

REDUCING RISK OF ENTRY INTO CONFINED SPACE MANURE STORAGE

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INTRODUCTION

This project developed computational fluid dynamics protocols to simulate removal of noxious contaminant gases, by forced ventilation, from solid and slotted floor covered confined space, on-farm manure storage tanks. These simulation protocols were then used to determine ventilation requirements (air exchange rates, fan and air outlet locations, and operation times) to reduce concentrations of contaminant gases to levels below gas specific TLVs for human entry. These ventilation requirements are applicable for a wide range of manure storage facilities typical of those on farms throughout the U.S. Subsequently, an international engineering safety standard, *Ventilating Manure Storages to Reduce Entry Risk*, was written and approved by the American Society of Agricultural and Biological Engineers (ASABE) and the American National Standards Institute (ANSI). Finally, an educational program was developed to inform extension educators, engineers, regulators, and farmers about the standard and how to use its provisions to reduce risk when entering confined space manure storage tanks. The educational program included: (1) A large scale trailer mounted demonstration model which can be used to identify the occupational hazards associated with entry into confined space manure tanks and facilities and explain how to mitigate the hazards with proper ventilation; (2) High quality videos of educational programs, using the demonstration model, to show how to properly ventilate solid and slotted covered confined-space manure storages; (3) Comprehensive instructional manuals for “education extenders” to use the ventilation demonstration unit in the field; (4) Four Fact Sheets covering Confined Space Manure Storage Hazards, Monitoring Manure Gases, Ventilating Storages Prior to Entry, and Emergency Rescue Procedures for Confined Space Manure Storages; and (5) A website, www.manurepitsafety.psu.edu, which contains the safety standard, educational videos, and fact sheets.

THE RESEARCH PROJECT

The project team conducted research work that spanned nearly eight years. This work has been published in a series of five journal articles (Pesce, et al., 2008 ; Zhao, et al., 2007a; Zhao, et al., 2007b ; Zhao, et al., 2008a; Zhao, et al. 2008b).

In experimental studies hydrogen sulfide (H₂S) was used as an indicator gas to investigate the effectiveness of forced-ventilation strategies for eliminating the toxic and oxygen-deficient atmospheres in the confined-space manure pits. Typical H₂S concentration reduction curves during forced-air ventilation were identified in a rectangular manure tank. Based on the experimental tests conducted in the research, the most promising candidate ventilation strategies were identified for the studied rectangular confined-space manure tank with solid, totally slotted and partially slotted

covers. In addition, based on results of experimental tests, a field-based database was developed for the validation of computational fluid dynamics modeling protocols (Pesce et al., 2008). As an important input parameter of the CFD modeling protocols, manure gas emissions were measured experimentally using the same rectangular tank. The influencing factors on gas emissions were identified as well (Zhao et al., 2007a).

Computational fluid dynamics (CFD) modeling protocols to simulate H₂S removal from fan-ventilated confined-space manure storages were developed and validated. The CFD model was used to conduct the simulations of evacuating H₂S during forced ventilation for the best ventilation strategies identified in the work by Pesce et al. (2008) for a typical rectangular on-farm manure tank with three cover types (i.e., solid, totally slotted, and partially slotted) and the validation of the CFD modeling protocols based on comparisons between simulated and measured H₂S evacuation times. Simulated and measured evacuation times within the confined-space manure storage facilities evaluated agreed within 10% at all measuring locations except those immediately adjacent to the ventilation fan jet for all three cover types for both high (5 AC min⁻¹) and low (3 AC min⁻¹) air exchange (AC) rates. Corresponding evacuation times agreed to within 15% for all cover types and air exchange rates in the high-velocity gradient region of the ventilation fan jet. These results demonstrated that the CFD modeling protocols developed satisfactorily predict the gas concentration decay during forced ventilation in confined-space manure pits (Zhao et al., 2007b, 2007c). The validated CFD modeling protocols were applied to conduct simulations for identifying manure gas evacuation times and oxygen level recovery in the confined-space manure pits with different footprints. The factors (i.e., air exchange rate, manure gas emission rates, gas initial concentration) influencing the gas evacuation time were identified (Zhao et al., 2008a, 2008b).

