treatment of livestock manure.**

Very little odor is produced from a properly managed anaerobic digester. Provided with adequate retention time and specific temperatures, a well-controlled anaerobic digestion process degrades the vast majority of compounds that contribute to odors. Powers et al. (1997), for example, found that odor intensity from dairy manure decreased linearly with increased HRT in a set of laboratory experiments. The effluent from complete-mix digesters with a 20-day HRT had about 50% less odor than the untreated manure (1.3–2.0% TS). Anaerobic filters with only 2.3-day HRT also reduced odor intensity.

Odor reduction from land-spreading operations achieved with anaerobically digested pig slurry was reported to be between 70% and 80% compared to undigested slurry (Pain et al. 1990). Their results also indicate that digested slurry was relatively stabilized. After 2 weeks of additional storage, odor emission was still 70% less compared to undigested slurry.

Considerable research has been devoted to the recovery and reuse of biogas generated by anaerobic digesters as well as to the odor abatement potential of these systems. Much has been learned about how manure can be used as an energy and nutrient source. Without the environmental benefits provided by anaerobic digestion technology, some farmers might have been forced out of livestock production. Anaerobic digestion is probably one of the few technologies that allow growth in the livestock production business. However, the performance data does not appear to be encouraging to a farmer 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 complete-mix and plug-flow technologies are 70% and 63%, respectively. The reasons 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. Other factors such as economics, erratic biogas production, and increased managerial skill requirements have limited the U.S. adoption of this manure utilization technology. One encouraging note is that the reliability of digesters built since 1984 is far better than for those constructed between 1972 and 1984. This is generally due to a resurgence of interest in farm-based anaerobic technology and the development of more simplified digester design.

Very little odor is produced from a properly managed anaerobic digester.

...the reliability of digesters built since 1984 is far better than for those constructed between 1972 and 1984.

**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 to minimize odor and other air emissions from livestock farms.**

**“...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.” [Miner 1995]**

### **Biological 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 to minimize odor and other air emissions from livestock farms. In addition to odor control, many 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 odor abatement. A recent laboratory study tested 85 different manure pit additives (NPPC 2001) and found that only four product reduced odor by a 75% certainty level. Approximately ten products reduced H<sub>2</sub>S by either a 95% or 75% certainty level while 12 products lowered ammonia by the same two percentages.

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). Each product has a specific method of application, frequency, quantity, and length of time before the product is considered “most effective.” Some products are pH and temperature dependent and only work within narrow ranges of pHs and temperatures.

Although bacterial genera or species exist that can decompose odorous compounds like volatile fatty acids 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 (1979), the key in using bacterial cultures for manure deodorization is to have the added bacteria become the predominant bacteria strain in the manure. For the added bacteria to flourish, the real environment should not deviate tremendously from the bacteria’s optimum growth range. Past work mainly focused on determining bacterial functions in the digestion of odorous compounds under optimum conditions, which does not guarantee that the bacteria will grow well in the field.

Results from laboratory additive testing are usually subjected to significant variations and do not allow for any definite conclusion. 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.”

### **Chemical additives**

Chemical addition can control sulfides in manure by chemical oxidation, pH control, or precipitation. It involves the addition of chemicals to form new chemical compounds. Table 43-4 gives some of the different chemicals that can be used for odor control and improvement of overall treatment efficiency.

Several researchers have tried adding chemicals (mainly precipitants and polymers or a combination of both) to manure to improve separation efficiency and to concentrate nutrients to a greater extent in the separated material. Volatile solids reductions of over 80% have been reported (Powers et al. 1995, Zhang and Lei 1996). Also high removals of phosphorus from the liquid fraction (over 90%) have been observed (Westerman and Bicudo 1998).

The effect of odors remaining in the effluent after physico-chemical treatment of flushed swine manure and anaerobic lagoon liquid was examined by Westerman and Bicudo (1998). The final effluent was found to have less odor intensity and better odor quality than either flushed wastes or the separated liquid. However, the odor intensity was “strong,” and the odor quality was “very unpleasant.” There was no significant difference in odor irritation between all treatments with flushed wastes. Treatment of lagoon liquid in the evaluated system resulted in odor increase in all odor parameters (intensity, irritation, and unpleasantness) in both the final effluent and thickened sludge. Odor increase during treatment of lagoon liquid was probably related to the formation of odorous compounds with the addition of chemicals (lime, FeCl<sub>3</sub> and polymer). Because physico-chemical treatment is not as effective when more dissolved material is being processed, such as the material contained in lagoon liquid, residual chemicals that did not react with inorganic compounds might have reacted with complex organic materials, originating more odorous-bearing compounds.

