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Logo Design
Ruth Cronje, and Jan Swanson;
based on the original design by Dr. Robert Dunlop

How can we mitigate pig barn emissions?

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There are many ways to mitigate pig barn emissions. Emissions can be reduced by preventing generation or entrainment into air or by capturing the emissions and treating the air. Before selecting a mitigation practice it is useful to identify what emissions need to be mitigated, their sources and the level of mitigation needed. The level of mitigation needed usually depends on the amount generated and the mitigation goal; the reason the emissions need to be mitigated. All mitigation practices increase capital and operating costs and each practice requires proper management to ensure that the practice is effective. When considering mitigation practices it is important to understand how the practice fits into to the pig production and manure handling system.

Why mitigate pig barn emissions?

There are several reasons for mitigating airborne emissions from pig barns. The most common reason for mitigating airborne emissions is to meet local or state regulation. Occasionally federal regulations come into play. Another common reason for adopting a mitigation practice is to foster good neighbor relations by reducing odor emissions, which may be important when planning future expansion or new production sites. There is also interest in reducing greenhouse gas emissions and claiming carbon credits and determining if some mitigation practices can reduce airborne disease transmission (ex. PRRS).

Some Minnesota local units of government require mitigation on pig barns to manage odors. Minnesota has a property line standard for hydrogen sulfide that may cause pig barn owners to use mitigation to manage hydrogen sulfide concentrations at a nearby property line.

In January 2009 US EPA finalized a rule providing a full exemption for reporting air releases of hazardous substances from animal waste at farms to the federal government and a partial exemption of reporting the releases to state and local governments. This new rule exempts all farms from reporting air releases under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The new rule requires only large animal feeding operations to report certain types of releases to local and state agencies, as directed by the Emergency Planning and Community Right-to-Know Act (EPCRA). According to an EPA fact sheet, pig farms with less than 2,500 pigs, each weighing 55 pounds or more, and farms with less than 10,000 pigs, each weighing less than 55 pounds are exempt from EPCRA reporting.

Most pig production operations are small enough that they are not regulated by US EPA air emissions standards unless they are located in a non-attainment area. Non-attainment areas are those regions where the ambient air does not meet the National Ambient Air Quality Standards (NAAQS). At the present time Minnesota, Iowa, North Dakota and South Dakota are all in attainment for all six NAAQS criteria pollutants (i.e., ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), respirable particulate matter with aerodynamic diameter ≤ 10 microns (PM_{10}), respirable particulate matter with aerodynamic diameter ≤ 2.5 microns ($PM_{2.5}$) and lead (Pb)).

Wisconsin has nine counties in eastern Wisconsin that are in non-attainment for ozone or $PM_{2.5}$ (US EPA, 2010). States with counties in non-attainment must file state implementation plans (SIPs) describing actions to be taken to bring the area into attainment. Those plans may limit sources emitting pollutants or precursor that contribute to the non-attainment pollutant.

A recent presentation by MPCA staff stated that Minnesota currently meets the annual $PM_{2.5}$ standard but that the Twin Cities will likely be over the current daily $PM_{2.5}$ standard using 2008-2010 data (Thorton et al., 2010). There may be more potential non-attainment areas in Minnesota depending on the 2011 $PM_{2.5}$ standards. Parts of Minnesota may also exceed the ozone standard, depending on final ozone standard.

A common reason for mitigating odors is to maintain good neighbor relations. This could be valuable for pig producers considering new building sites or expansion of existing operations. An inventory of local receptors (e.g., nearby neighbors, public areas, schools, roads, and towns) can help identify the potential impact of odor emissions from an operation and the value of adopting odor mitigating practices.

If greenhouse gas (GHG) emissions become regulated and carbon credits become valuable, practices that reduce GHG emissions may become worth mitigating.

What is involved in emissions process?

The emissions process begins with generation. It includes volatilization or entrainment into the air, transport from the emitting site to a receptor or the environment. Emitted compounds can be deposited downwind of a source through dry or wet deposition where the compounds can impact the plants, soil and water. The emissions and transport process may involve chemical or physical transformations as the emitted compounds are transported through the air from the emitting site to receptors down wind.

