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Reducing Risks from Manure Storage Agitation Gases

Manure Agitation

Manure storage systems allow for flexibility in the timing of manure application in order to reduce operational and environmental issues. Manure can stratify during storage, forming a crust on the surface and causing a build-up of solids on the bottom of the storage system. Agitation mixes the stored manure to resuspend the solids, reducing pumping and other operational issues and providing a more uniform nutrient consistency for application. During storage, naturally occurring microorganisms in the manure degrade organic material in the absence of oxygen (anaerobic conditions) producing gases including carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S). These gases are released from manure storage systems throughout the storage period. Larger quantities of these gases, which can be trapped within the manure, can be released during agitation. The gases released during agitation can cause concentrations to reach levels that are hazardous to human and animal health (Figure 1).

Since the early 1960s, nearly 150 people have died in the U.S. because of manure-related gas incidents in confined spaces (NCERA 2016). Of those cases, about half occurred on dairy operations. Almost 25% involved a young person under the age of 16. The most common activity at the time a person died was conducting repairs or maintenance on manure handling equipment (34% of the deaths) followed by actions associated with trying to rescue another person entrapped or overcome in a manure storage/reception pit (22% of the deaths) (Beaver and Field 2007).

Figure 1. Agitation of a manure storage from: a) the view of the tractor, and b) the view of the spray that can be produced during agitation (note that spray is not a good indicator of gas release).

Common Gases Released During Manure Agitation

Gases are continuously released from manure storage systems as organic compounds degrade. A variety of gases can be released from manure based on the manure's characteristics and other compounds that may be added. The most common gases of concern are carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3) and hydrogen sulfide (H_2S). Table 1 shows that concentrations of each gas carry different levels of risk based on toxicity and effect on the body. When outdoors, gases are typically dispersed into the atmosphere during agitation. This reduces the concentration of gases as they disperse, thereby reducing risks to humans and animals.

Odorless and colorless CO_2 and CH_4 have the potential to displace oxygen in confined spaces resulting in conditions that can cause asphyxiation. Displacement of oxygen to a point that would lead to human health impacts (less than 19.5% oxygen) is a greater concern in conditions where gas dispersion is impeded such as in a confined space. Without correct safety monitoring, both CO_2 and CH_4 are impossible to detect. In addition, CH_4 can be explosive at concentrations of 5-15% by volume.

Other gases of concern include NH_3 and H_2S, which are toxic and have human health impacts at relatively low concentrations. NH_3 can be extremely irritating to the eyes, respiratory tract, and other mucous membranes (Table 2) and is released from manure during storage and agitation.

H_2S is the gas of greatest acute concern when agitating manure storage systems, as it can cause human health impacts (including respiratory irritation, pulmonary edema, and death) at low concentrations (Table 3). At concentrations as low as 0.001 ppm, H_2S can have a strong rotten egg odor. While this is a good indicator of the presence of H_2S at low levels, one should not rely on smell. At slightly higher concentrations, H_2S can begin to affect the olfactory nerve, which is responsible for the sense of smell, preventing humans from smelling this highly toxic gas. H_2S can build up in stagnant air that does not disperse, resulting in increased concentrations especially during times when there is little or no air movement. Children may encounter higher exposure levels due to their proximity to the source of H_2S. Children also have additional exposure risk since they have smaller diameter airways and a higher lung-surface-area-to-body-weight ratio (ATSDR 2014). Although H_2S does not build up in the body, low-level chronic exposure over time can lead to a variety of physical and neurological disorders, including significant potential for eye injury and damage (ATSDR 2014).

Conditions that Increase Risk Related to Manure Gases

Managing Risk

Risk to human or animal health from manure gases is dependent upon a number of factors. This includes but is not limited to the concentration of the gas and the duration of exposure. To manage the risk associated with manure gases, the first strategy should be to eliminate the hazard altogether. If the hazard cannot be completely eliminated then safeguards and warnings, including safety training and education, should be used to protect against the hazard. Lastly, use personal protective equipment to reduce personal risk (Figure 2). In the case of manure gases, it is critical to minimize the factors that increase gas production and concentration and therefore risk. While the risk may be reduced, it likely cannot be completely eliminated. Therefore, it is important to also incorporate safeguards (e.g., fences, monitoring equipment, etc.) and provide warnings and training to those that may be exposed to the gases. When this is not sufficient, also provide personal protective equipment for those entering confined spaces.

