Appendix K

Manure Gas Safety – Review of Practices and Recommendations for Wisconsin Livestock Farms

MANURE GAS SAFETY

REVIEW OF PRACTICES AND RECOMMENDATIONS FOR WISCONSIN LIVESTOCK FARMS

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Safety Review Team

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I. INTRODUCTION

The death of five people from hydrogen sulfide inhalation on a Virginia dairy farm in July 2007 was a grim reminder of the hazards posed by gases associated with manure handling systems. The threat of accidents, combined with the increasing scale and complexity of manure management systems, prompted the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP) and USDA, Natural Resources Conservation Service (NRCS) to convene an interagency team (members are listed in Appendix A) to review safety considerations related to certain manure handling practices. In particular, the safety review team focused on the expanding use of drive-in, covered storage tanks and transfer channels intended to be entered with machinery for removing sand bedding. This was identified as a potentially hazardous practice. The team met from August 2007 to July 2008 to assess the safety aspects of this and other manure management practices and to provide recommendations to reduce the risk of accidents from manure management system gases. The group developed findings and reached recommendations through a consensus process that relied on the expert contributions from individual members and the review of research and industry findings and recommendations.

This report contains the findings and recommendations of the team. Chief among its findings, the team concluded that safety considerations currently incorporated into manure system designs and included in operation and maintenance plans have not kept pace with changes in manure management and the associated risks of manure gases. Safer system designs and management practices, along with increased awareness of these dangers, will be needed to help prevent manure gas tragedies from occurring on Wisconsin farms. This report addresses the following areas:

- Information and education
- Revision to technical standards
- Identification and notification to owners of unsafe systems
- Adoption of safety measures and practices
- Improved safety planning

II. OVERVIEW OF HAZARDS

The decomposition of manure in storage or handling systems generates gases, some of which are toxic, explosive, and oxygen displacing. The most hazardous gases are hydrogen sulfide (H_2S), ammonia (NH_3), methane (CH_4), and carbon dioxide (CO_2). Dangerous levels of these gases can accumulate in and around manure management systems, particularly when manure is being agitated or otherwise disturbed.

Hydrogen sulfide levels may increase a thousand-fold during agitation. This extremely toxic gas is the most dangerous manure gas as it is colorless, heavier than air, and may cause death in seconds at high concentrations. While hydrogen sulfide is commonly known for its rotten egg odor, the odor isn't detectable by the human sense of smell at higher concentrations. It affects eyes, respiratory system, and the central nervous system.

Ammonia has a sharp pungent odor and is generally higher in poultry manure. It is lighter than air. Ammonia causes irritation of the eyes and respiratory tract. At higher concentrations, this gas may cause permanent lung damage.

Methane is highly flammable. A spark from equipment, open flames, smoking materials, faulty wiring, or welding could provide an ignition source for an explosion or fire. Methane is odorless, colorless, and lighter than air. By displacing air at high concentrations, methane which is itself non-toxic, can become an asphyxiant and will cause rapid breathing, dizziness, and fatigue.

Carbon dioxide is heavier than air and will displace oxygen. Carbon dioxide exposure may result in headaches and dizziness. Death by asphyxiation is possible at high concentrations.

While manure is the primary source for the hazardous gases addressed in this report, the decomposition of other organic material, such as milking center waste, waste feed, feed leachate, and any combination of these materials, may pose similar risks.

III. GENERAL RECOMMENDATIONS

A. Information and Education

The team concluded that there is insufficient knowledge of the hazards associated with gases generated by manure management systems. There also appears to be a general disregard for safety practices that must be addressed to achieve the goals of this report. An information and education effort is needed that targets farm owners/operators, farm workers, manure applicators, manure system designers (private and public sector), equipment vendors, builders, and service providers. Information and education efforts, particularly for farm workers and builders, needs to be bilingual. The following actions are recommended to address these concerns.

1. Develop and disseminate “fast fact cards” on the dangers of manure gases. These cards would specifically focus on dangers of each of the four main manure gases.

2. Develop and disseminate press releases to agricultural newspapers and radio broadcasters related to manure gas safety and system design.

3. Develop bilingual podcasts on the dangers of manure gases and disseminate for agency use via UW Center for Agricultural Safety and Health website.

4. Develop bilingual training resources for safety assessments including monitoring, ventilation, and rescue procedures. Training resources will be developed for two audiences:

    - agency staffs, including UW Cooperative Extension, NRCS, DATCP, and County Conservation staff; and
    - farm personnel, including owner/operators, farm employees, and service personnel.

5. Conduct manure safety trainings for agricultural professional organizations, including a session at the WALCE Professional Development Conference in February 2009.

6. Offer joint agency statewide teleconferences or web seminars for staffs.

7. Design and staff a manure storage and handling safety display for use at the Wisconsin Farm Technology Days 2009 in Dodge County. Utilize the display and relevant materials at other farm expos and meetings as appropriate.

B. Standards and Specifications

The team recommends that the NRCS Waste Storage Facility Standard (313) and Manure Transfer Standard (634) be revised immediately to require that all waste storage facilities, reception tanks, pump chambers, and manholes be configured such that The American Society of Agricultural and Biological Engineers Standard ASAE EP470, Manure Storage Safety (ASAE EP470), criteria (attached) can be followed. Specifically, this emergency revision should prohibit drive-in, covered storage tanks and transfer channels that cannot reasonably be expected to be operated in accordance with ASAE EP470 procedures. Additionally, in conjunction with the expected routine revision of Standards 313 and 634 (to be initiated by the Standards Oversight Council in January 2009), the team recommends amending the standards to require that a safety assessment be conducted by the designer of manure storage and transfer systems and that a safety plan is developed to address manure gas hazards. In particular, sites of human entry into areas where manure gases could concentrate should be identified and addressed within a detailed plan for safe entry procedures and safety features.

