The central goal of this demonstration project was to collect on-farm observations during routine manure storage agitation operations and provide practical information to practitioners relative to potentially dangerous manure gas emissions, especially hydrogen sulfide. Of particular concern were farms managed with gypsum bedding. A promising manure additive was evaluated for ability to reduce hydrogen sulfide release. Personal-safety gas monitors were featured. Target audiences included dairy and livestock producers, professional manure applicators, and agricultural support industries. The project successfully completed all four primary deliverables:

1. A written document with recommendations on how project findings may be incorporated into NRCS technical guidelines.
2. Training of NRCS engineers in safety, air quality instrument use, and environmental issues associated with open-air manure storages.
3. A non-technical brochure for delivery to farmers as NRCS personnel work with them on issues associated with gypsum bedding use and manure handling.
4. Events to attend included two webinars and on-farm field day with technical findings suitable for producers and professionals.

In addition, several newspaper stories and trade press articles featured project findings and recommended solutions to improve worker safety around manure storage agitation events. Project findings were also shared at agricultural venues, professional and technical meetings via presentations, papers, and posters.
Manure gas risks associated with gypsum bedding at dairy farms: On-farm demonstration

Chapter 1 Executive Summary

Recycled gypsum products can provide a cost-effective bedding alternative that is popular among many dairy producers. Manufacturers report reduced odors, moisture and bacteria in the stall environment when compared to traditional bedding and farmers point to agronomic benefit of the gypsum bedding in the manure. Agitation of stored manure promotes release of volatile gases that typically contain ammonia, methane, hydrogen sulfide (H\textsubscript{2}S) and various odorants. Prior to the start of this project, incidents anecdotally linked injury and death of people and cattle to dangerous levels of H\textsubscript{2}S emission released from movement of manure containing gypsum-based bedding. Gypsum (CaSO\textsubscript{4}·2H\textsubscript{2}O) provides a sulfate source that can be converted to hydrogen sulfide under anaerobic manure storage conditions. In order to investigate and potentially mitigate elevated H\textsubscript{2}S release at farms using gypsum bedding, a manure amendment compound was identified that reduced H\textsubscript{2}S release at manure agitation. Of interest to customers of this project, low-cost personal gas monitors were demonstrated for improving safety around hazardous gas environments. Customers included dairy producers, manure haulers, agricultural service professionals, design engineers, safety personnel, product suppliers, and educators.

The primary project goal was accomplished: To measure manure gas risks associated with gypsum bedding at dairy farms using appropriate technologies and disseminating such findings in user-friendly materials to the agricultural community.

The method employed was a “full-scale on-farm demonstration” to determine efficacy of a manure amendment in reducing hydrogen sulfide risk. Observations at ten dairy farms from three management categories were compared: those that used (1) traditional, organic bedding; (2) gypsum-based bedding, and (3) gypsum-based bedding amended with a commercial product added to the manure. Portable gas meters placed around the perimeter of each dairy manure storage recorded H\textsubscript{2}S concentrations every minute prior to and during nineteen agitation events during fall and spring hauling seasons. Each farm operator wore a personal safety gas monitor to record their exposure to the heavier-than-air H\textsubscript{2}S gas. A detailed farm characterization documented manure characteristics and storage design parameters, manure handling practices and manure storage inputs.

Physical results from measurement events show that manure storage agitation at farms using gypsum in bedding were capable of producing H\textsubscript{2}S concentrations that were considered immediately dangerous to life and health (above 100 ppm). Increasing gypsum use significantly increased cumulative H\textsubscript{2}S concentrations. But not all gypsum
farms experienced hazardous conditions at all times. Farms that used the manure amendment reported to reduce H$_2$S concentrations, showed reduced H$_2$S concentrations compared to gypsum farms not using any amendment. Unfortunately, this effect was not statistically significant. However, this promising trend and effectiveness of other additive compounds offers promise for a simple amendment-based solution.

No farm practice, manure characteristic, or environmental condition consistently and significantly affected H$_2$S production and release from storage. However, empirical observations indicated lowered H$_2$S concentrations near storages during agitation when manure had been recently agitated or transferred from temporary pits before placement in long-term storage. Wind directing manure gas into areas where emissions may be trapped by proximate structures increased H$_2$S concentrations near the storage presumably due to reduced dilution with ambient air inhibiting dissipation. Notably a storage containing gypsum bedding and no surface crust, showed low hydrogen sulfide release during agitation.

Operator safety is enhanced by managing manure agitation activity above grade. Hydrogen sulfide concentrations were notably lower inside a tractor cab. Operators who adjusted manure agitation equipment at grade or within the perimeter of the manure storage were exposed to harmful H$_2$S gas during our observations. There remains downwind risk for elevated H$_2$S gas even 33 feet away from manure storage agitation sites.

Primary project findings:

- Gypsum bedding adds sulfur to manure that can lead to dangerous levels of hydrogen sulfide gas emission at agitation; but not all farms using gypsum had safety problems.
- Manure storage agitation creates greatest gas levels during the first hour of agitation.
- Crust-free manure and additives that inhibit crust formation seem to allow for continuous low level H$_2$S release lowering risk at agitation.
- Gypsum benefits for cow bedding and agronomic values must be balanced against the potential gas hazard.

Recommendations include:

1. Position operators above ground-level and away from edge of manure storage during agitation of manure storage that contains gypsum bedding.
2. Save lives by requiring operators working around manure storages with gypsum bedding to wear a hydrogen sulfide personal gas monitor.
3. Keep non-essential people (and cattle) away during agitation, especially children who are at increased risk, as H$_2$S concentration is greatest close to the ground.
4. Do not use gypsum bedding with under-barn manure storage. Potential is high for release of dangerous level of H$_2$S during any manure movement under such conditions.
Chapter 2 Introduction

Overview: Recent lethal and near-lethal exposures of humans and dairy cattle to unidentified conditions during open-air manure storage agitation prompted investigation. One seemingly-innocent common factor was gypsum bedding being used for good purpose in the barn for animal comfort and economic benefit. Yet could this be the culprit, based on anecdotal and preliminary laboratory findings? An on-farm project documented conditions that operators and nearby surroundings were exposed to during manure storage agitation in relation to safe air quality conditions. Theory suggests that increased sulfur content in manure, such as from gypsum bedding, promotes elevated \( \text{H}_2\text{S} \) gas emission concentrations. However, no scientifically-defensible evidence has linked gypsum bedding use with dangerous levels of \( \text{H}_2\text{S} \).