Table 1. Occupational Safety and Health Administration (OSHA) Occupational Standard.

Gas	8-Hour Time Weighted Average (ppm)*	Acceptable Ceiling Concentration (ppm)**	Additional Notes
Ammonia (NH_3)[a]	50	--***	--
Carbon Dioxide (CO_2)[a]	5,000	--***	--
Hydrogen Sulfide (H_2S)[b]	--***	20	50 ppm acceptable maximum peak above ceiling concentration for 10 minutes if no other measurable exposure occurs
Methane (CH_4)	--***	--***	No OSHA exposure limits; simple asphyxiate; oxygen levels must be maintained above 19.5%

*Average concentration over an 8-hour period.
**Maximum concentration at any given moment.
***While there may not be an existing standard, there may still be a risk; standards for a specific gas do not always include each category.
[a]OSHA 2016.
[b]OSHA 2006.

Table 2. Ammonia Toxicity Progression (Michigan Department of Environmental Quality 2006).

Property	Ammonia Concentration in Air (ppm)
Detectable odor	0.04-53
Eye, nose irritation	50-100
Strong cough	50-150
Airway dysfunction	150
Lethal in 30 minutes	2,500-4,500*
Immediately lethal	5,000-10,000*

*As of 2006, the cited report did not find any incidents of death resulting from manure-related ammonia exposure at permitted livestock facilities.

Factors that increase gas production

As the temperature of manure increases, the microbial activity and gas production also increase. For H_2S, this increase can be significant when manure temperatures climb, resulting in concentrations that can be dangerous to health (Figure 3). It is likely that this risk will increase during warm periods, such as summer or a warm fall, when

Table 3. Hydrogen Sulfide Toxicity Progression (OSHA 2017).

Concentration (ppm)	Symptoms/Effects
0.00011-0.00033	Typical background concentrations.
0.01-1.5	Odor threshold (when rotten egg smell is first noticeable to some). Odor becomes more offensive at 3-5 ppm. Above 30 ppm, odor described as sweet or sickeningly sweet.
2-5	Prolonged exposure may cause nausea, tearing of the eyes, headaches or loss of sleep. Airway problems (bronchial constriction) in some asthma patients.
20	Possible fatigue, loss of appetite, headache, irritability, poor memory, dizziness.
50-100	Slight conjunctivitis ("gas eye") and respiratory tract irritation after 1 hour. May cause digestive upset and loss of appetite.
100	Coughing, eye irritation, loss of smell after 2-15 minutes (olfactory fatigue). Altered breathing, drowsiness after 15-30 minutes. Throat irritation after 1 hour. Gradual increase in severity of symptoms over several hours. Death may occur after 48 hours.
100-150	Loss of smell (olfactory fatigue or paralysis).
200-300	Marked conjunctivitis and respiratory tract irritation after 1 hour. Pulmonary edema may occur from prolonged exposure.
500-700	Staggering, collapse in 5 minutes. Serious damage to the eyes in 30 minutes. Death after 30-60 minutes.
700-1,000	Rapid unconsciousness, "knockdown" or immediate collapse within 1 to 2 breaths, breathing stops, death within minutes.
1,000-2,000	Nearly instant death.

gas production and concentration increases. Agitating when manure temperatures are lower will reduce this risk. Research shows that manure below 64°F (18°C) greatly reduces H_2S emissions (Andriamanohiarisoamanana et al. 2015), but low temperatures cannot guarantee safe conditions because there are many other factors affecting gas production including sulfur content and pH. While temperature is an important driver of H_2S emissions, manure pH is also a significant factor. As the pH of the manure decreases, more of the dissolved sulfide is in the form of H_2S (Figure 4). This increases concentrations in the surrounding air. While increasing pH may reduce H_2S emissions and therefore risk, in practice this would be difficult to achieve without significant cost.