C. Identification and Notification of Unsafe Systems

The team concluded that drive-in, covered storage tanks and transfer channels cannot be operated in accordance with published safety standard ASAE EP470 and, therefore, present a potential safety hazard. It is estimated that more than 75 of these systems are currently in use in Wisconsin. The team recommends these systems be abandoned or retrofitted to safer alternatives. Furthermore, the team recommends that federal, state, and local cost-sharing program funds be made available to retrofit unsafe systems. An effort should be made to contact operators with these systems to provide them with the findings of this report along with information on the availability of any financial and technical assistance to retrofit their systems to safer alternatives. Notification should be made by County Land Conservation Departments or NRCS offices as well as through a press release in agricultural newspapers and radio stations. The team also recommends that NRCS or DATCP Engineers and Technicians, as well as County Land Conservation staff, no longer provide assistance to install new drive-in, covered storage tanks and transfer channels, modify existing facilities of this type for continued use, or provide other assistance that directly supports the installation or continued use of an unsafe system.

IV. PRACTICE ASSESSMENT AND RECOMMENDATIONS

The safety review team assessed manure management practices typically found on Wisconsin livestock farms. They are differentiated by their hazard level and recommendations for mitigating those hazards. Other practices and locations on farms may also be hazardous. This report is not intended to address all farm safety concerns. A safety walk-through should be conducted to fully assess safety risks on any farm. The following four categories of practices are areas where hazards from manure gases most commonly exist.

A. Drive-In, Covered Storage Tanks and Transfer Channels

1. Practice Description

   These systems are characterized by a vertical walled, concrete structure with either a slatted or solid top, or some combination of slatted or solid top or cover. They are distinguished by a ramp or opening that provides entry by a skid loader or other human-operated equipment into the tank or channel for the purpose of removing residual solids and sand. They are usually located beneath part of a barn or the entire barn, and they may form a conveyance channel that extends from the barn to an exterior storage structure. Their purpose is to provide short-term waste storage and/or transfer. Manure enters the structure from above through the slatted floor or slots cast into solid portions of the tank top, and is usually removed from the tank by pumping or by gravity flow.

2. Hazard Description

   These structures may contain toxic concentrations of hydrogen sulfide gas, particularly when wastes are being agitated and moved. Additionally, there is danger of asphyxiation by oxygen displacing gases as well as the risk of methane explosion. Risk of injury from falls and drowning risks may also exist.

3. Recommendations

   a. Practice Limitation

      Skid loaders or similar equipment cannot be operated in these tanks in accordance with published safety standards. All published safety procedures require testing for gases, ventilation, use of respirators, and some sort of retrieval method for a person entering the storage area. Standard ASAE EP470 applies to human entry into under-floor storages, underground covered storages or pumping stations, and above/below ground tanks (concrete, steel, etc.) without covers. The standard states:

      > "*Do not enter an under-floor (underground) covered storage or pumping station without using the proper respirator equipment. In addition, these safety practices are needed: (a) Shut off any manure pumps, (b) ventilate storage or pumping station at the maximum rate, (c) test the storage or station air for O_2 level and toxic gas levels, (d) attach a safety harness and rope to the working person with at least one person standing by to help with a mechanical retrieval device, and (e) have on hand an extra set of proper respirator equipment for the person standing by.*"

      While items a, b, c, and e can be accomplished, it is not possible to use a mechanical retrieval device for a person overcome with manure gases while operating a skid loader or similar equipment in these tanks.

   b. Practice Alternatives

      Larger reception tanks can include a pump that is used to transfer sand-laden manure to long-term storage. The reception tank can be designed to allow implementation of all of the ASAE EP470 safety procedures if human entry into

the reception tank is needed. Smaller, narrower transfer channels (typically 2 to 4 feet wide, 4 to 6 feet deep) can be designed with a removable top to transfer sand-laden manure to a larger reception tank located outside of the building. The smaller transfer channel can be cleaned from above by removing the top, such that human entry into the channel is not needed. Alternately, the channel could incorporate a mechanical cleaner to move sand without the need for human entry. There are three commercial products available to accomplish this:

1) a "sand boat" system that uses a mechanical cable driven system to transfer manure from a 3' x 3' channel to a reception tank;

2) an auger system, which uses horizontal augers to transfer manure from small in-barn channels to a reception tank, and

3) a pre-cast concrete "U-channel" with a removable top that transfers manure to a pre-cast reception tank outside of the building.

Non-mechanical systems can also incorporate a "chaser" of flush water to prevent sand accumulation.

c. Safety Features

All the practice alternatives listed above are designed to limit or eliminate the need for human entry into manure transfer areas. If entry into the reception tank portion of the system is ever required, all of the ASAE EP470 recommended safety measures can be implemented.

d. Safety Plans

Safety plans for the identified practice alternatives will need to be site specific. Entry into the reception tank portion of each system must be in accordance with ASAE EP470 recommended safety procedures.