Mitigation practices can attempt to reduce generation or emission (i.e. volatilization or entrainment) into the air. Some mitigation practices capture and treat emitted materials or enhance dispersion of odors to levels deemed non-offensive (i.e. odors) or inconsequential.

What is emitted?

Pig barns and associated manure storages can emit odors, numerous gases, particulate matter and bioaerosols. The gases, particulate matter and bioaerosols can have negative environmental and health impacts locally, regionally or globally. The impacts can depend on the concentration and exposure. The following outlines some emissions and their impacts.

Odors

Odors are a mixture of volatile compounds that evoke both an emotional and physiological response in people. A person's sense of smell is bombarded with both natural and man-made odorants. A person's reaction to an odor depends on the odor's intensity, duration, frequency and pleasantness or unpleasantness. The perfume and aromatherapy industries illustrate efforts to manipulate odors to stimulate emotional and physiological responses.

Odors from pig barns are commonly considered unpleasant and a local issue around sources including barns, manure storage units or fields where pig manure was land applied. When dealing with unpleasant odors the goal is to keep the odor below detection level at the receptor site, which may be a property line, neighbor's house or near-by public area (ex. road, school, park or town).

Gases

Pig barns and manure storages generate numerous gases. The list of compounds grows as the gas detecting capabilities increase over time. Kreis (1978) reported that swine wastes had 50 different compounds. O'Neill and Philips (1992) reported 168 different compounds from swine wastes and Schiffman et al. (2001) identified over 300 compounds from swine operations and manure storage units. Many of the gases are odorous. Some gases can be hazardous at elevated concentrations (ex. hydrogen sulfide (H_2S), ammonia (NH_3)).

Ammonia can injure plants at concentrations of approximately 20 ppm (Vallero, 2008). Ammonia can also react in the atmosphere to form ammonium sulfate ($(NH_4)_2SO_4$) and nitric acid (HNO_3) which can contribute to water and soil acidification after dry or wet deposition. Nitrogen deposition on forests in Europe was reported to be a key factor to triggering severe forest die-back in Europe (Nihlgard, 1985). Ammonia can also react with sulfur dioxide (SO2), HNO3 and sulfuric acid (H2SO4) in the atmosphere to form particulate matter which can cause haze and impair visibility (Barthelmei and Pryor, 1998). More details can be found in a review by Arogo et al. (2006). These impacts are commonly considered regional.

GHG include carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). They remain in the atmosphere for many years are considered to have a global impact.

Particulate matter

Particulate matter from pig barns includes airborne feed particles, dried skin, hair and dried feces. Particulate matter is commonly measured based on the particle size. PM10 is particulate matter with an aerodynamic diameter of 10 micron or less. PM2.5 is particulate matter with an aerodynamic diameter of 2.5 microns or less. Particulate matter can challenge human and animal respiratory tracts because small particles can penetrate deep into their lungs.

Particulate matter can also enhance odor and gas transport and dispersion (Day et al., 1965; Hammond et al., 1979). Gas molecules can be adsorbed onto particulates and be desorbed after warming in nasal passages where the odors and gases can be detected. Particulates with adsorbed odorous gases that become ensnared on clothing can desorb and be detected away from the original source.

Bioaerosols

Bioaerosols include bacteria, viruses, mold and fungal spores and endotoxins. Endotoxins are found in the cell walls of gram negative bacteria and many people have allergic reactions to them. Bacteria, viruses and spores can spread diseases through the air. Heber et al., (2001) measured elevated total aerobic bacteria concentrations up to 600 m from a pig finishing building but the bacteria were not pathogenic.

Porcine Reproductive and Respiratory Syndrome (PRRS) virus is a major disease challenge for pig producers. Airborne transmission plays an important role in neighborhood transmission (Torrison et al., 2001). University of Minnesota researchers have demonstrated that viable PRRS virus can travel 4.7 km in the air (Dee, personal communications, 2009).

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What are the key emissions sources?

Before selecting a mitigation practice to implement it is important to identify important sources where mitigation efforts will have an impact. Building emission rates depend on both the concentration of the emitted compound (i.e. odor, gas or PM) and the ventilation rate. Area sources such as land applied manure or uncovered manure storages depend on emission flux and the emitting surface area. (Table 1)

A comprehensive inventory of each potential source (i.e., building, road, manure storage unit, ventilation exhaust) and daily or seasonal practice (i.e. manure treatment, pumping or agitation) at each animal agriculture operation can help identify the most important.