**Other chemical additives.** 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), 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 is necessary. Masking agents are normally

**T**here was no significant difference in odor initiation between all [physico-chemical] treatments with flushed wastes.

**Table 43-4. Chemicals used for odor control.**

Category	Chemical Compound	Key Reactants	Advantages	Disadvantages
<b>Oxidizers</b>	Ozone	H <sub>2</sub> S	Strong oxidizing agent and disinfectant.	Unstable. Onsite generation required. Toxic as low as 1 ppm.
	Hydrogen peroxide	H <sub>2</sub> S	Good oxidant. Weak disinfectant. Nontoxic byproducts. Inhibits regeneration of sulfate reducers.	Does not treat ammonia or odorous organics. Long contact time required. Very costly.
	Potassium	H <sub>2</sub> S	Strong oxidizing agent. Stable, easily handled. Noncorrosive.	Does not treat NH or disulfides. Costly if large amounts needed. Creates insoluble MnO <sub>2</sub> precipitate.
<b>pH modifiers</b>	Lime, sodium hydroxide	Bicarbonates	Helps reduce BOD, SS, and PO <sub>4</sub> in the liquid stream. Odor-producing microorganisms are destroyed when pH > 12.	High pH induces NH <sub>3</sub> volatilization. Low pH induces H <sub>2</sub> S volatilization. Creates insoluble precipitate, usually high in P.
<b>Precipitants</b>	Divalent and trivalent ions such as iron and aluminum (e.g., ferric chloride)	Bicarbonates	Helps reduce BOD, SS, and PO <sub>4</sub> in the liquid stream.	Creates insoluble precipitate, usually high in P. Some products are highly corrosive. Can be expensive.

Adapted from WEF 1990.

The effectiveness of masking is difficult to predict due to varying odor characteristics and changing weather conditions.

“...the odor control capacity of most masking agents and counteractants may be too short lived for practical use... .”

[Miner 1995]

It is generally believed that windbreaks reduce odors by dispersing and mixing the odorous air with fresh air, although research has not confirmed these effects.

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). Nonvaporized agents are applied directly to the manure.

The effectiveness of masking is difficult to predict due to varying odor characteristics and changing weather conditions. Masking agents primarily used where the odor level 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 nonhazardous nature (WEF 1990). The disadvantage is the agent's tendency to separate from the odor downwind. 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.”

Counteractants do not react chemically with the malodor but reduce the perceived odor level by eliminating the malodor's objectionable characteristics. 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 chemical or biological materials that can collect odorous compounds on their surfaces (adsorb) or interiors (absorb). Examples are activated carbon, zeolites, sodium bentonite, sphagnum peat moss, sawdust, rice straw, etc. Zeolites have been used for ammonia emission reduction from composting piles (Burton 1997) and also from swine manure (Cintoli et al. 1995). Absorbents with a large surface area, such as sphagnum peat moss, have been found to reduce odor in some lagoons (Swine Odor Task Force 1995). Floating organic lagoon covers (straw) and soil biofilters are other examples of the use of odor-absorbing materials.

### Landscaping

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

It is generally believed that windbreaks reduce odors by dispersing and mixing the odorous air with fresh air, although research has not confirmed these effects. Windbreaks on the downwind side of manure storages create mixing and dilution. Windbreaks on the upwind side deflect air over the storages so it picks up less odorous air.

