AIR QUALITY

Additives for Improving Hog Farm Air Quality

AIR QUALITY EDUCATION IN ANIMAL AGRICULTURE

Mitigation Strategies: Additives

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This publication discusses eight types of additives that can improve hog farm air quality by reducing ammonia hydrogen sulfide and VOCs from hog house shallow pits and lagoons.

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North Carolina is the second largest producer of hogs in the United States, with an on-farm inventory of 9.5 million animals in December 2006. These hogs are mostly raised over shallow pits (18 to 24 inches deep) on slatted floors. Hog urine and feces, spilled feed, and water collected in the pits are periodically emptied into an anaerobic (absence of air or oxygen) lagoon. In the lagoon, anaerobic bacteria break down the organic material into simpler organic and inorganic compounds. However, during this process, organic gases (also called volatile organic compounds or VOCs) and inorganic gases (e.g., ammonia, hydrogen sulfide) are produced. Many of these gases, individually or in combination, produce objectionable odors. Schiffman and others (2001) identified 331 VOCs in hog barn air and lagoon waste samples that contribute to odors.

As the population of North Carolina grows, people continue to move to the countryside. Subdivisions are built close to hog farms, and homeowners complain about the air quality associated with hog production. In addition to smelling bad, some manure gases also can affect the health of the animals and workers when they reach high concentrations in hog houses. Jones and others (1997) showed that ammonia concentrations in the 10 to 15 ppm (parts per million) range reduced resistance to infection in hogs. Hence, while ammonia may be only a minor component of hog odors (the major ones being hydrogen sulfide and VOCs), both ammonia and other odor emissions from swine production can be reduced through use of technology and management practices. Air quality in hog production can be improved by dietary manipulation (e.g., reducing crude protein), technology (spraying oil in the houses), management (regular washdown of pens), or additives. This paper focuses on additives used in shallow pits and lagoons (*Figure 1*).

Figure 1. A system designed to evaluate different dosages of an additive in a lagoon.

When subdivisions are built close to hog farms, some homeowners complain about the air quality associated with hog production. Air quality can be improved by dietary manipulation, technology, management, or additives.

Additives

Additives for improving air quality by reducing emissions of ammonia, hydrogen sulfide, and VOCs from hog house shallow pits and lagoons fall into eight categories: (1) pH modifiers and acidifiers, (2) digestive additives, (3) oxidizing agents, (4) disinfectants, (5) adsorbents, (6) enzyme inhibitors, (7) saponins from yucca, and (8) masking agents and counteractants (McCrory and Hobbs, 2001). A single additive is unlikely to provide benefits for multiple gases, and, in fact, while reducing the emission of one gas, it may increase the emission of another. *Table 1* lists additives that have shown potential in the lab or field in improving air quality in hog production. *Table 2* provides information on costs and sources of promising additives. *Table 3* summarizes the potential advantages and disadvantages of various types of additives. Products that were evaluated in scientific studies and are currently available were chosen for inclusion.

(1) pH modifiers and acidifiers. Changing the acidity (pH) of the waste can result in biochemical changes that can increase or decrease the formation of certain gases. Increasing the pH to values greater than 12 by using alkaline material like burnt lime (CaO) or slaked lime ($Ca(OH)2$) can destroy odor-producing organisms; increasing the pH would also reduce hydrogen sulfide emissions. However, large amounts of such additives would be required in pits or lagoons, making their use uneconomical. Increasing the pH also would increase ammonia emissions.

Acidifiers, materials that reduce pH, (*Figure 2*) are effective in reducing ammonia emissions; however, they increase hydrogen sulfide emissions. Adding acids, acid-forming salts, and labile (unstable) carbon (C) can reduce the pH of the waste, resulting in more of the ammoniacal (ammonia plus ammonium) nitrogen being in the form of ammonium rather than ammonia. The acidity also creates unfavorable conditions for the bacteria and enzymes that contribute to ammonia formation. While many types of acid (e.g., hydrochloric, phosphoric, lactic) have been found to be effective, they may not be cost-effective or they may pose safety concerns. For example, Hendriks and Vrielink (1997) reported that treating hog waste with AMGUARD (a compound containing acetic acid) was effective but expensive (*Table 1, line 3*).