4. Implementation Strategy for Recommendations:

a. Modification to Conservation Practice Standards

The NRCS Conservation Practice Standards 634 - Manure Transfer, and 313 - Waste Storage Facility should be revised immediately to require that all waste storage facilities, reception tanks, pump chambers, and manholes be configured such that ASAE EP470 standards can be followed. Specifically, this emergency revision should prohibit drive-in, covered storage tanks, and transfer channels that cannot reasonably be expected to be operated and maintained in accordance with ASAE EP470 procedures. Additional safety criteria should be incorporated in the standards as part of the routine revision process described in Section III, General Recommendations.

b. Information and Education

General informational materials are discussed in Section III. Specific to this practice, operators with existing drive-in, covered storage tanks, and transfer channels should be educated on the hazards associated with them and encouraged

to abandon or retrofit these systems consistent with identified practice alternatives.

B. Open Manure Storage Pits and Tanks

1. Practice Description

   An embankment structure, excavated pit, dugout or fabricated structure that is used to contain manure, milking center waste and other organic waste generated by a livestock facility prior to land application or treatment. The manure surface of an "open" storage is exposed to the elements and is not under a building, nor does it have a lid, cover, slats, or other enclosing structures preventing open circulation and air exchange. The sides may be vertical or sloped.

2. Hazard Description

   The primary gas safety hazards are from hydrogen sulfide and ammonia exposure. Open manure storage is generally not as hazardous as covered storage or other manure facilities in buildings. However, during times when the manure is being agitated or when air movement is limited, gas levels may become dangerous within and near the storage.

3. Recommendations

   a. Practice Limitation

      None required based on hazardous gas.

   b. Practice Alternatives

      None warranted based on hazardous gas.

   c. Safety Features

      Provide fencing, warning signs and other means to exclude unauthorized or accidental entry. This is already required under NRCS standards and by local ordinances in some cases.

   d. Safety Plans

      The safety plan should include warnings to avoid agitation when air movement is limited and that entry should be minimized and only occur when natural ventilation is assured.

4. Implementation Strategy for Recommendations

   a. Information and Education

      A general information and education strategy focused on farmers and farm workers, on the fundamentals of manure gas safety, as described in Section III.

   b. Technical Standards Revision

      None specific to this category.

C. Reception Tanks, Pump Chambers, and Manholes

1. Practice Description

   A vessel in which manure, milking center waste, feed storage leachate, or other organic waste is collected or stored for short periods of time before removal or transfer to storage or treatment. The vessel is usually of a size and capacity to accommodate a single or several waste collection cycles, and may be emptied as frequently as several times daily or as long as weekly.

2. Hazard Description

   These structures may contain toxic concentrations of hydrogen sulfide gas, particularly when wastes are being agitated and moved. Additionally, there is danger of asphyxiation by oxygen displacing gases, ammonia exposure, risk of methane explosion, and non-gas related risks of falling, drowning, and moving mechanical parts.

3. Recommendations

   a. Practice Limitation

      It is difficult to limit the use of these structures. However, the need for human entry can be minimized and safeguarded.

   b. Practice Alternatives

      Design features that preclude the need for human entry for maintenance including removable pumps and “dry” pump chambers should be considered.

   c. Safety Features

      The following safety features should be incorporated into future installations of this practice:

      - signs warning of the dangers and prescribing the entry procedures;
      - covers, grates, fencing or railings to prevent unauthorized and accidental entry; and
      - mechanical ventilation, tripod or other attachment for a winching out a disabled worker.

   d. Safety Plans

      A site-specific safety plan should be developed for human entry. Plans should comply with ASAE EP470 recommended safety procedures and may include the following:

      - monitoring,
      - ventilation,
      - rescue procedures,
      - SCBA (Self Contained Breathing Apparatus), and
      - lock-out/tag-out procedures.

4. Implementation Strategy for Recommendations

    a. Modification to Conservation Practice Standards

        The NRCS Conservation Practice Standards 634 - Manure Transfer, and 313 - Waste Storage Facility should be revised immediately to require that all waste storage facilities, reception tanks, pump chambers, and manholes be configured such that ASAE EP470 standards can be followed. Additional safety criteria should be incorporated in the standards as part of the routine revision process described in Section III, General Recommendations.

    b. Information and Education

        A general Information and Education strategy focused on farmers, farm workers and service providers, on the fundamentals of manure gas safety, as described in Section III.

D. Manure Processing Rooms and Buildings

1. Practice Description

    Enclosed structures or portions of structures designed to provide protection from precipitation and freezing for manure processing, handling and storage equipment such as manure solids separators, sand separators, methane powered electrical generators, manure treatment equipment, manure reception and loading areas.

2. Hazard Description

    The primary gas safety hazards are from high levels of ammonia causing respiratory injury, from methane explosion, and from hydrogen sulfide exposure. Asphyxiation from engine exhaust from generator sets or handling machinery may also exist in buildings containing this equipment or adjacent buildings. Heat exposure and high decibel sound may also be safety hazards. Secondary hazards are associated with the corrosion of building components from hydrogen sulfide exposure, particularly electrical equipment, creating the risk of electrical shock or spark ignition of methane. These structures are usually not “confined areas” and may be intended for routine human occupancy.