An extensive literature review was conducted to identify the highest concentration levels and emission rates documented for NH₃, H₂S, CH₄, and CO₂ during typical manure operations. The highest documented concentration levels of NH₃, H₂S, CH₄, and CO₂ are, respectively, 270 ppm, 10,000 ppm, 700,000 ppm, and 450,000 ppm. For emission rates, the highest emission rates of NH₃, H₂S, CH₄, and CO₂ identified from the literature review were 0.71, 0.48, 2.35, and 7.25 mg s⁻¹ m², respectively (Zhao et al., 2008b). Additionally, a study on the mechanism of manure gas based on the literature review shows the time taken to evacuate H₂S and CO₂ from associated high concentration levels to the safe exposure limits is longer than the time for evacuating NH₃ and CH₄ from their associated high concentration levels to safe levels. As a result, the mixture of H₂S and CO₂ may be used to represent the manure gases mixture in simulations to identify maximum evacuation times for mechanically ventilated confined-space manure pits.

CFD simulations were conducted for the manure pits with the geometries and sizes representing a majority portion of the confined-space, on-farm manure pits in the US and Canada based on an informal survey of USDA-NRCS (Natural Resource Conservation Service) waste management engineers. The simulation results show gas evacuation times or oxygen replenishment times for a wide range of manure pit

geometries, contaminant gases, and initial conditions (i.e., gas initial concentration). The simulation results also generated profiles of pit zones in which contaminant gas or oxygen concentrations are below OSHA-defined safe levels after several intervals of ventilation.

Several conclusions have been drawn from this research:

- A non-linear relationship was identified between gas initial concentration and evacuation time.
- Non-significant difference of evacuation time was identified when the inter-contamination ratio was higher than 0.40.
- The ventilation time required to replenish oxygen from 0 % to 20.5 %, by volume, was almost (difference < 5%) the same time for confined space manure pits initially filled with either H₂S, CH₄, or CO₂.
- The time to evacuate H₂S from 10,000 ppm to OSHA PEL (10 ppm) and CH₄ from 700,000 ppm (70 % by volume) to TLV (1000 ppm) was nearly the same (difference < 5 %).
- There was no significant difference (<5%) of evacuation times for the confined airspace filled with a single gas or with a gas mixture.
- Ventilation time required to remove H₂S from maximum initial levels to PEL (10 ppm) was greater than or equal to time to remove other gases from maximum initial levels to their respective PELs or TLVs.
- Ventilation time required to replenish O₂ to ≥20 % by volume is less than time required to evacuate H₂S from 10,000 to 10 ppm.

The results of these simulations were used to formulate the ventilation protocols and specifications defined in the consensus engineering safety standard, ANSI/ASABE S607 “Ventilating Manure Storages to Reduce Entry Risk”.

SAFETY STANDARD DEVELOPMENT

The first engineering standard to address specific ventilation strategies, including fan location, outlet location, air exchange rates, and ventilation times required to reduce contaminant gases in confined space manure storages to below ACGIH defined TLVs for hydrogen sulfide, carbon dioxide, and methane, and to replenish oxygen levels from 0% to 20 % by volume at sea level has been developed (ASABE, 2010). The standards development project followed the protocols outlined by the American National Standards Institute (ANSI) and was managed by the Standards Department of the American Society of Agricultural and Biological Engineers (ASABE), an ANSI certified standards provider. ASABE assured that all appropriate standards writing and approval protocols were followed for a consensus ANSI standard. In brief the protocols were:

- An ASABE standards development committee, which had wide representation including, designers, researchers, users, and regulators, was formed.
- The committee developed a draft standard for comment and balloting.
- The draft standard was approved by the committee only after at least 50% of the committee responded, at least 75% of the responders voted to approve the draft

standard, and all comments from approval and disapproval ballots were addressed to the satisfaction of the critics and the entire committee.