Project primary objective: *To measure manure gas risks associated with gypsum bedding at dairy farms using appropriate technologies and disseminating such findings in user-friendly materials to the agricultural community.*

This project was a collaboration among those who could help diagnose and offer practical solutions to the agricultural community. Partners included the family farms (ten dairies), material suppliers (USA Gypsum), safety equipment manufacturer (Industrial Scientific), manure storage design agricultural engineers (NRCS) and academic professionals (Penn State Extension safety and air quality).

**Primary Project Personnel at Penn State:**
Eileen Fabian (Wheeler)
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**Collaborators with significant roles:**
Terry Weaver, USA Gypsum
Mike Platek, Industrial Scientific
Farm owners: ten family-owned dairies
NRCS Engineers

Project **funding** was provided by USDA NRCS CIG. In-kind contributions were provided by Penn State Extension with cash match from USA Gypsum, Industrial Scientific and PA State Conservation Commission (via PA Department of Agriculture).
Chapter 3 Background

3.1 Hydrogen Sulfide

Benefit to the agricultural industry is immediate and distinct when risk to dangerous conditions is reduced, particularly when those risks are invisible and often otherwise undetectable. In 1990, the agricultural industry had a death rate of 52 per 100,000 workers per year, more than five times the combined rate for all other industries in the United States (Purschwitz and Field, 1990). Injuries due to agricultural machinery, vehicles and animals constitute the majority of this statistic. Exposure to dangerous invisible levels of manure gases including hydrogen sulfide (H$_2$S), ammonia (NH$_3$), methane (CH$_4$), and carbon dioxide (CO$_2$) are rare but yield an extremely high mortality rate (Hallam, et al., 2012). Though manure gas is not the leading cause of injuries and fatalities, eliminating preventable accidents clearly benefits the industry.

Hydrogen sulfide is considered to be the most dangerous emission in manure gases because it is toxic and can cause serious injury or death during short-term exposures at high concentrations (>500 ppm). Routine day-to-day exposure at low concentrations (<10 ppm) (Costigan, 2003) can also cause injury. Because H$_2$S is heavier than air, it has the potential to displace fresh air in low lying areas causing an oxygen deficient environment where workers may be exposed. Exposure is especially dangerous in confined spaces. Despite the ‘rotten egg’ smell of this colorless gas, this warning sign disappears within a few minutes of exposure as olfactory senses are fatigued, thereby facilitating further exposure to unknowing victims above 100 ppm.

Conditions that promote H$_2$S production are a sulfur source and a population of bacteria in an oxygen deficient environment. Because there is little or no oxygen, the bacteria utilize the energy from the organic matter and reduce sulfate, which generates H$_2$S gas. These conditions commonly occur in dairy manure storage lagoons. When a manure storage crust is present, H$_2$S is trapped within the manure beneath a relatively impermeable crust layer. When the manure is agitated and the crust layer containment broken-up, high levels of various gases can be released into the environment, potentially creating a hazard for humans and/or livestock unfortunate enough to encounter the gas plume.
3.2 Gypsum bedding

Hydrogen Sulfide emissions have been implicated in incidents of human and animal death and injuries on dairy farms in Pennsylvania, New York and Maryland. Penn State Extension personnel have recorded elevated levels of H$_2$S at the sites of some of these tragedies. Anecdotally, some of these cases have been linked to farms that use gypsum as a bedding material. With removal of manure from the barn floor one to three times each day, bedding that spills from cow beds (including any added gypsum product) is carried with the manure from the barn floor into the manure storage. Gypsum (calcium sulfate - CaSO$_4$·2H$_2$O) provides a sulfur source that potentially increases H$_2$S production from manure storage facilities.

Many farms that use gypsum bedding have never experienced problematic H$_2$S emissions. Moreover, farms that have reported episodes of injury do not experience elevated H$_2$S during every agitation event. Surprisingly, open-air dairy manure storages have shown problems with dangerous gas levels whereas in the past the fresh air surroundings seemed to have dampened impact of manure gas release.

Notably, there are many benefits favoring the use of gypsum bedding. Gypsum bedding amendments originate from recycled wastes generated during gypsum board (drywall) manufacturing and related construction. This diverts a landfill waste stream. Because it is highly absorbent, keeping the animals dry, is non-abrasive and discourages bacterial growth, gypsum is considered to be an excellent alternative bedding material (Drumnakilly, 2015; USA Gypsum, 2015). Richard Webster Nutrition (2013) asserts that gypsum bedding lowers nitrogen loss from the manure storage and retains it for use by crops when land applied. Additionally, as a recycled product in abundant supply year round is a valuable bedding and contributes to agronomic improvements at land application (USA Gypsum, 2015).

Prior to project initiation, scientific investigation had not proven gypsum use as bedding is directly linked to elevated H$_2$S emissions during manure mixing or transport. Other factors such as sulfur source from water or feed may contribute to elevated sulfur availability. Preliminary bench scale studies conducted at Penn State found higher H$_2$S concentrations during agitation from gypsum-amended manure, versus manure without gypsum, following several weeks in undisturbed storage. However, these initial trials performed as preliminary experiments suggested the need for further more detailed work at farm-scale, with scientifically defensible findings. Among the preliminary findings was a manure amendment that reduced the burst of H$_2$S release at manure agitation. Accordingly, the USDA-NRCS in collaboration with private sector contributors and Penn State University launched a farm-scale project incorporating ten farms to demonstrate use and affordability of this manure amendment to reduce H$_2$S emissions. This project
demonstrated the practicality of personal safety instrumentation to inform and protect farm workers during agitation of manure storages.

In summary, the goals of this demonstration project were to:

1. Explore the impact of a promising manure additive to reduce potential for unhealthy bursts of hydrogen sulfide during manure agitation on farms using gypsum bedding.
2. Demonstrate personal H\(_2\)S gas monitors as air quality safety instruments, and
3. Disseminate such findings in user-friendly materials to agricultural producers, manure haulers, and NRCS professionals

### 3.3 Industry Concern

High levels of hydrogen sulfide (H\(_2\)S) gas in and around manure storage areas on dairy farms can present significant health risks to humans and livestock (Donham et al., 1982). Hydrogen sulfide is a hazardous, flammable, colorless gas known by its characteristic rotten egg odor. Human sensory detection is an unreliable indicator for presence of H\(_2\)S because prolonged exposure fatigues the sense of smell. Low concentration exposure can burn the respiratory tract and cause swelling around the eyes. At high concentrations, H\(_2\)S exposure inhibits respiration and can cause death according the Occupational Safety and Health Administration guidelines (OSHA, 2005). Physical effects for various H\(_2\)S exposure levels are summarized in Table 3-1.