3. Recommendations

    a. Practice Limitations

        Future applications of this practice should avoid locating processing rooms in multiple-use buildings, particularly those for frequent human occupancy. Potentially hazardous activities should be located in separate, isolated buildings.

    b. Practice Alternatives

        None

c. Safety Features

Ensure adequate ventilation to maintain safe conditions and a safe and practical temperature. In most cases, power ventilation will be required. Consideration should be given to equipping the building or room to ventilate at a base rate as well as a higher air exchange rate to evacuate the building or room before and during occupancy. In-place gas monitoring should be considered. Warning signs should be posted at entries.

d. Safety Plans

A site-specific safety plan shall be developed that may include the following:

- warning signs stating entry procedures;
- emergency response plans;
- monitoring protocols;
- hearing protection; and
- equipment maintenance and inspection.

4. Implementation Strategy for Recommendations

a. Information and Education

A general information and education strategy focused on farmers, farm workers, building contractors, and facility planners/designers, on the fundamentals of manure gas safety, as described in Section III.

b. Technical Standards Revision

NRCS Conservation Practice Standards 634 - Manure Transfer, and 313 - Waste Storage Facility are expected to undergo revision beginning in January 2009. As part of the revision of the Manure Transfer Standard, the considerations portion should be revised to recommend the safety features and plans cited above.

Appendix A

Manure Management System
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Manure Storage Safety

American Society of
Agricultural and Biological Engineers

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Manure Storage Safety

Developed by the ASAE Swine Housing Committee; approved by the Structures and Environment Division Standards Committee; adopted by ASAE January 1992; reaffirmed December 1996, December 1997, reaffirmed for one year February 2003; reaffirmation extended one year by SE-03 February 2004; reaffirmed February 2005.

1 Purpose and scope

1.1 The purpose of this Engineering Practice is to set forth existing known practices on manure storages that help (1) minimize the hazards of manure gases to livestock and humans, and (2) minimize the potential for drownings at manure storage sites.

1.2 This Engineering Practice does not include the design loads or structural specifications for manure storages (see ASAE Engineering Practice EP393, Manure Storage).

1.3 This Engineering Practice contains information on safety equipment, management suggestions on safety, and the manure gases hydrogen sulfide, methane, ammonia, and carbon dioxide. Also given is a listing of the maximum safe gas concentrations, related standards and practices, and pertinent references.

2 Background

2.1 Liquid or semi-solid manure that is handled or set in motion by pumping, mixing, spreading, or cleaning-out can release large amounts of gases. The quantity released depends on the animal species, temperature, fluidity of the manure, pH, length of storage time, and type of handling system. The gases of concern are hydrogen sulfide, H_2S, carbon dioxide, CO_2, methane, CH_4, and ammonia, NH_3. (See Section 8—Technical Information on Manure Gases, for more information on these gases.)

2.2 Manure gases have been fatal to both livestock and humans. Humans have died when they entered a manure storage without a supplied air respirator or a self-contained breathing apparatus. Animals and humans have died when liquid manure stored under slotted floors was agitated and gases were released. Animal performance in partial and total slotted floor enclosed buildings is impaired when pit gas concentrations exceed recommended limits.

3 Potentially lethal situations

3.1 Fatalities that occur when agitating manure are generally caused by compounding the toxic effect of H_2S with the asphyxiating effect of oxygen, O_2, depletion by other gases. (See Section 8—Technical Information on Manure Gases, for toxic levels.)

3.2 Methane explosions can result from concentrations of the gas within flammable limits. These concentrations can occur during agitation or when the gas is trapped in an improperly ventilated space over extended periods of time.

3.3 When ventilation equipment fails, the concentrations of manure gases and animal respiration air increase due to the lack of fresh air dilution.

3.4 Drownings of humans or animals can occur in aboveground tanks, below-ground tanks, or earthen storages. Livestock deaths have occurred due to structural failure of floorings or covers over storages or due to open gates.

3.5 Protective barriers or railings around openings can prevent accidents. Push-off platforms or ramps (piers) can be a site where the tractor scraper driver can tumble into an open storage. These should be protected with a sturdy railing or semicircular metal support embedded in concrete (i.e., hook).

3.6 Thick crusts on dairy and beef storage basins can appear solid, but may break under the weight of humans, animals, or equipment. Swine manure usually has a very thin crust if any.

4 Controlling manure gases with ventilation

4.1 Properly designed and operated ventilation systems help prevent accidents by removing or diluting levels of toxic gases in confinement units.

4.2 Exhausting air from below slotted floors, especially when agitating the manure, decreases concentrations of manure gases at animal level. However, the concentration still may be excessive for humans and animals. Two methods of gas removal are (1) isolated nonducted pit fans, and (2) pit fans connected to perforated plastic pipes or plenums under the slotted floors or under elevated pens (pig decks). Fans connected to correctly sized perforated ducts or plenums have more exhaust points and generally reduce the undesirable gas level more than isolated fans, especially at low airflow rates. As with the area fan, the duct or plenum needs to be at least 0.3 m (1 ft) above the manure level for reducing pit gas levels. Spacing of perforated ducts or plenums should not exceed 4 m (13 ft) in order to be effective.

4.3 The design of the air inlet system of a building has a significant effect on airflow patterns within the building and on pit gas concentrations. The airflow patterns should ensure that gases generated by the manure are moved away from the animals. (This airflow pattern may not always be the best design for keeping partially slatted pens clean in the case of swine.) Dilution and removal of gases is as important as controlling building temperature and humidity.

4.4 Isolated pit fans and pit ventilation should be installed at separate sites from the manure removal locations such as pump-outs and clean-out extensions. It is vital that ventilation continue at maximum rates during pit agitation.