Production of H_2S is related to the sulfur content in manure. In general, the higher the sulfur content in the manure storage, the higher the potential H_2S production. For liquid and slurry manures from all livestock and poultry animals, the median range from more than 22,000 samples was 0.6-3.2 pounds (0.3-1.5 kg) of total sulfur per thousand gallons (Laboski and Peters 2012). The maximum measured values were upward of 450 pounds (204 kg) per thousand gallons, indicating there is a wide possible range of sulfur in manure. Livestock require sulfur in their diets, but excess sulfur in the diet can be toxic to animals and results in more sulfur being excreted in the manure. Additional sulfur can find its way into a manure storage system through other farm byproducts, including silage runoff, spoiled feed, and bedding additives. For example, gypsum ($CaSO_4 \cdot 2H_2O$) contains high amounts of sulfur, and when added to animal bedding and then transferred to manure storages, has been shown to increase H_2S production (Hile and Fabian-Wheeler 2014). Laboratory analysis can determine the sulfur content in feed additives and in the total mixed rations to ensure recommended rates are not exceeded.

Ammonia (NH_3) is produced from ammonium (NH_4) during storage, therefore the higher the NH_4 concentration, the higher the NH_3 emissions. As the pH increases, the equilibrium shifts so that more of the NH_4/NH_3 present in the manure is in the form of NH_3, which can be released as a gas. In addition, as the temperature of the manure increases, the NH_3 emissions also increase.

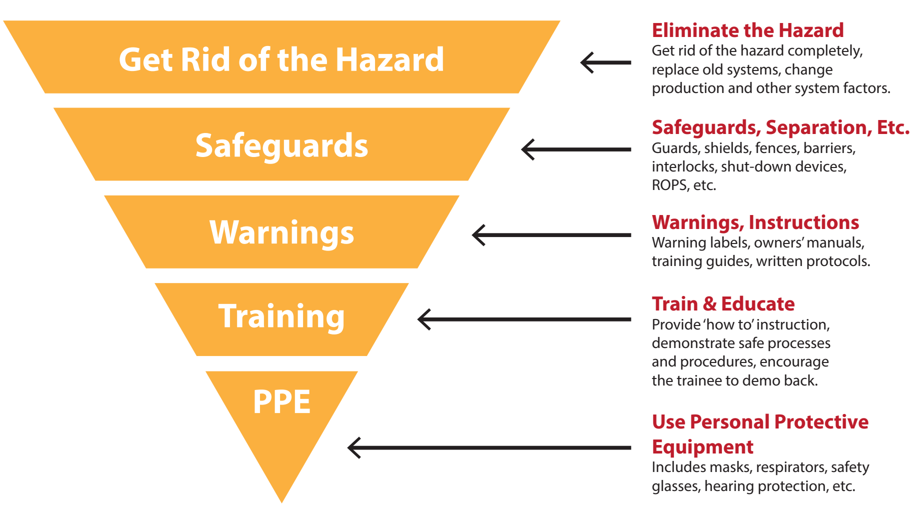

Figure 2. Safety Hierarchy.

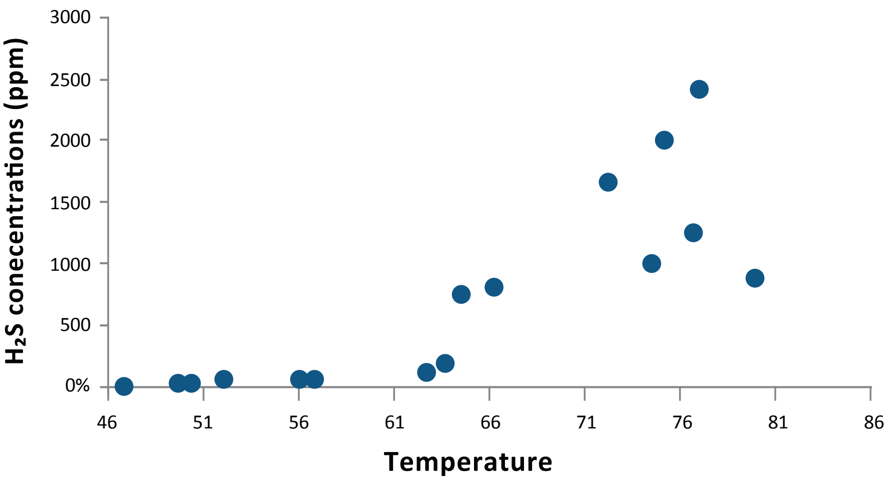

Figure 3. Temperature impacts on H_2S production (Andriamanohiarisoamanana et al. 2015). **NOTE:** this is an example for a specific system and concentrations may vary at different temperatures based on other influencing factors.