Acid-forming salts, such as aluminum chloride, aluminum sulfate (alum), ferric chloride, and calcium phosphate, though not as effective as acids, are safer to use and less expensive. While acidifiers favor the formation of hydrogen sulfide, alum may increase hydrogen sulfide emission more than other acidifiers by adding sulfur (Smith and others, 2001). Adding an acidifier directly to the lagoon to reduce ammonia emissions may be uneconomical: Large quantities of acidifier will be required to overcome the waste's buffering capacity. Calcium phosphate will reduce ammonia emission but increase the phosphorus (P) content of the waste, and, hence, its use is not recommended.

Figure 2. An acidifier being applied in a broiler house.

Table 1. Summary of recent studies on additives that were effective in improving air quality in hog waste management.

Authors	***Additive type***	***Scale; waste management system; duration***	***Additives and dosages***	***Key results***	***Comments***
1. Amon and others (1995)	Saponin	House; shallow pit and lagoon; 60 days	De-Odorase[1] added to feed and added in shallow pits (6.2 grams per day)	Ammonia concentration 11.8 ppm in control versus 8.8 ppm in treated rooms (26% reduction); odor concentration not reduced by additive	Weight gain was not affected by De-Odorase
2. Williams and Schiffman (1996)	Multiple types	Lab; fresh slurry	Odor counteractant[2] (natural oils), 125 ppm; digestive deodorant[2] (microorganisms and enzymes), 500 ppm; potassium permanganate (PP), 14,000 ppm; Sphagnum peat moss (SPM), 7,500 ppm; and chemical deodorant[2] (inorganic compounds), 5,000 ppm	PP improved odor quality and reduced odor intensity; counteractant improved odor quality; all other additives were ineffective	Field scale testing required
3. Hendriks and Vrielink (1997)	pH modifier	House; deep pit and slurry tank; 8 months	AMGUARD[1] (organic acid) added to reduce slurry pH to 5.5 units; labile carbon (C) added as milled wheat (3 lb/pig-week) and heated potato starch (2.7 lb/pig-week) to produce lactic acid	3.2 lb of ammonia emitted per pig place/yr (42% reduction) with AMGUARD and 3.0 lb of ammonia emitted per pig place/yr (45% reduction) with labile C	Ammonia reduction based on published value since there was no control treatment; producer estimated additives cost NLG[3] 28, 42, and 21 per pig place/yr for organic acid, milled wheat, and potato starch, respectively
4. Hendriks and others (1997)	Digestive	House; deep pit; 22 months	A total of 10 lb of additive[2] (mixture of enzymes, bacteria, yeast, and mold) added to pit 11 ft by 6.6 ft	Ammonia emission per unit live weight of animal was reduced by an average of 30% (0 to 51%) over four measurement periods	Producer estimated additive cost BEF[4] 1.00 per sold pig
5. Zhu and others (1997)	Multiple types	Lab; deep pit waste; 35 days	MPC[1,5] (chemical emulsifier), Bio-Safe[1] (enzymes and microbes), Shac[1] (enzyme), X-Stink[1] (aerobic bacteria), and CPPD[1] (chemical oxidizing agent)	MPC, Bio-Safe, Shac, and X-Stink reduced odor thresholds by 83-87%, while CPPD reduced odor threshold by 58%	Ammonia and hydrogen sulfide reductions not determined due to low levels; X-Stink and CPPD reduced pH