4.5 Sealed manure pits or capped pits within structures should be ventilated with an exhaust fan and air inlet(s) to provide for pit gas escape.

4.6 In mechanically ventilated buildings, a warning device should be installed to inform the farmer if there is a ventilation system failure. Brief power outages may be common in some areas. Stand-by generators are a good investment for confinement facilities (see ASAE Engineering Practice EP270, Design of Ventilation Systems for Poultry and Livestock Shelters).

5 Special design and construction safety considerations for new manure storage facilities

5.1 The following considerations should be incorporated in the design and construction of liquid manure systems for a new or remodeled building:

5.1.1 Manure slurry will tend to separate into solid and liquid fractions in storage. Agitation is needed to resuspend the solids and to aid in completely emptying a storage. Provisions such as pump-out ports, agitation pump drop-in access locations in the pit sidewall or pit lid or access for trailer-mounted pumps for earthen storages are needed. Without adequate agitation during unloading, solids will build up and result in reduced storage capacity and higher levels of gas production.

5.1.2 All manure pump-out openings should be located outside enclosed buildings in order to reduce the danger of working in a confined area

when unloading or agitating a storage. The number of manure access points and/or agitation points needed varies with pit size, under-slat style of storage, animal species, and ration. Vacuum tank pump out holes should be 6 m (20 ft) on center on both sides of enclosed total slotted floor deep pit building and on one side of an enclosed partially slotted floor deep pit building. Agitation holes for vertical shaft pumps can be spaced up to 20 m (65 ft) on center (depends on building width). An exception to keeping pump-out openings outside is buildings which are naturally ventilated and three sided or very open. Individual or gang slats are generally removed to drop in the vertical shaft liquid manure pump for agitation and manure removal. Divider walls in pits may be needed to keep ventilation air separate in multiple room buildings. This can affect the agitation hole and pump out hole spacings.

5.1.3 Tank openings should be guarded with grills and/or covers to prevent humans, animals, equipment, and other objects from accidentally falling into the storage structure. Removable covers and grills should be provided on openings for agitation and pumping equipment. Removable covers and grills should be designed to prevent their accidental loss into the tank and their unintentional removal. They should be designed for simple removal and replacement to encourage their use.

5.1.4 Ladders should not be installed on the outside of aboveground tanks unless they are terminated above the reach of an innocent bystander. A safety decal indicating to not leave ladders or climbing equipment near or around the structure should be located next to the ladder. The ladder cage and/or platform should conform to ASAE Standard S412, Ladders, Cages, Walkways and Stairs.

5.1.5 Railings are needed on open manure storages that are below or partially below ground. Storages that are open and above ground would not need a railing. All push-off platforms or piers for open, below-ground manure storage structures need a barrier strong enough to stop a slow-moving tractor or skid loader. Hinged grates, solid covers, or the equivalent are needed for all scrape-in openings to prevent the inadvertent entry of animals and people.

5.1.6 Open storages should be fenced in unless they are aboveground tanks. Warning signs should be posted (see paragraph 7.5).

5.1.7 When the manure storage is outside and pipe-connected to a building, a water seal, gas trap, or other device should be provided to prevent gases in the storage structure from entering the building, especially during agitation. A clean-out access external to the facility should be incorporated to allow unclogging of a drain pipe or storage filling pipe.

5.1.8 Buildings above manure pits should be ventilated at or above the minimum or cold weather ventilation rates given in ASAE Engineering Practice EP270, Design of Ventilation Systems for Poultry and Livestock Shelters. A heater may be needed in cold weather so minimum recommended ventilation levels can be achieved without lowering the building temperature below critical levels.

5.1.9 Typical holding tanks, which hold a week's supply of manure, should have 2 holes in their lids. One is needed for the pump or pump access (submersible), and one for a 0.6 m (2 ft) diameter corrosion-resistant exhaust fan. The holes should be on opposite ends of the tank. The fan should be wired to operate at full speed only. A manual on/off switch should be within 2 m (6 ft) of the fan. The fan is needed for emergency situations when human access to the tank is needed (see Section 7—Safety Equipment, Warning Signs, Management Suggestions).

5.1.10 Electrical equipment should conform to American National Standard ANSI/NFPA 70, National Electrical Code. An electrical shut-off should be installed outside the building (see ANSI/NFPA Standard 70).

6 Safety signs and operator's manual

6.1 The user of the manure storage shall be provided with the appropriate safety information. The information in Section 7—Safety Equipment, Warning Signs, Management Suggestions, should be used as a basis for safety instructions to be included in the operator's manual and on signs. These should be provided when the manure storage is constructed.

7 Safety equipment, warning signs, management suggestions

7.1 Hazard control and accident prevention are dependent upon the awareness, concern, and prudence of personnel involved in the operation, maintenance and use of equipment, and facilities. These safe practice messages are recognized as being effective for enhancing safety, but may not cover all possible hazardous situations; hence, they should be interpreted judiciously and not necessarily reproduced verbatim. These safety practices should be followed if the tank or pit has *ever* been used, regardless of how long ago.

7.2 Rescue equipment such as harnesses, ropes, respirators, and block and tackle should be located near the manure storage area. The location should be clearly marked. Gas detection equipment such as detector tubes and/or instruments designed to detect combustible gases and hydrogen sulfide should be available and located in a warm, dry area. Detector tubes and sensors in gas detection instruments have expiration dates. Checks should be made periodically to be sure that the equipment is operational and properly calibrated and has not been removed. The phone numbers of the local fire department/rescue squad should be posted in a box mounted on a pole near an outside storage or on a wall in an inside storage building. These numbers should be posted near all the telephones on the farm.