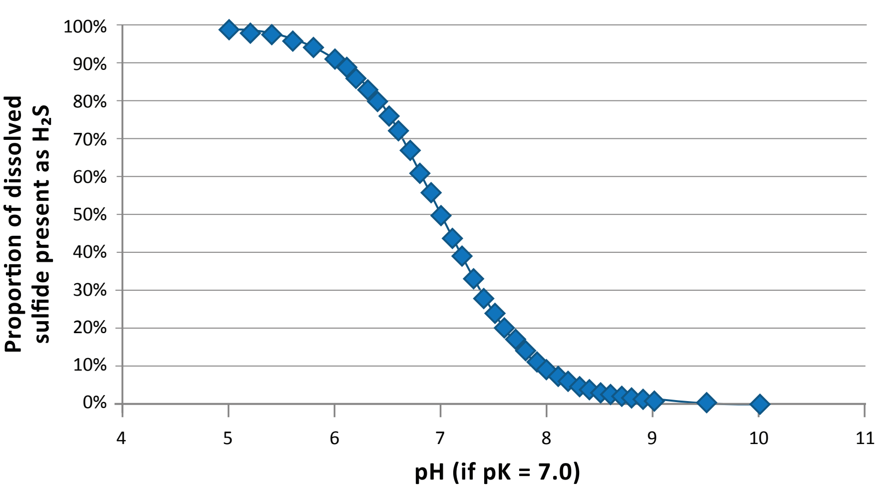

Figure 4. Proportion of dissolved sulfide present as H_2S (USEPA 1974).

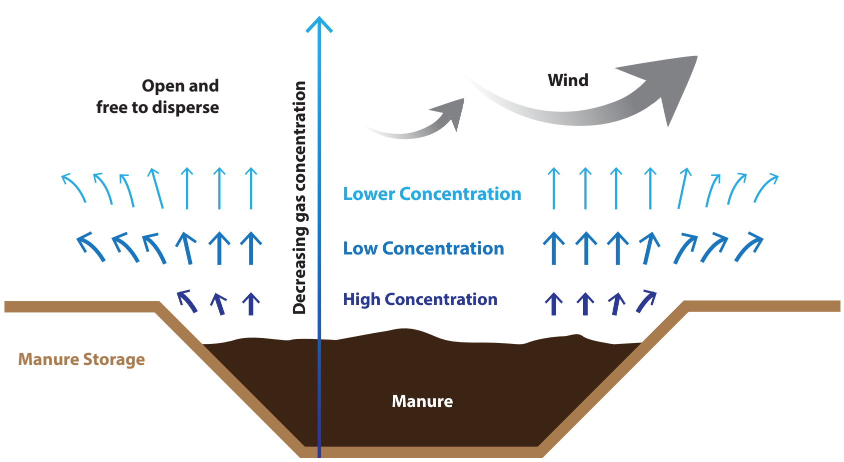

Figure 5. Open manure storage.

Factors that decrease gas dispersion

Gases are released throughout the duration of manure storage, and with proper dispersion into the atmosphere, concentrations are reduced to levels below those known to produce acute health impacts in most humans or animals (Figure 5). When dispersion is limited, the gases can become concentrated and may cause harm (Figure 6). There are many factors that can limit dispersion of gases. Never assume a no-risk situation, even when the conditions promote the greatest dispersion.

Manure storage covers can include impermeable (e.g. plastic) and permeable covers (including biomass covers and the natural crust that can form from manure solids). Covers can reduce the release of gases from manure storage systems. While valuable in retaining nitrogen and carbon in the manure and reducing gas losses, storage covers can result in a greater buildup of gases within the manure. These gases can be released during agitation, increasing human and animal exposure risks.