- Once committee approval was received, the ASABE Standards Committee confirmed that all ANSI consensus standard development protocols were followed and forwarded to ANSI for approval.
- ANSI reviewed and approved S607 as a consensus engineering standard.
- ANSI/ASABE S607, Ventilating Manure Storages to Reduce Entry Risk was published by ASABE in October, 2010.

SAFETY EDUCATION PROGRAM DEVELOPMENT

The research team has developed an outreach educational program, the overall aims of which are to demonstrate the hazards associated with entry into confined-space manure storages and to demonstrate how proper ventilation mitigates the hazards. The education program includes fact sheets, workbooks, educational videos and a safety demonstration model on mitigating hazards associated with manure pit entry events. The education program is flexible and can be tailored to various audiences including farmers, regulators, builders, or designers (Tillapaugh, et al., 2010a, 2010b, 2010c).

The educational program is based on several goals which are aimed at reducing risks when entering confined-space manure storages. Specific educational program goals include:

- Explaining hazards and risks associated with confined-space manure storages, and ways to eliminate or minimize those hazards and risks.
- Providing instructions for purchasing, using and maintaining gas measurement equipment.
- Presenting ventilation design details and requirements for existing and planned facilities.
- Teaching proper procedures for planned entry and responding to emergency situations.

There are several target audiences for the educational program. These include:

- Engineers/Designers/Builders/Inspectors - Presentations for this group are focused on understanding and using calculations and recommendations for forced air ventilation systems described in ANSI/ASABE Standard S607 (Ventilating Manure Storages to Reduce Entry Risk).
- Farmers/Operators/Users/Insurance - Presentations for this group are focused on understanding, identifying and minimizing hazards; employee/worker training; understanding and using gas detection equipment; planned entry procedures; and responding to emergency situations.
- Educators - An Instructor Guidebook has been developed for cooperative extension and other educators to teach confined-space manure storage hazards and safety practices to farmers, employees, family members, manure haulers, insurance personnel and other such groups. The Instructor Guidebook includes all information developed for the other target groups.

- Emergency Services - Presentations for this group focus on procedures for safely responding to emergencies involving manure storages.

Several educational tools are used to target audience these groups and cover the wide range of topics necessary for reducing risk when entering confined-space manure storages. A portable scale model demonstration unit representative of a confined-space manure facility has been constructed. Agricultural and Biological Engineering extension publications have been created and serve as reference materials for targeted audiences. A workshop has been developed and presented to teach engineers and building planners how to design ventilation systems for manure pits to reduce entry risk. Program presentations utilize the scale model demonstration unit, a PowerPoint slide deck, printed reference materials and web-based video presentations.

Scale Model Demonstrations. The scale model demonstration has been designed to illustrate and reinforce toxic gas hazards and proper ventilation of confined-space manure storages. An Instructor's Manual guides demonstrators through set up and tear down of the demonstrations, contains demonstration scripts, and contains the educational fact sheets and other handouts (Tillapaugh et al., 2011) The unit is built inside a seven foot tall by fourteen foot long enclosed trailer. Spectators watch the demonstrations through a four foot tall by twelve foot long hinged door in the side of the trailer. A PowerPoint slide presentation is used to help communicate important points. The scale model manure storage inside the trailer is constructed with a removable animal housing structure. With the barn removed, plastic floor panels can be exchanged to simulate storages with slotted or solid covers. Ventilation fans are installed at desired locations in the manure storage as well as in the barn structure (Figure 1).

Figure 1. Photograph of scale model demonstration unit



During presentations, the manure storage is flooded with carbon dioxide and fog to simulate and visualize accumulated toxic manure gases. Gas concentration measurements are displayed on large LED displays for the audience. A mannequin is

used to show the consequences of entering the manure facility without proper ventilation. Appropriate ventilation techniques are demonstrated. During ventilation demonstrations, audience members see gas concentrations decrease on the LED displays as the toxic gases are evacuated by forced ventilation. Simulations of manure pit ventilation are shown on a 46 inch LED television screen to help audience members visualize air flows and hazard reduction. These animations were created with SolidWorks Flow Simulation software and use color scales to show changing gas concentrations. A detailed set of instructions, complete with demonstration videos on CDs, for multiple demonstrations using the scale model have been developed.