**Table 43-5. Summary of technologies for odor control.**

Process/System	Description	Advantages	Disadvantages	Cost	
<b>Covers</b>	Straw (wheat and barley)	Straw is blown over the surface of the stored manure manure (about 100 bales to cover 1 acre of surface area with a layer of 12 inches).	Effectively reduces odors, H <sub>2</sub> S and NH <sub>3</sub> emissions	Temporary solution; straw sinks after a certain period	\$0.10/ft <sup>2</sup>
	Floating clay balls	Floating clay balls (Leca® or Microlite®) are placed over manure.	Effectively reduces odors, H <sub>2</sub> S and NH <sub>3</sub> emissions	Care must be taken during agitation and pumping	\$2-\$5/ft <sup>2</sup>
	Geotextile	Geotextile membranes are placed over the surface of the manure; for more effective results, straw may be blown over the geotextile.	Helps reduce odors, H <sub>2</sub> S and NH <sub>3</sub> emissions	Difficult to access basin for pumping if storage and not lagoon	\$0.20-\$0.40/ft <sup>2</sup>
	Plastic cover	Several varieties of plastic can be placed over manure storages (floating or rigid structures).	Helps reduce odors, H <sub>2</sub> S and NH <sub>3</sub> emissions	Capital cost	\$1-\$2/ft <sup>2</sup>
<b>Manure treatment</b>	Solid separation	Solids are separated from liquid slurry through sedimentation basins or mechanical separators.	May reduce odor and NH <sub>3</sub> emissions; easier agitation and pumping	Capital and operational costs; reliability; adds another "waste" stream for farmer to manage	\$1-\$3/pig marketed
	Aerobic treatment	Biological process where organic matter is oxidized by aerobic bacteria; mechanical aeration is required to supply oxygen to the bacterial population.	Effectively reduces odor, organic matter, and nutrients (if needed)	Capital and operating costs	\$2-\$4/pig marketed
	Composting	Biological process in which aerobic bacteria convert organic material into a soil-like material called compost; this same process decays leaves and other organic debris in nature.	Reduces odor and organic matter; produces a saleable product; can include other byproducts	Capital and operational costs; if product is to be sold, marketing skills required	\$0.20-\$0.40/pig marketed
	Oversized permanent pool for anaerobic lagoon	Lagoon permanent pool designed larger to allow more dilution water	Reduces odor by lowering VS loading rate	Additional cost for more earthwork to build larger structure	\$200 or more per 1,000 lbs bodyweight capital cost; if properly operated, energy may provide return
	Anaerobic digestion	Biological process where organic carbon is converted to methane by anaerobic bacteria under controlled conditions of temperature and pH	Reduces odor and 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	



**Table 43-5. Summary of technologies for odor control (continued).**

Process/System		Description	Advantages	Disadvantages	Cost
<b>Biological additives</b>		Chemical or biological products are added to manure.	May reduce odor and NH <sub>3</sub> emissions; easy to use	Usually questionable products; may not achieve desirable results under field conditions	\$0.20-\$1.00/pig marketed
<b>Land-scaping</b>	Shelterbelts	Rows of trees and other vegetation are planted around a building, creating a barrier for dust and odorous compound removal from building exhaust air. Trees can absorb odorous compounds, and they create turbulence that enhances odor dispersion upward.	May effectively reduce dust and odor emissions	May take several years to grow effective vegetative windbreak	\$0.06 and up/pig bldg capacity

## APPENDIX A

### Environmental Stewardship Assessment: Manure Storage

The goal of this assessment is to help you confidentially evaluate environmental issues that relate to outdoor air quality. For each issue listed in the left column of the worksheet, read across to the right and circle the statement that best describes conditions on your farm. If any categories do not apply, leave them blank.