Authors	Additive type	Scale; waste management system; duration	Additives and dosages	Key results	Comments
6. Wu and others (1999)	Oxidizer	Lab; fresh and stored manure; 21 days	Ozone applied at 0, 0.25, 0.5, 0.75, and 1 ppm to manure	Ozonation at 0.5 ppm reduced odor to acceptable level even after 3 weeks of storage; ozonation reduced sulfide levels rapidly	Total cost $2.65 per 100 gal[6]
7. Chastain (2000)	Digestive	Lab; recharge pit; 6 days	Bio-Safe[1] (enzymes and microbes) mixed with effluent at 0, 67, 100, and 200 ppm	100 ppm additive reduced odor by 36%; 100 and 200 ppm were no different	Unclear how ammonia volatilization increased despite reduced pH
8. Heber and others (2002)	Digestive?	House; deep pit; 6 months	0.44% Alliance[1] sprayed to achieve concentration of 300-350 ppm in waste	24% reduction in treated buildings compared with untreated buildings; however, 20% waste dilution in treated buildings not considered	Not cost-effective considering modest reduction and considerable additional investment
9. Varel (2002)	Disinfectants	Lab; fresh hog waste in jars; 56 days	Natural antimicrobials carvacrol and thymol in dosages of 2.5 ppm; also other dosages and combinations of the two compounds	Stopped production of odorous compounds	No measurements of odor or ammonia; also suppressed anaerobic bacteria and fecal coliform
10. Smith and others (2004)	pH modifier	House; pit recharge; 42 days	Aluminum chloride added to pits at 0, 0.25, 0.5, and 0.75% of manure volume	Effective in reducing pH and ammonia concentration with higher concentrations more effective; at 0.75% concentration, ammonia emission from pit was 52% compared with control over 42 days	Phytase treatment results not reported; use of aluminum chloride also reduced soluble P in waste (Smith and others, 2001)

Aluminum chloride solution added to shallow pits reduced ammonia concentrations (*Table 1, line 10*) in the hog house (Smith and others, 2004). It is estimated that 1,000 pounds of hogs (liveweight) will produce 65 pounds of manure daily (ASAE D384.2, 2005). Assuming there will be an additional 5 pounds of wasted feed and water, at the highest rate of 0.75 percent aluminum chloride solution used by Smith and others (2004), about 8.5 ounces of aluminum chloride solution will have to be added daily to the pit per 70 pounds (about 8.4 gallons) of fresh waste. (Suppliers sell only solution of aluminum chloride; they do not sell bulk quantities of commercial grade aluminum chloride salt.) The aluminum chloride solution can be sprayed beneath the slats over the pit liquid with a sprayer system or metered into the flush tank for flushing systems. Since a 5 percent aqueous solution of aluminum chloride has a pH of 2.5 to 3.5 and will corrode metal, the solution should be sufficiently diluted (as in the flush tank) and applied with a plastic spray system. While aluminum chloride may not help with other odorous gases, it will conserve nitrogen (N) and reduce soluble P losses in runoff when the waste is land-applied (Smith and others, 2001). However, the volume of waste to be handled will increase.

Authors	*Additive type*	*Scale; waste management system; duration*	*Additives and dosages*	*Key results*	*Comments*
11. Schneegurt and others (2005)	Digestive	House and lagoon; shallow pit and lagoon; 71 days for houses and 51 days for lagoon	Five barn pits sprayed with Bio-Kat[1] to concentrations of 0, 0.5, 1, 1.5, and 2 ppm; lagoon sprayed at 0, 3, and 10 days; additional Bio-Kat applied to lagoon to maintain 1 ppm until day 51	Ammonia concentration in barn decreased with increasing additive dosage; ammonia concentration in 2 ppm barn was 50% of 0 ppm barn after 71 days; concentrations of ammonia and total N decreased in lagoon receiving Bio-Kat	Hog losses and antibiotics use decreased in treated barns; solids decreased in lagoon
12. Govere and others (2005)	Enzyme and oxidizers	Lab; slurry tank; 3 days	Minced horseradish roots (HR; enzyme) (10% weight/ volume of waste), calcium peroxide (CP; 1,872 and 2,448 ppm), hydrogen peroxide (HP; 1,156, 1,768, and 2,312 ppm) - HR only, oxidizer only, and combination of enzyme and one oxidizer	Compared with control, HR and HP reduced odor intensity and unpleasantness, some thought HR+HP was more effective; HR+CP more effective than HR+HP at same oxidizer concentrations; HR+CP prevented recurrence of phenolic compounds for 3 days	Authors emphasize use of additives just prior to land application; longer term odor suppression unclear; impacts of higher solid content on application unclear

[1] Proprietary names
[2] Names not disclosed
[3] Netherland guilder [€1 (euro) = NLG 2.2 in Nov. 2001]; as of June 2007, €1 = $1.33
[4] Belgian franc (€1 = BEF 40.35 in Nov. 2001)
[5] Bio-science Environmental Services, the manufacturer of MPC, reported that it was a mixture of enzymes and bacteria and was being sold currently as 104-E
[6] £0.38 per 100 liters (£1 = $1.98 as of June 2007

Labile C will stimulate anaerobic microbes in the waste to produce organic acids, thereby reducing the waste pH (McCrory and Hobbs, 2001). Hendriks and Vrielink (1997) found labile C sources to be effective but expensive (*Table 1, line 3*) when used to reduce ammonia emission. Its impact on total solids (for handling) also should be considered. If suitable bacteria for producing lactic acid can be used, this method may prove economical in reducing ammonia emissions (McCrory and Hobbs, 2001).