Risk increases when dispersion of gases is reduced, such as when natural wind conditions are still or during temperature inversions. When there is little air movement, gas concentrations can increase close to the point of release near the surface. During temperature inversions, a layer of colder denser air is near the Earth's surface with a warmer layer of air above. Temperature inversions can greatly reduce convective air movement and trap pollutants near the Earth's surface. This is different from typical conditions where temperature decreases with increased distance from the Earth's surface. While temperature inversions and low wind increase risk, it is nearly impossible to specify the exact weather conditions that are sufficient to reduce concentrations below what is known to be damaging to human health. Even in windy conditions there may be situations where concentrations can be hazardous to health, therefore gas monitoring is always recommended regardless of the weather conditions.

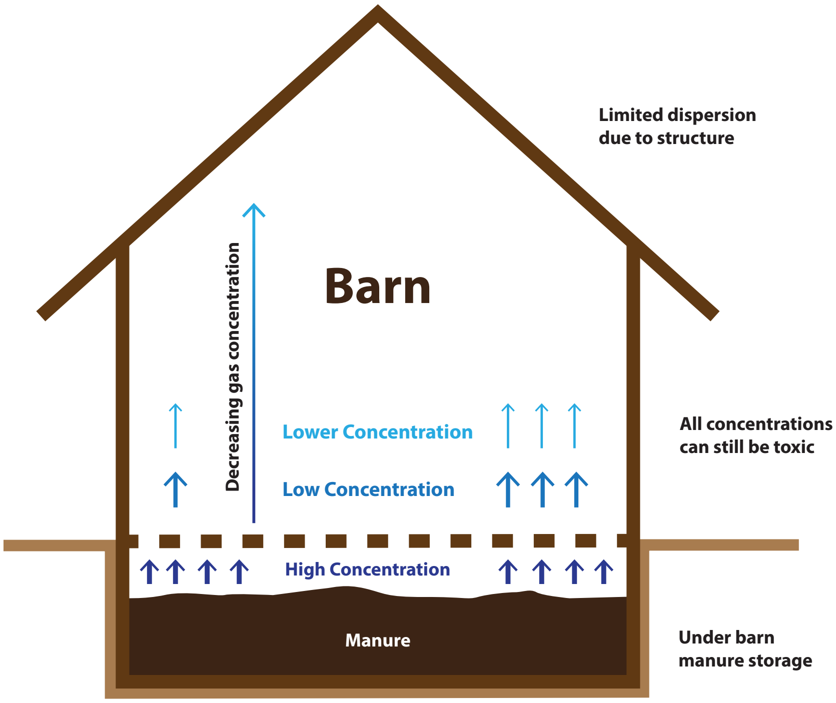

Figure 6. Under-barn manure storage with reduced gas dispersion.

Recommended Safety Practices

Predicting gas emissions for a given set of manure and onsite environmental conditions is difficult. Therefore, monitoring is recommended to alert workers or others of toxic conditions near manure storage facilities. Monitors should give an audible, visual, and vibrational alert. While asphyxiation is unlikely at the edge of a manure pit where air moves freely, monitoring for oxygen will alert workers when concentrations drop below safe levels (19.5% oxygen). Previous incidents suggest exposure of workers to toxic concentrations of H_2S is of greatest concern.

There are three general types of measurement systems: optical sensors, metal oxide sensors, and electrochemical sensors. Optical sensors generally change color to indicate the concentration of the gas and can be purchased very cheaply. Metal oxide sensors are commonly used as permanent sensors or for remote sensing. Electrochemical sensors are available in single and multi-gas monitors, have relatively quick response time, and are designed for ease of use.

Multi-gas monitors allow the operator to simultaneously monitor for oxygen, H_2S, CH_4, and NH_3. While monitoring for multiple gases simultaneously is desirable, these systems are more expensive than single-gas monitors that measure individual gases. Even when a multi-gas monitor is in use, additional personal single-gas monitors provide greater protection for individuals working in high-risk areas and for sites with multiple workers. Single-gas monitors can be purchased for $150 or more and are designed to attach to the individual near or just below breathing height. Additional multi-gas or single-gas monitors can be purchased and placed around the site at high risk areas or near the controls of an agitator or tractor.