7.3 After agitating manure storages under buildings and before entering, NH_3, CH_4, and H_2S levels in the building should be monitored. Animals should be observed through windows for strange behavior. These gases should also be monitored in small collection pits or manure transfer pits and in aboveground storages before going down into these pits or storages with appropriate safety equipment.

7.4 If it is absolutely necessary to enter a transport tank, a below-ground storage, or a pit, then specialized safety equipment such as a supplied air respirator, which supplies grade D breathing air, or a self-contained breathing apparatus must be used by those who are trained and familiar with the use of this equipment. Persons who are not familiar with the equipment and proper maintenance should not purchase or borrow air supplied breathing apparatus for use in potentially life threatening environments. In rural areas, the local fire department, sheriff's office, or rescue unit should be contacted and requested to come to the site. In many cases where people are overcome by pit gases or lack of oxygen two or more people have died. It is not possible to "hold your breath" and rescue someone. Procedures in the National Institute for Occupational Safety and Health (NIOSH) publication, No. 80-106, Working in Confined Spaces, should be followed.

7.5 Warning sign contents—safe management suggestions. Another important piece of safety equipment, in addition to the safety sign in paragraph 5.1.6, is a warning sign dealing with the management of the storage. The management suggestions that pertain to the manure storage should be listed prominently on at least one corrosion resistant sign. These suggestions could be condensed and referenced to an operator's manual. ASAE Standard S441, Safety Signs, should be followed. Special hazardous considerations which should be addressed through appropriate safety signs for various types of storages include but are not limited to the following (wordage only suggested):

7.5.1 Under-floor storages. Sign(s) should be located on the outside of the building wall and near the entry door.

7.5.1.1 After agitation of manure in under-floor storage, the atmosphere in the storage and in the building space above the storage may contain hazardous gases, explosive air mixtures and/or insufficient oxygen for animals and humans.

7.5.1.2 Always maintain at least 0.3 m (1 ft) freeboard between the manure surface and bottom of the flooring in under-floor storages to minimize pit gas concentrations at floor level for animals. This same freeboard is necessary before commencing agitation to ensure that pit

gases can be removed by pit fans. If pit ducts and plenums are used, they should be inspected for dust accumulation every year and cleaned if needed. Ducts and plenums can be cleaned with pressure washers or with chimney sweep brushes. Leaving a small diameter cable or wire in small rigid PVC pipe type ducts allows pulling brushes through them. Holes should be placed in the bottom of the ducts instead of at 9 and 3 o'clock positions to make cleaning easier and to reduce dust build-up. Pit fans should have their guards removed permanently on the side toward the pit because they will quickly clog with dust and reduce the fan's capacity.

7.5.1.3 Provide maximum ventilation during pumping and agitation. Keep all pit ventilation in operation during manure removal and for at least 12 h afterward (ideally 3 to 4 days). If the pit is pumped out in winter, use the maximum ventilation rate as long as possible, since the highest hydrogen sulfide levels occur shortly after start-up of agitation pumps. The building interior should be off-limits to people, and if possible, animals should be evacuated.

7.5.1.4 Do not try to rescue an animal if it falls over during pit agitation. Turn off the pump and ventilate the building until gases have had a chance to escape and be diluted. Test the building atmosphere for toxic gas levels before entering (H_2S is most critical toxic gas).

7.5.1.5 Do not enter an under-floor covered storage or pumping station without using the proper respirator equipment. In addition these safety practices are needed: (a) Shut off any manure pumps, (b) ventilate storage or pumping station at the maximum rate, (c) test the storage or station air for O_2 level and toxic gas levels, (d) attach a safety harness and rope to the working person with at least one person standing by to help with a mechanical retrieval device, and (e) have on hand an extra set of proper respirator equipment for the person standing by.

7.5.1.6 Don't smoke, weld, or use an open flame in confined, poorly ventilated areas where CH_4 can accumulate. Maintain electric motors and wiring in good condition near manure storages. Use watertight and dust-tight electrical fixtures (see ANSI/NFPA Standard 70, National Electrical Code). A sign should be posted to say "Danger No Smoking" during agitating and for 3 to 4 days after.

7.5.1.7 Keep all safety guards and shields in place on pumps, pump hoppers, tank wagons, power units, etc. Do not allow children or irresponsible people near any operating equipment. Do not enter tank wagons. Use caution when changing spout direction on agitation pumps in order to prevent falls.

7.5.1.8 Consult with your physician if you have been exposed to H_2S or NH_3 in concentrations severe enough to cause irritation to the respiratory tract (as indicated by difficulty in breathing).

7.5.2 Underground covered storages or pumping stations. Locate sign(s) near agitation hole(s).

7.5.2.1 Make sure hazardous gases are not being pulled back into a livestock building when agitation is occurring (see also paragraph 5.1.7).

7.5.2.2 Do not enter underground covered storage or pumping station without using the proper respirator equipment. In addition these safety practices are needed: (a) Shut off any pumps, (b) ventilate the storage or pumping station at the maximum rate, (c) test the storage or station air for O_2 level and toxic gas levels, (d) attach a safety harness and cable to the working person with one person standing by to help with a mechanical retrieval device, and (e) have an extra set of proper respirator equipment on hand for the person standing by.