(2) Digestive additives. Digestive additives may contain a mix of bacteria and/or enzymes that break down the odorous compounds in the waste, thereby improving air quality. Some manufacturers claim that their products reduce ammonia emissions by converting the ammonium to organic N. Some digestive additives also are said to reduce total solids in the waste, thereby improving waste handling.

The success of digestive additives in improving air quality in hog production has been shown to be limited. While some studies showed varying levels of success (see *Table 1: Zhu and others, 1997, line 5; Chastain, 2000, line 7; Heber and others, 2002, line 8; Schneegurt and others, 2005, line 11*), digestive additives failed in other studies (e.g., Williams and Schiffman, 1996, line 2; Warburton and others, 1980). Among those digestive additives evaluated recently, Bio-Kat (*Table 1, line 11*) may hold the most promise, as it improved both air quality and performance at the farm scale (Schneegurt and others, 2005).

In addition to smelling bad, some manure gases can affect the health of animals and workers when they reach high concentrations in hog houses. Ammonia is the chief concern.

Digestive additives are more likely to perform in a narrower range of conditions than acidifers or oxidizers.

There are reasons for the inconsistent performance of digestive additives. Depending on the types of bacteria and/or enzymes in the additive, that formulation may reduce the concentration/s of only one or two compounds, and if those compounds are not the main sources of odor, the additive will not reduce odor (Ritter, 1989). If a digestive additive is designed to work in an anaerobic environment, it may perform better in deep pits where waste is cleaned out every six months, rather than in pit-recharge systems that are emptied every week. Also, bacteria in the additive may not survive in the waste management system (Ritter, 1989). Finally, with proprietary products (not just digestive additives), the exact mode of action of the product is unknown since the manufacturer does not provide that information. Consequently, the user cannot optimize the performance of the additive (say, by changing the pH) nor improve the product to work under a wider range of conditions.

(3) Oxidizing agents. Potassium permanganate, hydrogen peroxide, and ozone reduce odors not just by oxidizing odorous organic compounds into less odorous prod-

Table 2. Cost (2007 prices) of using some potentially promising additives and their sources.

Additive, category	*Source*	*Dosage per 100 gal of fresh waste*[1]	*Cost to treat 100 gal of fresh waste*[2]	*Comments*
Aluminum chloride solution, acidifier/pH modifier	Kemiron (800-879-6353)	34 lb of 5% solution	$2.10[3]	Based on study #10 in *Table 1*; 28% solution diluted to 5% on the farm
104-E, digestive	Bio-Science (866-463-2511)	3.33 gal	$73.50[3]	Based on study #5 in *Table 1*; MPC has been renamed 104-E
Shac Manure Digester, digestive	Shac Environmental Products (888-533-4446)	0.008 gal	$0.30	Based on study #5 in *Table 1*
Bio-Kat, digestive	NRP Inc. (954-970-7753)	0.0002 gal	$0.90[4]	Based on study #11 in *Table 1*; average of 12 oz ($65/gal) needed to treat waste from 1,000 hogs in wean to finish operation
Carvacrol, disinfectant	Sigma Aldrich (800-325-3010)	2.1 lb	$62[3,4]	Based on study #9 in *Table 1*; liquid has to be diluted in ethanol prior to addition to waste due to low water solubility
Ozone, oxidizer	Based on design by Wu and others (1999)	0.00005 lb	$2.65[5]	Based on study #6 in *Table 1*; for farm with 13,400 lb liveweight (e.g., 89 150-lb finishers) at 1999 prices
Potassium permanganate, oxidizer	Ohio Pure Water Company (888-644-6426)	1 gal of 5% solution	$2.20[3,4]	Based on study #2 in *Table 1*; crystals (0.42 lb) dissolved in 0.95 gal water to form 5% solution
Hydrogen peroxide (H_2O_2), oxidizer	DFWX Company (903-496-2813)	1 gal of 5% solution	$3.33[3]	Based on study #12 in *Table 1*; 35% H_2O_2 diluted to 5% solution on the farm