Potential Odor Risk	High Risk	Moderate Risk	Low Risk
Relative risk associated with alternative types of manure storage systems	Formed manure storage, earthen storage basin, or undersized anaerobic lagoon	Properly sized anaerobic lagoon OR Partially covered manure storage OR Open lot runoff holding OR Dry manure storage where liquids are separated and drained to separated storage or absorbed by bedding.	Anaerobic digester or other treatment system is included with manure storage. OR Purple anaerobic lagoon OR Composted manure storage OR Manure is stored for less than one week before land application. Properly covered manure storage
Location of storage or lagoon relative to confinement animal housing (Dusty ventilation air moving across storage or lagoon surface picks up and transports additional odors.)	Prevailing winds or ventilation fans direct building ventilation air across storage or lagoon surface.		Manure storage or lagoon is remotely located from animal housing. OR Prevailing winds or ventilation fans DO NOT direct building ventilation air across storage or lagoon surface.
<b>Manure storage or earthen basins only</b>			
Manure surface	Manure surface is exposed and does not form a crust.	Storage is loaded below liquid surface, AND crust forms over only part of storage surface due to top loading, regular agitation, wind, or other factors. OR Crop residue cover is in place at least six months of year during periods of greatest odor concerns. OR Manure surface is partially covered by crop residue, plastic membrane, or other type of cover.	Storage is loaded below liquid surface, AND stored manure forms undisturbed crust over the entire surface. OR Manure is held in enclosed manure storage tank or completely covered year-round with crop residue, plastic membrane, or other type of cover. Surface aeration maintains oxygen concentration of 1 mg/liter or greater.
Agitation during emptying	Storage is aggressively agitated by manure stream directed above manure surface.	Storage is aggressively agitated by manure stream directed below manure surface.	No agitation use during storage emptying.



## APPENDIX A

### Environmental Stewardship Assessment: Manure Storage (continued)

Potential Odor Risk	High Risk	Moderate Risk	Low Risk
<b>Anaerobic lagoon only</b>			
Signs of improved treatment for reducing odors... Active lagoons stabilize odors.	Lagoon is dark brown or black in color and shows few signs of active bubbling during warm weather.	Lagoon is dark brown or black and is actively bubbling from spring through fall.	Lagoon is maintained in aerobic state (1 hp of aeration capacity/150 finish hogs, 50 beef, or 30 dairy animals) OR Deep purple or red-colored lagoon
Permanent pool (or first stage of two-stage lagoon) Size...Large permanent pools dilute incoming manure and provide a better stabilization of odors.	Sizing of permanent pool is unknown or not sized according to standard engineering. OR Animal numbers have increased above designed capacity for lagoon.	Permanent pool is sized following standard engineering recommendations.	Permanent pool is sized for odor control (twice standard engineering recommendation).
Permanent pool management...	A permanent pool of 1/3 of the total volume or less is maintained.	A permanent pool is maintained that is at least 50% of the overall storage volume.	Markers are used to identify "Stop Pumping Point" for maintaining permanent pool, AND permanent pool never drops below marker.
Lagoon loading... Frequent feeding is preferred to infrequent feeding.	Lagoon is loaded less frequently than weekly. OR Manure loading rates are highly variable.	Lagoon is loaded weekly with fairly similar quantities of manure.	Lagoon is loaded daily with fairly similar quantities of manure.
Lagoon unloading... Infrequent pumping causes buildup of salts and ammonia that can become toxic to anaerobic bacteria.	Lagoon is pumped infrequently or not at all due to evaporation and seepage generally matching liquid additions.	Lagoon is pumped annually to permanent pool marker.	Lagoon is pumped annually to permanent pool marker, AND in dry years, lagoon is pumped below permanent pool marker, and fresh water is added to marker.
Electrical conductivity...	No measurement OR Readings > 12 mmho/cm	Infrequent measurements OR Reading between 8-12 mmho/cm	Quarterly measurements OR readings < 8 mmho/cm



## APPENDIX A

### Environmental Stewardship Assessment: Manure Storage (continued)

Potential Odor Risk	High Risk	Moderate Risk	Low Risk
<b>Open lot runoff holding pond/Settling basins/Filter strips</b>			
Holding pond unloading	Holding pond is regularly more than half full.		Liquid is dispersed through a grass filter strip. OR When ground is not frozen, liquid is pumped out when ever ground will accept liquid without runoff. Pond is kept dry or with minimal liquid pools.
Draining of settling basins or channels	Liquid pools in settling basin often remain for multiple weeks.	Liquid pools in settling basin often remain for multiple days.	Liquids drain from settling basin, and a dry solid surface is observed within a few days after a storm event.
Drainage of open channels for transporting runoff	Liquid pools in open channels remain for multiple weeks.	Liquid pools in open channels often remain for multiple days.	All liquids drain from open channels.
<b>Solid Manure</b>			
Stockpiling	Stockpiling often occurs near public roads or neighbors. OR Precipitation and seepage pools in vicinity of stockpile.		Stockpiling is avoided for most of year and harvested manure is directly land applied. OR Stockpiling is done in remote locations away from neighbors, AND all precipitation and seepage drains away from stockpile.
Composting	Wet manure is commonly stockpiled and never turned.	Crop residue is mixed with stockpile manure, but stockpile is not turned.	Only dry manure (< 45% moisture) is stockpiled. OR Crop residue is mixed with stockpiled manure to achieve < 45% moisture. OR Stockpiled manure is turned weekly to encourage composting until no additional heating occurs.