7.5.2.3 Keep all safety guards and shields in place on pumps, pump hoppers, tank wagons, power units, etc. Do not allow children or irresponsible people near any operating equipment. Do not enter tank wagons. Use caution when working on the agitation pump spout to change its direction in order to prevent falls.

7.5.2.4 Consult with your physician if you have been exposed to H_2S or NH_3 in concentrations severe enough to cause irritation to the respiratory tract (as indicated by difficulty in breathing).

7.5.3 Earthen storages. Sign(s) should be located on the fence near entry gate.

7.5.3.1 Post warning sign(s) that say "Danger Manure Storage" or "Danger Keep Out," or "Danger Keep Away."

7.5.3.2 Dairy and beef manure may crust over and even have growing vegetation in bottom loaded storages, but the surface will not support the weight of humans, animals or equipment.

7.5.3.3 Keep all guards and safety shields in place on pumps, pump hoppers, tank wagons, power units, etc. Do not allow children or irresponsible people near any operating equipment. Do not enter tank wagons. Use caution when working on the agitation pump spout to change its direction in order to prevent falls.

7.5.4 Above/below-ground tanks (concrete, steel, etc.) without covers. Sign(s) should be located at eye level on tank surface near agitation location.

7.5.4.1 Post warning sign(s) that say "Danger Manure Storage" or "Danger Keep Out," or "Danger Keep Away."

7.5.4.2 Keep all safety guards and shields in place on pumps, pump hoppers, tank wagons, power units, etc. Do not allow children or irresponsible people near any operating equipment. Do not enter tank wagons. Use caution when working on the agitation pump spout to change its direction in order to prevent falls.

7.5.4.3 Consult with your physician if you have been exposed to H_2S or NH_3 in concentrations severe enough to cause irritation to the respiratory tract (as indicated by difficulty in breathing).

7.5.4.4 Do not enter the storage before (a) testing the pit air for toxic gas levels, (b) using the proper respirator equipment, and (c) attaching a safety harness and rope to the working person with at least one person standing by to help if needed.

8 Technical information on manure gases

8.1 Hydrogen sulfide (2), (10), (11)

8.1.1 Hydrogen sulfide, the most dangerous of manure gases, is colorless and smells like rotten eggs, although at low concentrations this odor is easily masked by other building odors. It is heavier than air (specific gravity relative to air=1.190 at 20 °C [68 °F], and 760 mm Hg) and soluble in water at basic pH's. It is produced from the anaerobic decomposition of organic materials. Hydrogen sulfide is normally released from all stored manure, but it is most dangerous with agitated liquid manure. The release is generally very slow in undisturbed manure and at low temperatures. Concentrations reaching 280–420 mg/m^3 (200–300 ppm) have been reported within a few minutes after the start of manure agitation and have been as high as 1400 mg/m^3 (1000 ppm) during vigorous agitation. In addition to times of agitation, H_2S is also released from liquid which is recycled back from lagoons and reduced solids level storages for flushing. The solids levels can be reduced by gravity separation in settling tanks or mechanical separators. Excessive levels of 220 mg/m^3 (160 ppm) have been measured in pig buildings even with mechanical separators and when recharging from a separated liquids storage pond (not lagoon). Unless fresh water is added lagoons can turn into storage ponds when drought conditions occur.

8.1.2 H_2S's characteristic odor does not give adequate warning because it paralyzes the olfactory system. Thus the sense of smell is rapidly diminished, and high concentrations do not give a perceived proportionally greater odor. The effects on humans of various concentrations are given in Table 1.

8.1.3 Pigs are made uncomfortable (stressed) by prolonged exposure to low levels of H_2S. Pigs exposed continuously to at least 28 mg/m^3 (20 ppm) develop fear of light, loss of appetite, and nervousness. Continuous exposure to 70–340 mg/m^3 (50–240 ppm) causes vomiting, nausea, and diarrhea. In acute poisoning, H_2S acts so rapidly that there are few symptoms of imminent danger. Sudden nausea and unconsciousness are followed by death at concentrations of 1120 mg/m^3 (800 ppm) or above.

Table 1 – Hydrogen sulfide effects at various concentrations (4), (10)

Concentration mg/m^3	(H_2S) ppm	Effect on humans
0.007	0.005	Barely detectable
5.6	4	Easily detectable, moderate odor
14	10	Eye irritation
38	27	Unpleasant odor
140	100	Coughing, eye irritation, loss of smell after 2–15 min exposure
280–420	200–300	Eye inflammation and respiratory tract irritation after 1 h
700–980	500–700	Loss of consciousness and possible death in 30–60 min
1120–1400	800–1000	Rapid unconsciousness, cessation of respiration and death
1400	1000	Diaphragm paralysis on first breath, rapid asphyxiation

8.2 Methane (2), (7), (10), (11)

8.2.1 Methane is colorless, odorless, and lighter than air (specific gravity relative to air=0.554 at 20 °C [68 °F] and 760 mm Hg). It is slightly soluble in water. Methane is generated from the anaerobic decomposition of manure. All manure storages release CH_4, but the rate of production varies with temperature. Although temperatures of approximately 35 °C (95 °F) are considered ideal for CH_4 production from manure, a small amount of CH_4 is produced from manure at lower temperatures found in under-floor manure storages. Explosive concentrations of methane may be released during liquid manure agitation and remain for several weeks after emptying the storages. Air mixtures containing from 33,000 – 99,000 mg/m^3 (50,000–150,000 ppm or 5–15%) CH_4 are explosive. Methane is not toxic and is unlikely to adversely affect animal and human health and performance in normally ventilated buildings. Methane is an asphyxiant and can cause suffocation by displacement of oxygen from the lungs. Replacing oxygen should revive a victim.