[1]Dosages are meant for addition in shallow pits or to flush tanks; the dosage of additive is not meant for the total volume of waste in pit recharge or flush systems. For addition to the lagoon, the manufacturer should be contacted.
[2]Does not include cost of application system, except where indicated.
[3]Price of additive plus freight. Freight prices, when included, are approximate. Cost of the product plus freight will vary widely based on the size of the order as well as fuel prices; for example, Victor Johnson of Kemiron reported that prices of aluminum chloride range from $0.15/wet lb for a 46,000-lb truck load to $0.35/wet lb (used above) for a tote weighing 2,650 lb (September, 2006).
[4]Excluding freight
[5]Total cost (1999 prices)

ucts but also by destroying odor-producing bacteria, including those that produce hydrogen sulfide and ammonia. Williams and Schiffman (1996) reported that 14,000 ppm of potassium permanganate reduced odor from hog waste (*Table 1, line 2*); however, even 500 ppm of potassium permanganate or hydrogen peroxide was effective in reducing short-term odor from hog waste (Cole and others, 1976). While potassium permanganate and hydrogen peroxide were effective in dosages of as little as 100 ppm in cattle slurry (Ritter, 1989), it is unclear if such concentrations would provide effective odor reduction in hog waste for a reasonable length of time. Spraying 0.5 percent solutions of hydrogen peroxide and potassium permanganate on the surface of liquid dairy manure reduced emissions of hydrogen sulfide and ammonia, though suppression of ammonia was short-lived with potassium permanganate (Xue and Chen, 1999). Govere and others (2005) also reported that hydrogen peroxide and calcium peroxide, singly or in combination with minced horseradish roots (containing the enzyme peroxidase), were effective in reducing odor (*Table 1, line 12*). The enzyme-oxidizer combination (particularly using calcium peroxide) was more effective than either the enzyme or oxidizer used alone (Govere and others, 2005). Ozone reduced odor and sulfide levels in hog manure for up to three weeks (Wu and others, 1999).

Hydrogen peroxide is effective but it breaks down rapidly; further, at concentrations exceeding 8 percent (in water), it is corrosive. Potassium permanganate, because it does not break down as rapidly, is probably preferable to hydrogen peroxide even though its crystals are corrosive and it is a strong oxidizer. Using hydrogen peroxide or potassium permanganate solutions for treating waste will increase the volume of waste. Overall, oxidizers can be effective and economical in improving air quality in hog production. The costs of some oxidizers are compared in *Table 2*.

(4) Disinfectants. Disinfectants can reduce odor by killing bacteria in the waste. Some disinfectants that have been used for odor control in waste management include orthodichlorobenzene, chlorine, hydrogen cyanamide, formaldehyde, paraformaldehyde, carvacrol, and thymol. Orthodichlorobenzene, present in Tec II and Ozene, has shown mixed results (McCrory and Hobbs, 2001). McCrory and Hobbs, citing published research, reported that hydrogen cyanamide (also called alzogur) reduced odor emissions and eliminated hydrogen sulfide emission from hog slurry. Formaldehyde and paraformaldehyde reduced ammonia and hydrogen sulfide levels by reducing bacterial populations (Ritter, 1981).

Natural antimicrobials like carvacrol and thymol were very effective in stopping production of certain odorous compounds in the laboratory for two months *(Table 1, line 9*) (Varel, 2002). While carvacrol and thymol also may be effective in reducing odor from hog waste in the field, they are expensive (*Table 2*) and toxic. Disinfectants may reduce odor, ammonia, and hydrogen sulfide emissions, but generally, they are rapidly neutralized and frequent applications would be required. Hence, they are neither practical nor economical for use at the farm scale (McCrory and Hobbs, 2001).