**Table 3-1: Physical effects of exposure to various levels of H\(_2\)S (ANSI, 1972)**

<table>
<thead>
<tr>
<th>H(_2)S Concentration (ppm)</th>
<th>Physical Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13</td>
<td><em>Minimal perceptible odor</em></td>
</tr>
<tr>
<td>4.6</td>
<td>Easily detected, moderate odor</td>
</tr>
<tr>
<td>10</td>
<td>Beginning eye irritation</td>
</tr>
<tr>
<td>27</td>
<td>Strong, unpleasant odor, but not intolerable</td>
</tr>
<tr>
<td>100</td>
<td>Coughing, eye irritation, loss of sense of smell after 2 to 5 minutes</td>
</tr>
<tr>
<td>200-300</td>
<td>Marked conjunctivitis (eye inflammation) and respiratory tract irritation after one hour of exposure</td>
</tr>
<tr>
<td>500-700</td>
<td>Loss of consciousness, cessation (stopping or pausing) of respiration, and death</td>
</tr>
<tr>
<td>1,000-2,000</td>
<td>Unconsciousness at once, with early cessation of respiration and death in a few minutes. Death may occur even if individual is removed to fresh air at once</td>
</tr>
</tbody>
</table>

According the U. S. Department of Labor (1997), occupational H\(_2\)S exposure must not exceed 20 ppm unless no other measurable exposure has occurred during the 8-hour work
shift. Exposure may exceed 20 ppm, but not more than 50 ppm, for a single time period up to ten minutes. At 100 ppm, \( \text{H}_2\text{S} \) is considered an immediate danger to life and health.

Records of human deaths (Dai and Blanes-Vidal, 2013; Hooser et al., 2000) and animal deaths (Maebashi et al., 2011; Oesterhelweg and Püschel, 2008) have been attributed to dangerous levels of \( \text{H}_2\text{S} \) gas from manure storages. Multiple incidents involving deaths in manure storages in the mid-Atlantic region have been reported (Torres, 2012, Harrison, 2012). Penn State extension personnel have reported elevated levels of \( \text{H}_2\text{S} \) shortly after these incidents occurred. The elevated levels of \( \text{H}_2\text{S} \) were often linked to farms that use gypsum-based bedding. Penn State Extension personnel have recorded levels of \( \text{H}_2\text{S} \) gas during manure agitation ranging from <10 ppm to over 300 ppm. Concentrations >50 ppm were measured nearly an hour after agitation was initiated.

In 2012, the Natural Resources Conservation Service (NRCS) issued a news release warning farmers of the potential for dangerous levels of \( \text{H}_2\text{S} \) during agitation of their manure storage (NRCS, 2012). In the United Kingdom, \( \text{H}_2\text{S} \) concentrations > 2,700 ppm have been observed on farms using gypsum as a bedding material (RREC, 2013). Parts of the United Kingdom have considered restricting or banned gypsum use as animal bedding (SEPA, 2012; EA, 2012; RWN, 2013).

Research is very limited regarding \( \text{H}_2\text{S} \) production of dairy and cattle manure (Andriamanohiarisoamanana et al., 2015). Moreover, dangerous \( \text{H}_2\text{S} \) levels on dairy farms using gypsum bedding have not been reported in the scientific literature. Notably, the majority of work performed on manure \( \text{H}_2\text{S} \) production originates from the swine industry (such as in Blanes Vidal et al., 2009; Bicudo et al., 2002; Blunden and Aneja, 2008).

### 3.4 Hydrogen Sulfide Generation

Conditions that promote \( \text{H}_2\text{S} \) generation in manure include a population of sulfur reducing bacteria and sufficient sulfur (S) content in an anaerobic environment. Sulfate reducing bacterial include *desulfovibrio, desulfotomaculum, desulfovacter, desulfoococcus, desulfonema* and *desulfosarcina* (Atlas and Bartha, 1987). These anaerobes utilize the energy produced from the breakdown of organic matter and transfer electrons from the organic substrate to the most oxidizing electron acceptor in the environment to maximize the energy yield. Table 3-2 lists the oxidation-reduction potential hierarchy for common electron acceptors.
Table 3-2: Oxidation-reduction potential (ORP) ranges for microbial utilization of potential electron acceptors.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Oxidation-Reduction Potential (Volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen Respiration</td>
<td>O$_2$ $\rightarrow$ H$_2$O</td>
</tr>
<tr>
<td>Denitrification</td>
<td>NO$_3^-$ $\rightarrow$ N$_2$</td>
</tr>
<tr>
<td>Manganese Reduction</td>
<td>Mn$^{4+}$ $\rightarrow$ Mn$^{2+}$</td>
</tr>
<tr>
<td>Iron Reduction</td>
<td>Fe$^{3+}$ $\rightarrow$ Fe$^{2+}$</td>
</tr>
<tr>
<td>Sulfate Reduction</td>
<td>SO$_4^{2-}$ $\rightarrow$ H$_2$S</td>
</tr>
<tr>
<td>Methanogenesis</td>
<td>CO$_2$ $\rightarrow$ CH$_4$</td>
</tr>
</tbody>
</table>

When manure is stored in holding structures and accumulates over time, chemically reducing conditions are created in the deeper strata of the manure as the microbial population exhausts the higher yielding electron acceptors, including oxygen.

Typical sources of S in dairy manure come from diet nutrients such as dried distiller’s grains with solubles (DDGS), S from drinking water and concentrate-based feed. Gypsum (calcium sulfate, CaSO$_4 \cdot 2$H$_2$O) as part of bedding material, provides an extra source of S and therefore creates potential for additional H$_2$S production. Hydrogen sulfide is created naturally when bacteria utilize the energy available from the organic content of the manure and use sulfur compounds as the terminal electron acceptor as shown in Equation 3-1 (Arogo et al. 2000 and Castro et al., 2000). As carbon is oxidized, sulfate is reduced in an anaerobic environment. While bacteria population and sulfur content in an anaerobic environment promote potential H$_2$S generation, other biochemical, environmental and physical factors affect H$_2$S production.

**Organic Matter (C, H, O) + H$^+$ + SO$_4^{2-}$ $\rightarrow$ H$_2$S + CO$_2$ + H$_2$O**  
Equation 3-1

### 3.4.1 Biochemical Factors

Figure 3-1 shows H$_2$S is in equilibrium with bisulfide (HS$^-$) and sulfide (S$^{2-}$) based on pH (Snoeyink and Jenkins, 1980). Hydrogen sulfide dominates under acidic conditions (pH<5), while higher pH conditions (pH>8) promote dissociation of H$_2$S into HS$^-$ and S$^{2-}$ (Figure 3-1). Andriamanohiarisoamananana et al. (2015) found that H$_2$S concentrations in the reactor headspace above dairy manure almost tripled (increased 285%) when pH decreased from 7.32 to 6.83. Molecular H$_2$S is elevated at pH below 7 and H$_2$S gas concentration will increase in reactor headspace under such conditions (Blunden and

**Figure 3-1:** Fractions of sulfide species vs. pH at 25°C showing that increasing manure pH above 8 will reduce hydrogen sulfide formation (Snoeyink and Jenkins, 1980).