What are some common mitigation practices?

There are numerous mitigation practices that are actively being researched. The following section summarizes some practices being used with pig production. Individual practices are grouped depending on where they work in the emissions process.

Reduce generation

Diet and feed management

Pig diets are comprised of multiple feed ingredients and designed to provide all the essential nutrients and energy needed for optimum production. Digestibility and nutrient availability affect nutrient absorption and retention in the body and in turn the amount of nutrients in the waste. Most diets are formulated to provide excess nutrients as a safety factor to avoid limiting animal performance. Ongoing swine nutrition research strives to more accurately understand dietary needs that allow producers to formulate diets that optimize production while reducing nutrient emissions in the feces and urine, enteric emissions and subsequent emissions from stored and land applied manure.

Diet and feed management practices to reduce gas emissions include using phase feeding and split-sex feeding, reducing crude protein levels in the diet and adding amino acids to more closely match animal needs, reducing sulfur levels, adding copper sulfate, adding fiber, using growth promotters, and adding organic acids to adjust digestive system pH. Particulate emissions can be reduced by reducing feed waste, using low-dust feeding systems, adding fat to feed, adding water to feed and pelleting feed.

Diet and feed management is not practiced as widely as it might for emissions management because diet costs generally increase and without an economic benefit for

Table 1: Partial list of potential gas and particulate matter sources and practices of pig operations.

Potential source/practice	Likely emissions
Pigs	Gases including carbon dioxide from respiration, volatile enteric gases from digestive system. Particulate matter including dander, dried skin and hair pieces.
Manure collection, transport, treatment and storage	Dried manure particulate matter. Gases from urine and manure on slatted floors and degrading wastes in manure pits and manure storage tanks
Manure agitation and mixing	Gases including ammonia, hydrogen sulfide, methane and many volatile organic compounds
Land application	Gases from manure applied crop land to recycle nutrients at agronomic rates by injection, surface spreading or irrigation
Animal buildings	Ventilation exhaust from building housing animals, manure collection, transport, treatment, processing or storage
Animal mortalities	Gases
Spilled and wash water	Gases
Unpaved (gravel) roads	Particulate matter
Disinfectants, vehicles, building materials	Volatile organic compounds, nitrogen oxides (NOx), particular matter

the producer there is no incentive at this time to incur the added feed cost.

Chemical and biological additives

Chemical additives can be added to the manure to reduce emissions during storage, agitation prior to emptying the storage and land application. Chemicals can be added to oxidize some volatile compounds, adjust pH or react with volatile compounds and form precipitates. Some chemical additives are used as masking agents that cover one smell with another. Counteractants are chemicals that neutralize some odorants. In most cases the chemical costs are too high for common use.

Biological additives attempt to change the biochemical pathways that produce odorous gases. Their effectiveness is not always predictable and the additional cost is usually considered too high for common use.

Reduce emissions

Covers

Covers on manure storage units can reduce or mitigate odor and other gases emissions. Covers create a barrier between the stored manure and airflow above it. The barrier can be either permeable or impermeable. Permeable covers allow gas molecules and water to pass through while impermeable covers trap most gas molecules between the cover and the manure. Impermeable covers can cut emissions by nearly 100%. Properly installed and maintained covers can be effective and economical tools for mitigating odor and gas emissions from manure storage units.

Impermeable covers are typically made of plastic but they can be made of concrete or wood. Plastic covers include geomembranes and geosynthetic materials made of High Density Polyethylene (HDPE), Linear Low Density Polyethylene (LLPDE) or Polyvinyl Chloride (PVC). They can be multilayered to reduce permeability, reinforce and strengthen the membrane or provide ultraviolet or chemical protection. Membrane thicknesses typically range from 10 to 60 mils (0.01 to 0.06 inches).

Plastic impermeable covers can be installed as floating, positive air pressure (PAP), and negative air pressure (NAP). Floating impermeable covers simply lay on a manure storage unit and lie on the manure surface. The cover may be partly inflated with gases that form large gas bubbles under the cover. The large bubbles can make a flexible cover vulnerable to high winds, which stress the cover fabric. A thicker plastic cover can solve the bubble problem but is also more expensive to purchase.