(5) Adsorbents. Unlike digestive additives that absorb and chemically transform odorous compounds, adsorbents bind odorous compounds on their surfaces. Adsorbents, such as clintoptilolite (a type of zeolite, silicate material found naturally) and Sphagnum peat moss, have been used for improving air quality in hog production. Zeolite (powder or pellet) can bind ammonium and reduce ammonia volatilization. While Portejoie and others (2003) reduced ammonia emissions from hog slurry in the lab by placing zeolite over a perforated polystyrene float placed over the slurry, adding bulk zeolite in the lagoon as an amendment would be difficult. Zeolite could reduce ammonia emissions inside hog houses if applied to the pits, but distributing the solid material throughout the pits under the slats would be difficult. Further, increased total solids in the waste, both inside the house and in the lagoon, may modify the handling characteristics of the waste. McCrory and Hobbs (2001) reported that use of zeolite would likely have limited effect on odors.

Sphagnum peat moss can adsorb about 3 percent of its dry weight in ammonia (McCrory and Hobbs, 2001). While a peat moss cover eliminated ammonia volatilization in the lab (Portejoie and others, 2003), spreading peat at the rate of at least 27 tons per acre on the lagoon surface does not seem practical or economical. Furthermore, peat moss must be oven-dried at 221°F for five hours to make it float. Williams and Schiffman (1996) found no benefits of using a peat moss cover for reducing odors

Acidifers like aluminum chloride solution sprayed over the liquid surface in shallow pits inside hog houses will reduce ammonia levels in the effluent. This will reduce the potential for water pollution.

(*Table 1, line 2*). Hence, adsorbents may not be effective as additives in improving air quality in liquid waste management systems. However, they may be more useful in lagoon covers or in solid bedding systems where they may be mixed into the straw bedding.

(6) Enzyme inhibitors. In hog production, the enzyme inhibitors that improve air quality the most are those that inhibit the enzyme urease, thereby preventing or reducing the speed at which urea (from animal urine) is converted into ammonia. Other inhibitors might impact other odorous gases. While urease inhibitors like phenyl phosphorodiamidate (PPDA) have been shown to be effective, they are expensive and require repeated applications (McCrory and Hobbs, 2001). Hence, enzyme inhibitors are considered neither practical nor economical in liquid waste management systems.

(7) Saponins from yucca. Saponins from yucca, a desert plant, likely bind or convert ammonium into organic-N, thereby reducing ammonia emissions (McCrory and Hobbs, 2001). Amon and others (1995) showed that De-Odorase, a product containing yucca, when fed to hogs and added to waste, reduced ammonia levels by 26 percent, even though it had no impact on odor (*Table 1, line 1*). Based on review of multiple studies, McCrory and Hobbs (2001) reported yucca was not effective in all studies in reducing ammonia levels.

(8) Masking agents and counteractants. A masking agent covers the objectionable odor with a more pleasant one, and a counteractant neutralizes the odor. Both compounds are usually made from a mixture of aromatic oils. Ritter (1989) reported that the masking agents Alamask 518B and 151A masked odors of liquid dairy waste. Pine oil in Pine-Sol® at concentrations of 1 to 2 quarts per 4,000 gallons of liquid dairy manure added to the slurry tank reduced the offensiveness of odor during land application (*http://www.engr.uga.edu/service/extension/aware/vol2_2.html*). Since the natures of hog and dairy wastes are different, it is unclear how effective Pine-Sol will be with hog waste. There is a need to evaluate the impact of low-cost, easily available masking agents, such as pine oil compounds, in reducing odors associated with hog waste.

Summary

Hog production results in the emission of various gases from hog houses, lagoons, and land application sites. These gases, typically ammonia, hydrogen sulfide, and VOCs, can adversely impact the environment and public health, and also can harm the health of the animals and workers if the concentrations inside the hog houses

Figure 3. Controlling gas or odor emissions from manure lagoons with additives requires farmers to carefully evaluate available products for effectiveness on the type of emissions they want to reduce.

Table 3. Summary of advantges and disadvantages of various categories of additives.