Extension Publications. In an effort to organize educational program subject matter, extension publications for the targeted audiences have been developed. These extension publications are:

- *Confined-space Manure Storage Hazard.* This publication (Steel et al., 2011a) targets any person seeking general manure storage safety information. Topics covered include manure storages and confined-spaces, monitoring gas levels, positive pressure ventilation systems, regulatory issues, and planned entry into confined-space manure storage.
- *Confined-Space Manure Gas Monitoring.* This publication (Steel et al., 2011b) targets those seeking information for selecting, using, maintaining, and calibrating manure gas detecting and testing equipment. This includes the benefits of gas measurements for calculating required ventilation times, and personnel safety. Comparisons of detector tube equipment, electronic sensors and multiple gas detectors are also given.
- *Confined-Space Manure Storage Ventilation System Design.* This publication (Manbeck et al., 2011) targets designers, contractors, and inspectors. Details are based on the ANSI/ASABE S607 standard and address techniques to calculate ventilation requirements based on storage dimensions and selection of appropriate fans. These ventilation calculations are valid for designing ventilation in both existing and planned storages, as well as portable and permanently installed systems.
- *Confined-space Manure Storage Emergencies.* This publication (Hill et al., 2011) targets farmers, employees, family members, manure haulers, and emergency response personnel. The importance of using confined-space entry best safety practices to rescue victims in manure pits is explained.

Video Presentations. Two professional level video presentations of the confined-space manure storage ventilation demonstrations, with voice-over narration and graphics, have been developed. One video presentation addresses solid covered storages and is 24 minutes (Steel et al., 2011c). The other video covers slotted floor storages and has three parts: a) high initial gas concentration in the storage; low initial gas concentration in the storage; and c) low level of contaminant gas in the ducted ventilation air supply (Steel et al., 2011d). This video is 27 minutes long.

Website. A dedicated website (www.manurepitsafety.psu.edu) has been developed (Murphy et al., 2011). The website contains all of the educational information including

the video presentations, the ANSI/ASABE S607 standard, the extension publications, and links to other relevant websites. The website features an automated pre and post survey that allows us to measure impact, whenever a person visits each of the fact sheet and video sites. This allows us to understand who may be using the site, the value they assign to our educational products, and suggestions for improvement.

FUTURE WORK

Evaluation of the education program is on-going. We are in the process of conducting a baseline survey of a sample of dairy and swine farmers in several states to assess their current knowledge of manure storage hazards, current safety practices, and the ability to mitigate the hazards with properly designed and installed ventilation systems. A follow-up survey 3 to 5 years from now is anticipated to assess the effectiveness of the developed educational program to induce farmers to adopt the manure pit ventilation interventions developed in this research and development project.

A currently funded project is titled *On-Line Tools for Designing Ventilation Systems to Reduce Manure Pit Entry Risk*. This 5-yr project began September 1, 2011 and has as a goal the development of an on-line, web-based, computer-aided-design tool to simulate the performance of ventilation systems for removing noxious gases and to replenish oxygen prior to entry. We will validate the design tool against previously published field and simulation results. The developed on-line tool will be alpha- and beta-tested by two nationwide pools of practicing agricultural facilities planners prior to launching it on the web. A training program to teach planners how to properly use the developed design tool will be developed and delivered in webinar, on-line university and live workshop formats. A small sample of practicing facilities planners will evaluate the training session. The training program will subsequently be revised based on the critiques prior to launching the training sessions on the web. Finally, we will write and submit proposed revisions to the current consensus safety standard (ANSI/ASABE S607), *Ventilating Manure Storages to Reduce Entry Risk*, to include the developed on-line tool for specifying ventilation requirements for on-farm, confined-space manure storage tanks.

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