## About the Authors

This lesson was written by Larry Jacobson, Extension Engineer and Livestock Housing Specialist, University of Minnesota, St. Paul; Jeff Lorimor, Extension Engineer and Manure Management Specialist, Iowa State University, Ames; Jose Bicudo, Assistant Extension Professor, University of Kentucky, Lexington; and David Schmidt, Assistant Extension Engineer, University of Minnesota, St. Paul.

The authors can be reached at these e-mail addresses:

Larry Jacobson	jacob007@tc.umn.edu
Jeff Lorimor	jclorimo@iastate.edu
Jose Bicudo	jbicudo@bae.uky.edu
David Schmidt	schmi071@tc.umn.edu

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## Glossary

**Additives.** Compounds that can be added directly to freshly excreted or stored manure for odor abatement.

**Adsorbents.** Chemical or biological materials that can collect odorous compounds on their surfaces such as zeolites.

**Aerobic.** Achieving solids reduction in manure mixtures using microorganisms that require oxygen. Thus, the breakdown of organic material tends to be odor free.

**Anaerobic.** Transformation of manure by microorganisms that do not require oxygen.

**Carbon-to-nitrogen (C:N) ratio.** Ratio of the weight of organic carbon (C) to that of total nitrogen (N) in an organic material.

**Chemical oxygen demand (COD).** Indirect measure of the biochemical load exerted on the oxygen content of a body of water when organic wastes are introduced into the water.

**Composting.** Aerobic treatment system applicable to solid or semi-solid manure in which microorganisms convert organic materials such as manure, sludge, leaves, paper, and food wastes into a soil-like material called compost.

**Digestive deodorants.** Mixed cultures of enzymes or microorganisms designed to enhance the degradation of solids and reduce the volatilization of ammonia and/or hydrogen sulfide.

**Hydraulic retention time (HRT).** The time that liquids are retained in a treatment facility such as an anaerobic digester. In general, the longer the HRT, the more thorough the treatment.

**Sedimentation.** Separation from water, by gravitational settling, of suspended particles that are heavier than water.

**Settling velocity.** The speed with which solid particles migrate downward in an aqueous solution. The settling velocity depends on several factors including the particle size, particle density, and liquid viscosity.

**Shelterbelts.** Rows of trees and other vegetation historically used for snow and wind protection in the Midwest.

**Solids retention time (SRT).** The time that solids are retained in a treatment facility. This may be the same as the SRT if the liquids and solids are thoroughly mixed as they move through a treatment vessel or may be significantly longer if solids are allowed to settle and “stay behind.”

**Specific gravity.** The weight of a liquid or solid compared to the weight of water. If the object is the same weight as water, its specific gravity is 1.0.

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## Reviewers

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Ted Funk  
Extension Specialist  
Agricultural Engineering  
University of Illinois

Carol Galloway  
USEPA Ag Center  
Kansas City, KS

Mohammed Ibrahim  
Extension Specialist  
North Carolina A&T State University

Gary Jackson  
Professor, Soil Science, and Director,  
National Farm\*A\*Syst Program  
University of Wisconsin, Madison

Barry Kintzer  
National Environmental Engineer  
USDA-NRCS  
Washington, D.C.

Rick Koelsch  
Livestock Environmental Engineer  
University of Nebraska

Deanne Meyer  
Livestock Waste Management Specialist  
University of California-Davis

Mark Risse  
Extension Engineer, Agricultural Pollution Prevention  
University of Georgia

Peter Wright  
Senior Extension Associate, PRO-DAIRY  
Cornell University

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# Livestock and Poultry Environmental Stewardship Curriculum: Lesson Organization

This curriculum consists of 27 lessons arranged into six modules. Please note that the current lesson is highlighted.