### 3.4.2 Environmental Factors

Ni et al. (2000) found that a decrease in temperature reduces sulfur reducing bacteria activity. Bicudo et al. (2002) confirmed a negative temperature correlation with ambient H$_2$S concentrations downwind of swine facilities, however, Bicudo’s et al. (2002) measurements for temperature and humidity are of the ambient air and not of the manure. Andriamanohiarisoamanana et al. (2015) measured a tenfold decrease in H$_2$S concentrations (3.500 ppm to 306 ppm) above dairy manure when temperature decreased from 23.9 to 9.8 °C. Further experimental results show an exponential increase in H$_2$S concentration as temperature increases from 8 to 26 °C as shown in Figure 3-2 (Andriamanohiarisoamanana et al. (2015). In addition to sulfur-reducing bacteria activity, the rate of transformation from aqueous H$_2$S to gaseous H$_2$S is slower when temperature is decreased (Ni et al., 2000 and Yongsiri et al., 2004). Zhu et al. (2002) found that 75% of the aerobic bacteria counts were destroyed in swine manure when the temperature rose 10 degrees (15 °C to 25 °C) and the oxidation reduction potential decreased 100 mV (+40mV to -60 mV). This implies that increased temperatures yield reducing environments and may produce more sulfide. However, Wang et al. (2014) concluded that temperature had no effect on H$_2$S emissions when investigating digested pig slurry.
A negative correlation was also observed between wind speed and H$_2$S concentration (Bicudo et al. 2002). Wind will dilute and dissipate H$_2$S concentrations, so even with elevated H$_2$S emissions, ambient H$_2$S concentrations above open manure storages may not persist in the presence of high wind speeds.

### 3.4.3 Physical Factors

Ni et al. (1999) observed release of H$_2$S concentrations in bursts, or highly concentrated pockets of H$_2$S gas from stored swine manure. Hydrogen sulfide is most likely generated in the deeper strata of the manure storage where there is little to no oxygen. Delayed emissions to the surface can be due to the time it takes for the gas to migrate to the surface and through a crust that forms on top of the storage creating a sealed top layer. Clanton et al. (2001) found that straw covering can reduce H$_2$S emissions from dairy manure storages. Bicudo et al. (2000) measured elevated H$_2$S concentrations above swine and dairy manure during agitation. Andriamanohiarisoamanana et al. (2015) found low H$_2$S concentrations emitted from dairy manure at low mixing speeds (<200 rpm), short mixing durations (<15 min) and frequent mixing events (>4 times per day). Scully et al. (2007) provides a review of studies investigating dairy and beef manure that found elevated H$_2$S concentrations at or above hazardous levels during agitation and mixing of manure.
Bicudo et al. (2002) documented significant differences in H\textsubscript{2}S emissions based on types of manure storage structures and production facilities for the swine industry. Facility management practices may also influence H\textsubscript{2}S emissions.

### 3.5 Need for Solution

The need for odor control and the prevalence of H\textsubscript{2}S in the swine industry have prompted discussion and research endeavors regarding H\textsubscript{2}S reduction from swine manure storages. Clanton et al. (2001) provides an overview of research conducted by various scientists on temporary covers made of various materials for manure storages to reduce odors, H\textsubscript{2}S and NH\textsubscript{3}. Though successful, manure storage covers are not typically practical during agitation of the manure unless extensive resources are invested in a permanent structure that would enable control of emissions from the manure surface.

As noted in Table 3-2, selected microbes are able to utilize alternative terminal electron acceptors in the absence of oxygen. The highest electron potential or energy yield available will be reduced. Xue and Chen (1999) reported that adding potassium permanganate and hydrogen peroxide both reduced H\textsubscript{2}S emissions by increasing the redox potential in the manure. The energy yield for reducing sulfate to H\textsubscript{2}S is much less than the energy yields for these oxidizers. Thus, the presence of electron acceptors having higher energy yield inhibit H\textsubscript{2}S emissions. Smith and Nicolai (2005) found that potassium permanganate and hydrogen peroxide oxidized H\textsubscript{2}S into its elemental sulfur form and reduced H\textsubscript{2}S emissions by over 90% for each category. The cost to treat a swine pit sized at 61m x 12m x 1.5 m (200ft x 40ft x 5ft) was approximately $2,000 to $5,000. Dairy manure storages can be significantly larger and the cost for these additives would not be practical in most cases.

Most farms using gypsum bedding have not reported deaths or injuries due to H\textsubscript{2}S exposure. Farms that have had reported safety incidents have not experienced problems every time the manure is agitated. However, anecdotal occurrences of multiple events in the northeast raise concern over health issues from H\textsubscript{2}S exposure potentially related to use of gypsum-containing bedding.

This review of the literature has not identified any scientific evidence that proves gypsum-based bedding is linked to excessive release of H\textsubscript{2}S gas from manure. A substantial set of observations is first required for analysis. Biochemistry supports the conditions for H\textsubscript{2}S production from gypsum mixed with manure. Dangerous levels of H\textsubscript{2}S emissions occur due to a variety of factors. Environmental conditions, biochemical characteristics and even management practices can promote H\textsubscript{2}S production. Yet, addition of products or thoughtful management practices can reduce H\textsubscript{2}S emission at
manure movement and agitation. Understanding the factors beyond the conditions that generate H₂S is crucial to identifying solutions that reduce or eliminate hazardous conditions. Developing evidence for commercial amendments that mitigate H₂S emission levels would provide solutions for those in the dairy industry that use gypsum bedding.

Chapter 4 Review of Methods with Quality Assurance

This demonstration comprised quality-assured field measurements of manure gas concentrations and manure physical and chemical properties as well as a characterization of each farm involved. The field measurements compared bedding categories via statistical comparisons to find conditions that promote accelerated H₂S production.