PAP (or inflated dome) covers usually have a central post and are filled with air from a blower. The blower air produces enough pressure under the cover to hold the plastic cover up and withstand forces from wind, rain and snow. PAP covers are deflated for manure agitation and pumping and the cover rests on the central post. Manure is agitated and removed through an opening in the deflated cover.

Negative air pressure (NAP) covers use one or more fans to pull air out from under the cover, creating a vacuum that helps hold the cover in place on the liquid surface. The small fan airflow rate keeps gas emissions small. An effective suction system prevents large bubbles, which can be buffeted by wind, from forming under NAP covers.

Vegetable oil sprinkling

Airborne particulate matter from pig barns can be a problem and contribute to odor dispersion. Several research studies have shown that sprinkling vegetable oil inside pig barns reduces indoor airborne particulate matter concentrations and emissions from the building. Oil application at a rate of approximately one gallon per day per 1000 head of finishing pigs can be done either manually with a hand held sprayer or automatically with an automated sprinkler system installed in a barn. Once-a-day application is recommended. Uniform oil distribution is important. Very small droplets should be avoided to avoid creating a respiratory hazard for employees and the pigs. Oil sprinkling use is limited due to issues with cost, potential slipperiness and extra effort needed for cleaning between batches of pigs and insufficient producer benefit.

Capture and treat

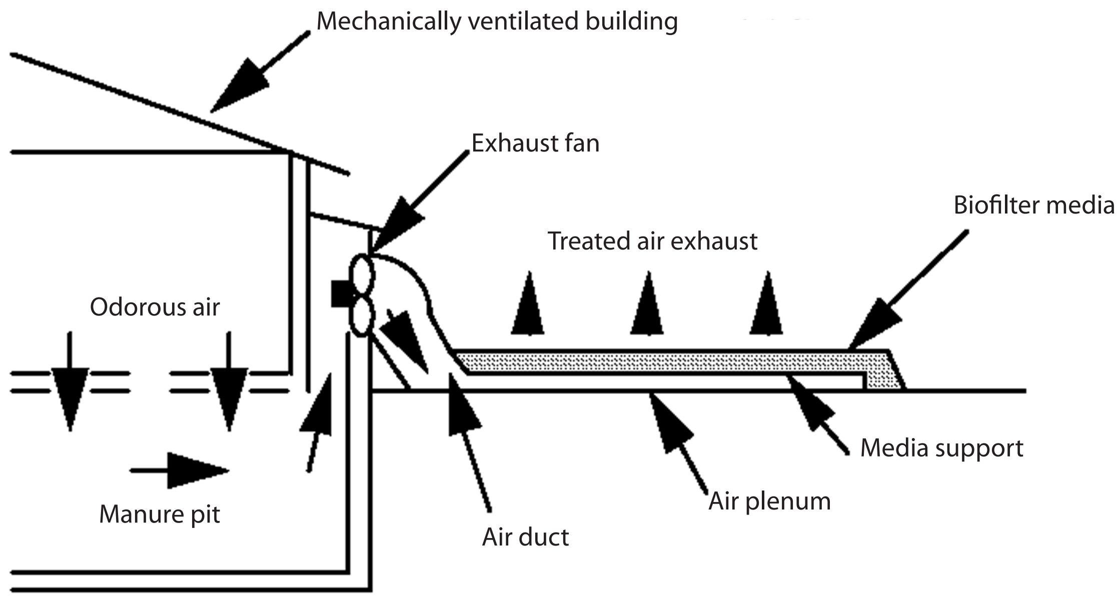
Capture and treat systems treat ventilation air exhaust from pig barns. Capture and treat can also be used to treat air from covered manure storage units.

Biofilters

Gas-phase biofilters can be used to treat ventilation air exhaust or air from manure storage units. They work by absorbing noxious gases into a biofilm where microorganisms breakdown the gases into carbon dioxide, water, salts and use the energy and nutrients to grow and reproduce. Biofilter systems have an odor or gas source, a fan for moving air from the source through ducts, a distribution plenum and the media (Figure 1). Biofilters are very effective treating airstreams with gas mixtures at low concentrations, which describes most odorous airstreams. Well designed and managed biofilters can reduce odors and hydrogen sulfide by as much as 95% and ammonia by 80%. They have been used by non-agricultural industries for many years and on pig barns since the mid 90's.