If a monitor's alarm goes off, those in the area should immediately move away from the at-risk area and not return until measurements show there is no longer a health risk. When an alarm goes off repeatedly in one area, even after there is no longer a health risk, it is important to reevaluate the systems and try to again eliminate or reduce the hazard. For those working in high-risk areas, small self-contained respirators that contain a bottle of compressed breathable air are recommended. In the chance that an alarm alerts a worker to unsafe conditions, this escape respirator bottle will provide sufficient clean air while the worker moves to a safe area. Even if an escape respirator is available, it is recommended that workers leave the area immediately if a personal alarm is set off. Workers should not reenter the area until it is determined to be safe. It is important to note that any type of respirator worn to provide protection from airborne contaminants carries with it some risk. Individuals who might find themselves wearing a respirator need to be cleared by a qualified health professional, and the employer must fulfill other requirements of a respiratory protection program including fit testing, training, and proper respirator selection. Dust masks, pesticide cartridge respirators, and other **masks** that filter air contaminants from the air provide **no protection** from H_2S or oxygen-deficient situations.

Additional precautions should be used when a farm has under-barn manure storage, also known as a deep pit. This type of manure storage can produce dangerous gas concentrations in the barn, particularly when agitating. This increases health risks to animals and humans (Figure 6). It is highly recommended that animals and people be moved from the barn prior to agitating an under-barn manure storage for the duration of agitation. Additional ventilation is also recommended for these systems.

It is critical to identify an emergency response plan (including a route for escape) prior to agitating or working around any manure storage. This plan should be discussed with all those working at the facility, including outside contractors who might come onsite to provide services. If a worker becomes incapacitated during an emergency situation, procedures must be in place to safely remove the downed worker(s). The procedures should not involve another person entering the potentially dangerous area without a fully self-contained breathing apparatus, as this could result in additional persons being exposed. Appropriately designed warning signs should also be used to warn people to the risk of gases, particularly when agitating. It is recommended to establish contact with the local fire department prior to agitating or emptying manure storages to ensure the department is aware of the potential risks and possesses the necessary training and equipment if a response is needed.

Confined Spaces

Because of the complexity and hazards associated with manure handling and storage equipment, especially within confined spaces, it is strongly recommended that repair, maintenance, fixing plugged systems, and other work be done from a safe location outside of the confined space. If that is impossible, work involving entry into a confined space must be done by persons with the relevant qualifications, technical training, and safety equipment to complete the job safely.

Safe confined space entry where manure gases or oxygen deficiency are known to be present or have the potential to be present (i.e., all manure storage structures) requires at least:

- Continuous air monitoring and testing equipment (a calibrated, four-gas electronic monitor is recommended).
- Ventilation fans, blowers, ducting, etc., to dilute or remove toxic gases and increase oxygen levels to a measured safe level.
- Personal retrieval equipment (harness, cables, winch systems, etc.).
- Respiratory protection equipment (a supplied-air respirator is required, such as a self-contained breathing apparatus for oxygen levels below 19.5% or gas levels that are immediately dangerous to life and health (IDLH). The IDLH level for hydrogen sulfide is 100 ppm.

Additional Information

Gypsum bedding impact to H_2S production – http://extension.psu.edu/animals/dairy/health/facilities/gypsum-bedding/safety-risk-from-manure-storages-of-dairy-cows-bedded-with-gypsum.

Manure Gas Webinar Recording – http://fyi.uwex.edu/agsafety/2016/09/13/manure-gas-safety-webinar/.

Non-Enclosed Manure Storage Safety Tips – http://fyi.uwex.edu/agsafety/confined-spaces/manure-storagehandling/non-enclosed-manure-storage-tips/.

Preventing Deaths of Farm Workers in Manure Pits – https://www.cdc.gov/niosh/docs/90-103/.

Confined Spaces from the National Agricultural Safety Database (NASD) – http://nasdonline.org/browse/12/confined-spaces.html.

Research and Extension Agenda for Agricultural Confined Spaces – https://extension.entm.purdue.edu/grainsafety/pdf/Agricultural%20Confined%20Spaces%20White%20Paper.pdf.

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