4.1 Field Measurements Collection

Farms in Pennsylvania were chosen in each of three categories to demonstrate the use of manure amendments to reduce the potential for H₂S release: [1] farms that use traditional bedding (non-gypsum); [2] farms that use gypsum as bedding or as part of the bedding material (gypsum), and [3] farms that use gypsum-based bedding along with a manure amendment to reduce H₂S emission levels (gypsum with amendment). Ten farms participated in the demonstration study. In total, 19 site visits were conducted for measurements during manure storage agitation. Protocol insisted that measurements be during the first agitation of the manure hauling and application season (spring or fall). Table 4-1 lists the farms, category and amendment used at participating farms. Each farm was characterized by their management practices. Any differences in farm characteristics or management were noted at each visit. Manure gas concentrations emitted during agitation of the storage were measured and manure was sampled and analyzed for physical and chemical properties. All storages were open-air, unroofed structures with most (9 of 10 farms) in-ground structures. The primary manure additive demonstrated as an amendment was Vital™ Breakdown (manufactured by Homestead Nutrition, New Holland, PA; information sheet included in Appendix A). Another amendment, OK-1000 (manufactured by Pro-soil Ag Solutions, Hawkins, TX) was used on one farm included in this demonstration (Appendix A).
Table 4-1: Participating farms and their gypsum category

<table>
<thead>
<tr>
<th>Farm ID</th>
<th>Location</th>
<th>Category</th>
<th>Manure Amendment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CY</td>
<td>Lititz</td>
<td>Gypsum with amendment</td>
<td>Breakdown</td>
</tr>
<tr>
<td>HR</td>
<td>Carlisle</td>
<td>Gypsum with amendment</td>
<td>OK 1000</td>
</tr>
<tr>
<td>BL</td>
<td>Danville</td>
<td>Gypsum with amendment</td>
<td>Breakdown</td>
</tr>
<tr>
<td>BR</td>
<td>Lititz</td>
<td>Gypsum with amendment</td>
<td>Breakdown</td>
</tr>
<tr>
<td>CP</td>
<td>New Bloomfield</td>
<td>Non-gypsum</td>
<td>none</td>
</tr>
<tr>
<td>SH</td>
<td>Newport</td>
<td>Non-gypsum</td>
<td>none</td>
</tr>
<tr>
<td>HT</td>
<td>Belleville</td>
<td>Non-gypsum</td>
<td>none</td>
</tr>
<tr>
<td>WR</td>
<td>Lykens</td>
<td>Gypsum</td>
<td>none</td>
</tr>
<tr>
<td>WE</td>
<td>Pine Grove</td>
<td>Gypsum</td>
<td>none</td>
</tr>
<tr>
<td>SR</td>
<td>Reinholds</td>
<td>Gypsum</td>
<td>none</td>
</tr>
</tbody>
</table>

4.1.1 Farm Characterization

The type of bedding for each farm was identified as being in one of the three categories (non-gypsum, gypsum and gypsum with amendment). The bedding material was further categorized based on how much gypsum was used on a per cow basis. Manure management practices were described in terms of the manure storage loading frequency (barn to storage). Storage design parameters were identified and all storage inputs were noted. Further characterization included the diet consumed by the herd. Information collected for each participating farm is included herewith as Appendix B. Table A-1 summarizes the manure storage and handling characteristics.

4.1.2 Manure Gas Concentrations

A total of nine gas monitors recorded conditions during farm site visits. Three portable multi-gas meters (MX6, Industrial Scientific, Pittsburgh PA; product information sheet is shown in Appendix C) were placed around the perimeter of the manure storage at approximately 1.2 m (4 ft.) above the top of the rim of the storage structure, when possible. When these locations were not accessible, meters were placed on tripods approximately 1.2 m (4 ft.) above ground level adjacent to the exterior wall of the structure. An example of meter placement is shown in Figure 4-1.
Figure 4-1: H$_2$S concentrations were measured during agitation events using portable meters placed around the manure storage.

Each meter was positioned prior to the start of agitation to datalog multiple gas concentrations, including: H$_2$S; CH$_4$; NH$_3$; carbon monoxide (CO); CO$_2$; O$_2$ and % lower explosive limit (LEL). Two gas meters (M40, Industrial Scientific) were placed approximately ten meters downwind from the edge of the storage structure on tripods, one measured gas (H$_2$S) concentrations 0.3 m (1 ft.) above the ground and the other 1.2 m (4 ft.) above the ground. One single gas meter (Tango, Industrial Scientific; product information sheet is shown in Appendix C) was worn on collar or belt by the agitation tractor operator for the duration of the event for safety. Three other Tango H$_2$S single gas meters were placed at selected locations around the perimeter of the manure storage to capture additional gas concentration data. All gas monitoring equipment recorded gas measurements on one minute intervals starting at least 30 minutes prior to agitation and continued throughout agitation for at least the first hour of mixing. Additionally, wind speed, wind direction, air temperature and humidity were recorded every minute during these events using a weather station (Kestrel Communicator model 4500, Nielsen-Kellerman, Birmingham, MI). The list of weather parameters recorded during each event and an example measurements set are provided herewith in Appendix D. Table A-2 summarizes the environmental conditions measured in the field for each agitation event.
4.1.3 Manure Analyses

Prior to the start of agitation, two manure samples were collected, one from just below the surface crust and one from the bottom of the storage (just above any accumulated solids on the storage bottom). Once maximum agitation was achieved, based on visual evaluation by equipment operator, another manure sample was collected from the middle of the storage to represented well-mixed manure. Each manure sample was collected using a 5-meter long, hollow core sampling tube equipped with a ball check valve on the end of the sampling tube. Each sample was analyzed for pH, temperature and oxidation-reduction potential (ORP). Sample ORP was measured immediately when brought to the surface using a field probe (Model SDL100, Extech Instruments, South Burlington VT). Samples were analyzed for physical and chemical properties at Penn State’s Agriculture Analytical Services Laboratory located in State College, PA. Manure characterization analysis parameters and example results are provided herewith in Appendix D. Table A-3 summarizes the manure analytical results collected at each farm.

4.2 Hydrogen Sulfide Concentrations Comparison

Gas concentrations measured at the perimeter of the storage were compared across bedding groups (non-gypsum, gypsum and gypsum with amendment). Concentrations were plotted over time from the start of agitation. The maximum gas measurement for each time stamp was chosen among the perimeter meters and plotted with time to eliminate variance related to changes in wind direction. Maximum \( \text{H}_2\text{S} \) concentrations were used to demonstrate worst case scenarios since these levels represent the greatest health and safety concerns. The area beneath these time versus concentration curves (cumulative \( \text{H}_2\text{S} \) concentration) was determined via integration over the first 60 minutes. The integration was performed numerically using the trapezoid rule and was calculated in Microsoft Excel™ according to Equation 4-1. The integration generated cumulative \( \text{H}_2\text{S} \) concentration over 60 minutes for each farm, which enabled comparison across categories.

\[
I_A = I_{A-1} + (T_A - T_{A-1}) \times (C_A + C_{A-1})/2
\]

Equation 4-1

Where:
- \( I_A \) = Integration representing cumulative \( \text{H}_2\text{S} \) concentration at time A
- \( I_{A-1} \) = Integration at time A-1
- \( T_A \) = Time at A
- \( T_{A-1} \) = Time at A-1
- \( C_A \) = Gas concentration at time A
- \( C_{A-1} \) = Gas concentration at time A-1
Chapter 5 Findings

Observations collected as a part of this project demonstrate elevated H$_2$S levels from farms that use gypsum bedding during manure agitation. Hydrogen sulfide concentrations were compared across farm categories.