Some Minnesota counties require biofilters on all pit fans to reduce odor emissions. Additional counties use Odor From Feedlot Setback Estimation Tool (OFFSET) in the permitting process for new or expanding swine facilities. If the OFFSET results indicate potential neighborhood odor problems the operator may be required to install

Figure 1: Typical open-face flat-bed biofilter schematic



a mitigation practice and biofilters are one of the most common selected.

Biofilters impact the ventilating system by adding airflow restrictions. The airflow restrictions are due to the ducting that connects the building to the plenum, airflow through the plenum and airflow through the media.

Biofilters are being actively researched. Research is being done at the University of Illinois to develop a sensor to measure the biofilter media moisture content in the field automatically. Moisture control is very important to maintain biological activity and nitrous oxide (N_2O) generation.

Two non-refereed studies reported that biofilters may generate small amounts of nitrous oxide due to anaerobic processes occurring in biofilters treating air from swine facilities. Martinec et al. (2001) reported both nitrous oxide removal and generation (different samples and media) from fine (small) structured media used to treat air from swine facilities. The data set was too small to draw a conclusion. Melse and van der Werf (2005) reported a relatively consistent increase in nitrous oxide concentration from 0.6 mg/m^3 (inlet air) to 1 mg/m^3 (outlet air) in an experimental biofilter using a mixture of garden compost and expanded perlite inoculated with activated sludge treating air from a swine manure storage unit. Recent research at the University of Kentucky has document N_2O generation and the relation to media moisture content. It is hypothesized that N_2O generation in tight woodchip and compost media is similar to that in soils where nitrogen fertilizer was added and the soil is too wet. Research at the University of Minnesota funded by the Minnesota Pork Board is evaluating the effectiveness of alternative media (i.e. pine nuggets and lava rock) that is more porous than the traditional wood chip and compost mixtures used. N_2O generation is being monitored as well as odor, NH_3, H_2S, CH_4 and non-methane hydrocarbon removal.

Wet scrubbers

Wet scrubbers use a liquid, commonly water with either an acid or base added, to remove water soluble gases and particulate matter by absorbing them onto wet surfaces or into liquid droplets or wet surfaces. The liquid with the captured gases and particulate matter needs to be handled properly to avoid polluting water, soil or air. Well designed scrubbers can be very effective removing 50 to 99% of volatile organic compounds, particulate matter, 90 to 99% oxides of nitrogen (NOx), sulfur oxides (SOx), and hydrogen sulfide. Very small liquid droplets are very effective because they have more surface area than larger droplets but the small droplets can be more difficult to remove from the airstream. Wet scrubbers are being used in Europe to remove NH_3 from pig barn emissions.

A research team at the Ohio State University is working on a low cost wet scrubber for removing NH_3 and produce NH_4SO_4 which can be used as a fertilizer (Manuzon, personal communications, 2010). Their pilot scale unit is being evaluated at the Southern Research and Outreach Center at Waseca. Additional work will be needed before the unit will become available for commercial use.

Water and chemical costs plus wastewater handling will be hurdles to be overcome if use is to increase.

Enhance dispersion

Enhanced dispersion can be used to manage odors, where dispersion can reduce the odorants and gases to below detection levels. Enhanced dispersion can also be used to manage gases that have property line concentration limits. Enhanced dispersion is not a useful practice where emission rates are regulated. Enhanced dispersion does not mitigate emissions so the practices will not be discussed in detail here.

Odor dispersion is enhanced using vegetative buffers, wind walls, chimneys and increased separation distances between odor sources and receptors (i.e. neighbors, towns, schools, parks and other public areas).

What is the take home message?

Several mitigation practices are being used and researched that can mitigate emissions from pig barns. Currently, the primary emission being mitigated is odor. Potential regulations related to ammonia and greenhouse gas emissions may increase the need for more pig producers to implement emissions mitigation practices. It is important to confirm what emissions needs to be mitigated, the level of mitigation needed, how a practice impacts other production practices (i.e., feeding, ventilation, manure management and sanitation) before selecting a practice. All mitigation practices increase capital and operating costs and each practice requires proper management to ensure that the practice is effective. Air emissions and mitigation practices are expected to be active areas for research and product development for the foreseeable future.

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