8.3 Ammonia (2), (3), (4), (6), (10), (11)

8.3.1 Ammonia is colorless with a characteristic pungent odor. It is lighter than air (specific gravity relative to air=0.596 at 20 °C [68 °F] and 760 mm Hg) and highly soluble in water. Ammonia concentrations are higher in warm buildings than cold buildings. Enclosed buildings with scrapers or with bedded packs can have NH_3 levels as high as those found in shallow and deep pit buildings. The minimum perceptible level of NH_3 for people is variable, ranging from 0.36 to 39 mg/m^3 (0.5 to 54 ppm).

8.3.2 At high concentrations ammonia can cause ulceration of the eyes and severe irritation to the respiratory tract. Ammonia irritates the eyes at about 36 mg/m^3 (50 ppm) and the respiratory tract is affected at about 72 mg/m^3 (100 ppm). Since NH_3 is very irritating at levels of 72 mg/m^3 (100 ppm) a person would leave unless trapped before encountering the harmful levels of 720 – 1080 mg/m^3 (1000–1500 ppm).

8.3.3 Ammonia tends to produce discomfort in animals. Excessive quantities 36 mg/m^3 (50 ppm) for prolonged periods predispose swine, poultry layers, broilers, and turkeys to respiratory diseases with the added risk of secondary infections. With baby chickens, the symptoms usually become apparent by the fifth week of age. The symptoms include watery eyes, closed eyelids, rubbing of eyes on the wing, decreased growth rate, poor feed conversion, huddling together of affected birds. Levels up to 54 mg/m^3 (75 ppm) will not usually retard growth but will induce an unhealthy appearance. Hen comfort needed for high egg production becomes affected when NH_3 exceeds 14 mg/m^3 (20 ppm). Layers exposed to 72 mg/m^3 (100 ppm) will not lay as well as those unexposed. Removal of NH_3 did not permit egg production to return to normal. At 72 – 144 mg/m^3 (100–200 ppm), NH_3 induces sneezing, salivation, and loss of appetite in swine. Measured levels have ranged from 0 – 77 mg/m^3 (0–110 ppm) in poultry and swine buildings.

Table 2 – Maximum safe gas concentrations for an 8-H exposure for humans (3)

Gas	TLV-TWA* mg/m^3	TLV-TWA* ppm
Carbon dioxide, CO_2	9000	5000
Ammonia, NH_3	18	25
Hydrogen Sulfide H_2S	14	10
Methane, CH_4	655	1000

*TLV-TWA stands for Threshold Limit Value (Time Weighted Average). The values listed are for 25 °C (77 °F). The concentration of these gases is temperature dependent.

8.4 Carbon dioxide (2), (10), (11)

8.4.1 Carbon dioxide is a colorless, odorless gas heavier than air (specific gravity relative to air=1.529 at 20 °C [68 °F] and 760 mm Hg) and soluble in water. The normal atmosphere contains about 540 mg/m^3 (300 ppm) of CO_2. Within an animal housing facility, more CO_2 is released through respiration of the animals than by manure decomposition. Typical concentrations of CO_2 in well-ventilated buildings are in the 900 – 9000 mg/m^3 (500–5000 ppm) range for livestock, depending on season of the year. Levels for people in an office building run about 1260 mg/m^3 (700 ppm) or less for good air quality.

8.4.2 Carbon dioxide is not highly toxic to humans or animals. Its main danger is that of contributing to an oxygen deficiency which can result in asphyxiation or suffocation. It also slows growth in animals because it inhibits their appetite. Air containing 72,000 mg/m^3 (40,000 ppm) causes deeper and faster breathing. More than 180,000 mg/m^3 (100,000 ppm) may produce dizziness and unconsciousness. Death will occur after a few hours at concentrations of 450,000 mg/m^3 (250,000 ppm) or more.

8.5 Maximum safe gas concentrations (9), (12)

8.5.1 Animals in confinement are exposed to their environments continuously, whereas, people can get relief from hazardous or irritating situations. For this reason, it is important that careful consideration be given to the quality of the environment within the animal zone or the level just above the floor. The only standards governing permissible levels in confinement buildings are those providing safe environments for workers (see Table 2). The maximum safe gas concentrations for an 8 h workday and 40 h workweek exposure for humans, established by the American Conference of Government Industrial Hygienists, are called threshold limit values, TLV. The values are expressed in milligrams per cubic meter, mg/m^3, or parts per million, ppm. Safe gas levels for animals have not been established. However, several researchers have reasoned that animal responses are similar to those of humans. The allowable levels should vary with animal weight and time exposure.

8.5.2 The establishment of maximum safe concentrations of gases is complicated by the fact that animal environments also include dust. Dust particles carry harmful bacteria and viruses which the animals and people can inhale into their respiratory systems. Higher levels of dust, which often occur in cold weather when ventilation rates are minimal, can compound the effect of these gases, especially NH_3, on animals and people. (12)

Cited Standards:

ANSI/NFPA 70, National Electrical Code
ASAE EP270, Design of Ventilation Systems for Poultry and Livestock Shelters
ASAE EP393, Manure Storages
ASAE S412, Ladders, Cages, Walkways, and Stairs

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