5.1 Hydrogen sulfide

Figure 5-1 shows H$_2$S concentrations observed at the perimeter of manure storages for farms observed in all three categories. These figures present H$_2$S concentrations at identical scales to facilitate visual comparison. It is readily evident that farms using gypsum, with or without manure amendments, exhibited elevated H$_2$S concentrations and farms that did not use gypsum bedding were observed to have low (<20 ppm) H$_2$S concentrations. Notably, less than 1 ppm H$_2$S was observed prior to the start of manure agitation for all farms.

Observations confirm anecdotal reports of elevated hydrogen sulfide (H$_2$S) levels during manure agitation from farms that use gypsum bedding. Figure 5-2 summarizes the cumulative H$_2$S concentrations over 60 minutes during agitation plotted against amount of gypsum used for each cow per day, for all participating farms.
Figure 5-1: Maximum H$_2$S concentrations over the first 60 minutes of agitation for participating farms show elevated H$_2$S concentrations at farms that use gypsum bedding.
Figure 5-2: Cumulative H$_2$S concentration for first 60 minutes of agitation vs. gypsum use.

Gypsum and non-gypsum farms are represented by the diamonds. Gypsum and non-gypsum categories are grouped together because non-gypsum farms have a gypsum use of zero. The observations depicted by the squares represent farms that use Vital™ Breakdown (Homestead Nutrition), an amendment reported to reduce H$_2$S emissions. One of the farms observed, also identified in Figure 5-2 by the triangles, uses OK-1000 (Pro-soil Ag Solutions) as a manure additive.

A trend line, represented by the solid black line, was drawn through the observations associated with farms that use gypsum with no manure amendment and the observations represented by farms that do not use any gypsum (at 0 gypsum use). Note that one of the farms was agitated two weeks prior to our observation collection. It is hypothesized that H$_2$S gas escaped during the initial agitation that was not available for monitoring during collection date two weeks later. Thus, this observation (“prior agitation” in Figure 5-2) was not used as part of the trend line for the gypsum and non-gypsum observations. The octagon near the origin of axes encloses five observations superimposed on each other at this resolution. These five non-gypsum farms exhibited concentrations below 20 ppm over the duration of manure agitation and thus resulted in low cumulative H$_2$S cumulative concentrations. These observations show that lower gypsum use results in lower cumulative H$_2$S concentrations in the absence of amendments.
Each of the four squares surround two observations conducted at the same farm during one fall collection event and one spring collection event. Notably, H$_2$S concentrations recorded during different seasons were very similar for the same farm sites (Figure 5-2). Hence, seasonal variation did not appear to play a substantial role in H$_2$S generation or cumulative concentrations for these farms.

One exception is a farm where three observations were collected, these three observations are circled in Figure 5-2. The Bl farm changed their gypsum bedding use, which explains the offset in the two observations below 5,000 ppm in Figure 5-2. Additionally, as shown in Figure 5-3, the wind direction in fall 2014 differed substantially from fall 2013 and spring 2014. Two observations with <5,000 ppm cumulative H$_2$S were recorded during the fall 2013 and spring 2014 agitation events during prevailing wind direction ranging from 73 to 90 degrees (azimuth), out and away from the farmstead. The observation called out in Figure 5-2 by a photo showing the change in wind direction is plotted above 20,000 ppm recorded a wind direction ranging from 322 to 352 degrees from North during the fall 2014 agitation, which is directly into an adjacent heifer barn. This likely provided a barrier to H$_2$S dissipation by wind. Based on these observations, it appears that wind direction obstructed by nearby farm structures affect H$_2$S concentrations found near the storage during agitation. These observations suggest wind direction and physical obstructions can have a dramatic effect on H$_2$S build-up in nearby areas.

Figure 5-3: Changing range of wind directions at Bl farm impacted H$_2$S exposure via trapped gas emission near buildings from manure storage agitation. The solid arrows (pointing right) represent range of wind direction during both the fall 2013 and spring 2014 agitation events. The dashed arrows (pointing left) represent the wind directions during fall 2014 agitation event with high H$_2$S conditions.
Figure 5-4 shows trends for gypsum farms (non-gypsum) as well as farms that use manure amendment plotted against gypsum use. Farm categories were compared to distinguish if there were any significant effects among farms that do not use amendments and farms that use Vital™ Breakdown. It appears from Figure 5-4 that the farms using Vital™ Breakdown reduced cumulative H₂S concentrations. However, statistical analysis indicates that Vital™ Breakdown did not significantly (alpha = 0.05) reduce cumulative H₂S concentrations during 60 minutes of agitation. More observations may help confirm the significance among farms that use Vital™ Breakdown and those that do not in regards to cumulative H₂S concentrations. Because only one farm used OK-1000 as an amendment, the significance of this treatment could not be determined. It is notable that when both amendments were combined for analysis there is a significant reduction in cumulative H₂S concentration, suggesting that H₂S emissions may be decreased using manure amendments.

![Cumulative H₂S Concentration for First 60 Minutes of Agitation vs. Gypsum Use](image)

**Figure 5-4:** General linear model regression line through cumulative H₂S concentrations vs. gypsum use for all farms observed except for two farms that were outliers due to pre-agitation and wind direction.

Recall that two farm observations (Wr farm observed in spring 2014 and Bl farm observed in fall 2014) were excluded from the linear model findings in Figure 5-4. One farm had agitation prior to our field collection date. Because this was outside of the research protocol, and known to reduce subsequent emissions, this observation set was
excluded from the general linear model. Additionally, one of the farms that used gypsum with a manure amendment was not included in this analysis because it was found the wind direction shifted into the direction of closely adjacent structures causing limited dissipation of the H_2S plume resulting in elevated cumulative H_2S concentrations close to the storage.

5.2 Operator Exposure

Personal monitors provided a way to measure operator exposure to H_2S during the observed 60 minutes of agitation. Recall that H_2S exposure should not exceed 20 ppm during an 8-hour period (U.S. Department of Labor, 1997) although exposure may exceed 20 ppm, but not more than 50 ppm, for a single time period up to ten minutes (USDL 1997). Hydrogen sulfide is considered an immediate danger to life and health (IDLH) at 100 ppm.