Category	***Gas control***	***Odor control***	***Sludge reduction***	***Volume effects***	***Ease of handling***	***Overall cost***	***Comments***
Acidifier (aluminum chloride)	Effective on ammonia	Not studied	Not studied but unlikely	Slight increase	Corrosive	Moderate	Practical for shallow pits only
Oxidizers	Effective on multiple gases	Effective	Not studied but possible	Slight increase (not with ozone)	Toxic	Moderate	Ozone may be practical for lagoon application
Digestives	Some effective on ammonia; others may be effective on multiple gases	Some effective	Some effective	Negligible increase	Mostly safe	Inexpensive to very expensive	Practical for both pits and lagoons
Disinfectants	Effective on multiple gases	Effective	Not studied	Negligible increase	Toxic	Expensive to very expensive	Frequent applications are required
Adsorbents	Effective on ammonia	Not effective	Unlikely	Increase	Safe	Unknown	Not practical for application in pits and lagoons as additive; however, zeolite-impregnated lagoon covers may reduce ammonia emissions
Enzyme inhibitors	Effective on ammonia	Not studied	Not studied but unlikely	Unknown	Unknown	Very expensive	Not practical due to cost
Saponins from yucca	May be effective on ammonia	Not studied but unlikely	Not studied but unlikely	Unknown	Safe	Unknown	Performance in reducing ammonia levels is inconsistent
Masking agents and counteractants	Not studied	Some effective	Not studied but unlikely	Negligible increase	Safe	Unknown	Need for additional studies to evaluate impacts of low-cost and easily available additives, e.g., pine oil

are high enough. Ammonia is the gas of chief concern, both for animal health and air quality reasons. Odor emissions are also a concern, as they impact the quality of life of neighbors. This is especially true in North Carolina and large parts of the southeastern United States, where shallow pits and lagoons are used for waste collection and treatment, respectively. Lagoons allow a substantial loss of ammonia, as does land application.

Applying additives or amendments to the waste in the pits or lagoons can improve air quality associated with hog production. The most effective additives seem to be acidifiers, oxidizers, and digestives. Many manufacturers say their additives reduce emissions of ammonia, hydrogen sulfide, and VOCs. However, an additive that might work in one situation may not perform well in another.

Oxidizers such as potassium permanganate have been shown to be effective in reducing odor intensity and improving odor quality.

As yet, no cost/benefit analyses of using additives have been carried out. Few of these products have been evaluated in scientific studies, and even fewer have been found effective in improving air quality.

Some additives currently on the market that have been shown to be effective are discussed here. Some additives mentioned in this publication may no longer be available, and other effective additives may not be included in this paper. Here are some recommendations:

1. Where ammonia reduction inside the houses is a priority, acidifiers like an aluminum chloride solution sprayed over the liquid surface in shallow pits will reduce ammonia levels (as well as soluble P) in the effluent. This, in turn, will reduce the potential for water pollution. While adding acidifiers to an outdoor lagoon also may be beneficial, it will be more expensive than applying it to the indoor pits. Acidifiers applied in the pits provide residual benefits in the lagoon. Acidifiers will increase N in the waste and, thus, boost the fertilizer value of the waste, but also may increase the acreage required for waste disposal. Acidifiers are more expensive than some digestive additives but slightly cheaper than oxidizers.

2. Digestive additives are more likely to perform in a narrower range of conditions than acidifiers or oxidizers. Adding digestive additives to the lagoon rather than to flush systems will likely be more beneficial in improving air quality or reducing sludge because of the longer residence time in lagoons. Spraying digestive additives in the hog houses will be more beneficial in pit-recharge or pull-plug systems where the waste stays in the houses for a longer time. Some manufacturers may require the addition of their products to both the pit and the lagoon. Digestive additives vary widely in price.

3. Oxidizers such as potassium permanganate have been shown to be effective in reducing odor intensity and in improving odor quality, and they may help to reduce ammonia and hydrogen sulfide levels. Spraying oxidizer beneath the slatted floors may improve air quality inside the houses. Potassium permanganate is probably the most cost-effective additive at this time. Oxidizing additives seem to be more expensive than acidifiers and some digestive additives but less expensive than all other additives.

Contact the manufacturers of all additives to confirm that the additives do not react with one another to reduce the effectiveness of one or both compounds and that they do not create toxic byproducts.

While new products are entering the market rapidly, less effective products may be taken off the shelf or, worse, sold under a different name. Manufacturers also may modify their products and require a different dosage. If a product showed promise in a scientific study, it will likely be more reliable than one that was evaluated only by its manufacturer. Products with money-back guarantees also may be more reliable.

Be very careful when handling additives. Read all manufacturers' guidelines on how the product should be used and handled. Obtain material safety data sheets (MSDS) for each product used. Always use personal protective equipment such as gloves, and stick to proven safety and security standards in your total hog operation.

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