Fifteen of the 19 observations showed exposure below 20 ppm as shown in Figure 5-5. Figure 5-6 shows four sets of observations that reach above 50 ppm of H_2S during agitation. Operators that were considered safe, therefore not exposed to over 20 ppm H_2S, controlled the agitator hydraulics from within the cab of the tractor elevated from ground level as shown in Figure 5-7.

![Operator exposure to H_2S concentrations below 20 ppm during agitation](image)

Figure 5-5: Fourteen (of nineteen) operators were able to manage manure agitation equipment in relative safety while exposed to less than 20 ppm H_2S during agitation.
Figure 5-6: Four operators were periodically exposed to over 50 ppm H$_2$S (above safe labor standards) during manure storage agitation, with some exposures above the IDLH level of 100 ppm.

Figure 5-7: Operator controlling agitator hydraulics from within an elevated, enclosed tractor cab had reduced exposure to hydrogen sulfide release.

Three of the four higher exposures (above 20 ppm H$_2$S) were associated with operators positioned over the rim of the storage as shown in Figure 5-8 and Figure 5-9. One operator who controlled the agitator hydraulics from within the tractor cab was exposed to over 20 ppm for a total of 12 minutes, much less than the other three operators in close proximity to the manure storage.
Figure 5-8: Operator manually positioning nozzle was exposed to high gas concentrations over rim of storage.

Figure 5-9: Operator inspecting drive chain was exposed to high gas concentrations over rim of storage.
Awareness limits exposure to H$_2$S even when a dangerous environment exists. Use of personal gas monitors is demonstrated to raise awareness of conditions that might not be immediately obvious during toxic gas exposure. It is evident from this study that use of gypsum bedding on a dairy farm can create a toxic environment near agitated manure. High-risk avoidance should be practiced when working in the vicinity of known danger.

5.3 Downwind Concentrations

A profile of high and low meters was positioned 10 m (33 ft.) downwind from the manure storage perimeter. “Downwind” direction was based on the prevailing wind direction recorded by the portable weather station (Kestrel®) during measurement collection events for each farm. The object was to quantify the exposure to H$_2$S proximate to the storage. Table 5-1 lists maximum H$_2$S exposure 10 m (33 ft.) away from the manure storage for each observation event. Recall that OSHA recommends that exposure not exceed 20 ppm. Note that none of the non-gypsum farms exhibited observations of H$_2$S concentrations above 5 ppm downwind of the manure storage. Eight of 14 farms that used gypsum (including the farms that use a manure amendment to reduce H$_2$S emissions) showed downwind conditions above 20 ppm H$_2$S.

Table 5-1: Maximum H$_2$S concentrations 10 meters (33 ft.) from manure storage.

<table>
<thead>
<tr>
<th>Category</th>
<th>Farm</th>
<th>Gypsum Use</th>
<th>Maximum Downwind Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(lbs cow$^{-1}$ day$^{-1}$)</td>
</tr>
<tr>
<td>Non-gypsum (NG)</td>
<td>Ht F13 NG</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Cp F13 NG</td>
<td>0.0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cp S14 NG</td>
<td>0.0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Ht S14 NG</td>
<td>0.0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Sh S14 NG</td>
<td>0.0</td>
<td>3</td>
</tr>
<tr>
<td>Gypsum (G)</td>
<td>Wr F13 G</td>
<td>5.1</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Wr S14 G</td>
<td>5.1</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>We S14 G</td>
<td>0.6</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>Sr S14 G</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>We F14 G</td>
<td>0.6</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Sr F14 G</td>
<td>0.3</td>
<td>42</td>
</tr>
<tr>
<td>Gypsum with treatment (GT)</td>
<td>Bl F13 GT</td>
<td>2.0</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Bl S14 GT</td>
<td>3.4</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Br S14 GT</td>
<td>0.4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Cy S14 GT</td>
<td>1.2</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Hr S14 GT</td>
<td>7.4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Hr F14 GT</td>
<td>7.4</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>Br F14 GT</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Bl F14 GT</td>
<td>3.4</td>
<td>1000</td>
</tr>
</tbody>
</table>

Notes: Codes for sampling seasons are F13 = fall 2013, S14 = spring 2014 and F14 = fall 2014. Codes for treatment groups are NG = non-gypsum, G = gypsum and GT = gypsum with treatment.
Six farms that use gypsum had maximum \( \text{H}_2\text{S} \) concentrations under 20 ppm 10 m downwind from the manure storage. Five of these can be explained by farm characteristics. Both the Sr and Br farms had relatively low gypsum use. The Sr farm had one elevated \( \text{H}_2\text{S} \) concentration of 42 ppm confirming anecdotal reports that some farms using gypsum bedding experience no problems with \( \text{H}_2\text{S} \) levels, but at other times encounter hazardous conditions. It seemed that frequent movement decreased \( \text{H}_2\text{S} \) emission risk at any one manure movement event. Manure at the Br farm is transferred through two sumps. Dairy barn manure is scraped into a pit at the end of the barn and from there is transferred weekly to another sump beneath the heifer barnyard before being pumped into the long-term concrete manure storage once every two weeks. It is thought that \( \text{H}_2\text{S} \) generated during transfer is lost to the atmosphere before reaching the long term concrete storage structure, thus reducing \( \text{H}_2\text{S} \) available for emission during storage agitation. Recall that the Wr storage had been agitated within two weeks prior to the agitation monitoring event during spring 2014 resulting in greatly reduced emission in subsequent agitation.

The Cy farm differs from other participating farms in that the manure storage is a metal structure 6.1 m (20 ft.) above grade, as shown in Figure 5-10. All the other farms used subgrade concrete structures or earthen storages. Hydrogen sulfide plumes may not have reached the gas monitors offset 10 m from storage at ground-level by the time \( \text{H}_2\text{S} \) escaped over the edge of the storage. Note though that \( \text{H}_2\text{S} \) at 10 m distant was measured at 11 ppm for the Cy farm during the spring 2014 agitation.

![Figure 5-10: Manure storage for Cy farm was 20 ft. above-grade steel structure.](image)

These results measuring \( \text{H}_2\text{S} \) 10 m (33 ft.) away from the manure storage provide additional support for concluding that gypsum promotes greater risk of \( \text{H}_2\text{S} \) exposure. Though these concentrations are not as dangerous as the levels measured right at the perimeter, it shows that exposure can still occur downwind from the storage. Animals, children and other workers downwind are susceptible to \( \text{H}_2\text{S} \) exposure even if they do not
have direct involvement with manure agitation tasks immediately adjacent to the manure storage.

5.4 Manure Handling Practices and Farm Characterization

Not all dairy farms that use gypsum products have safety incidents. Moreover, farms that do incur problems with elevated H\textsubscript{2}S concentrations do not have these issues every time the manure storage is agitated.

Figure 5-2 and Figure 5-4 show that increased gypsum use results in elevated H\textsubscript{2}S cumulative concentrations after 60 min of agitation. Table 5-2 shows other independent variables, or factors that were quantified or characterized during each field visit. These factors were investigated to see if these independent variables had any effect on cumulative H\textsubscript{2}S concentrations.

Table 5-2: Manure characteristics, environmental parameters, manure handling practices and sulfur sources that were analyzed for effect on H\textsubscript{2}S concentrations.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Manure surface temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure characteristics</td>
<td>Oxidation-reduction potential (ORP)</td>
</tr>
<tr>
<td></td>
<td>Manure temperature</td>
</tr>
<tr>
<td></td>
<td>pH</td>
</tr>
<tr>
<td>Environment parameters</td>
<td>Ambient temperature</td>
</tr>
<tr>
<td></td>
<td>Wind speed</td>
</tr>
<tr>
<td>Storage engineering</td>
<td>Storage volume</td>
</tr>
<tr>
<td></td>
<td>Storage design</td>
</tr>
<tr>
<td>Manure handling</td>
<td>Manure transfer technique</td>
</tr>
<tr>
<td></td>
<td>Thickness of solids on bottom of storage</td>
</tr>
<tr>
<td></td>
<td>% crust cover</td>
</tr>
<tr>
<td>Sulfur sources</td>
<td>Copper sulfate foot bath</td>
</tr>
<tr>
<td></td>
<td>DDGS grains in feed ration</td>
</tr>
</tbody>
</table>

None of the independent variables in Table 5-2 had a statistically significant effect on cumulative H\textsubscript{2}S concentrations during manure agitation. Surprisingly, no temperature effect on H\textsubscript{2}S cumulative concentration was found as this is a documented influence with greater temperature increasing H\textsubscript{2}S gas release under controlled conditions. But as typical of field demonstrations, manure surface temperatures during Fall 2013 were not significantly different than for spring 2014 and fall 2014. There was a wide variation of manure surface temperatures collected during the fall 2013 sampling season likely due to a late start in the sampling season when temperatures were dropping rapidly.
No effect from wind speed on \( \text{H}_2\text{S} \) concentration was detected, however, it should be noted that wind direction could be a localized factor. Observation of highly elevated \( \text{H}_2\text{S} \) concentrations were documented during the third field collection event at one site (Bl farm as shown in Figures 5-2 and 5-3) where adjacent structures trapped manure storage emissions and inhibited dissipation of gases from the open-air storages.

Limiting sources of sulfate in manure storages would limit \( \text{H}_2\text{S} \) production. Observations showed that repeated movement or mixing of the manure released \( \text{H}_2\text{S} \) gas trapped beneath the storage crust, leading to reduced emission at subsequent agitations, but this was not found to be significant by statistical analysis. More measurements could support the observational findings collected with this demonstration, however, this demonstration has provided evidence that elevated \( \text{H}_2\text{S} \) concentrations occur at farms using gypsum products.

**Chapter 6 Conclusions and Recommendations**

Nineteen open-air, manure storage agitation events were monitored at ten dairy farms over a 14 month period. Hydrogen sulfide gas release was measured along with environment features, management practices and manure parameters thought to impact development and emission of \( \text{H}_2\text{S} \) gas. Findings include:

6.1 Conclusions

- Gypsum bedding use clearly and significantly increased \( \text{H}_2\text{S} \) release during manure storage agitation versus farms with conventional bedding materials (non-gypsum farms).

- Measurements collected before and after agitation show \( \text{H}_2\text{S} \) concentrations at gypsum bedding farms immediately begin at the start of agitation.

- Increased gypsum bedding use (amount per cow) was correlated with increasing risk of elevated \( \text{H}_2\text{S} \) gas release at manure storage agitation.

- The manure amendment Vital™ Breakdown showed a promising trend in diminishing hydrogen sulfide release, but did not significantly reduce cumulative \( \text{H}_2\text{S} \) concentrations with respect to farms that do not use manure amendments.
• Manure amendments did reduce H$_2$S concentrations when all farms that used products were considered together, offering hope that mitigation of risky gas levels may have some relatively simple solutions.

• Environment measurements did not significantly affect cumulative H$_2$S concentrations during manure agitation. These included: average ambient air temperature, average manure surface temperature, manure temperature at depth, pH, ORP and wind speed. Limited measurements and high variability in environmental conditions were challenges affecting evaluation of their effect on H$_2$S concentrations during the monitored events.

• Similarly, neither design parameters nor manure characterization measurements (storage design, manure transfer, crust cover, crust thickness) were found to significantly affect cumulative H$_2$S concentrations at agitation.

• Though statistical evidence from this research did not estimate significant environmental effects, farm observations must consider empirical analysis at each farm. Wind direction that is obstructed by proximate barns or outbuildings can cause elevated H$_2$S concentration near the storage during agitation.

• Awareness greatly reduces risk of H$_2$S exposure. Four out of 19 operators were exposed to elevated levels of H$_2$S at farms that used gypsum in bedding. Careful implementation to avoid dangerous plumes of manure gas can prevent exposure such as operating the agitator from an elevated, closed tractor cab. Efforts that require operators to work at the rim of the storage or lean over it are susceptible to high risk of H$_2$S exposure.

• Unacceptable H$_2$S concentrations (greater than 20 ppm) exist 10 meters away from manure storage during agitation events when gypsum bedding is used. Children, workers and animals are at risk at least 10 meters away from a manure storage that contains gypsum.

• With the bedding and agronomic benefits of gypsum, a balance exists between these rewards and the risk of H$_2$S gas toxicity during manure agitation.
6.2 Recommendations

Overview: Highly elevated H\textsubscript{2}S concentrations are likely to occur in the vicinity of manure, which contains gypsum bedding, during agitation or movement. Awareness of dangerous environments is crucial to limiting risk. With awareness, safer practices can be implemented to limit risk to exposure of H\textsubscript{2}S and reduce health hazards. Safety can be improved through awareness of conditions via personal gas monitors and, perhaps, manure amendments to lower H\textsubscript{2}S emission during agitation. Because of this demonstration project, knowledge of the extent of risk and awareness of the types of hazards have been communicated to the agriculture community.

General Recommendations for any outdoor manure storage:

- **Access during agitation**: Keep non-essential people away during agitation, especially children who are at increased risk as H\textsubscript{2}S is typically at higher concentration close to the ground. Nearby cattle are also at risk.
- **Secure** storage from entry: provide **rescue** and fall protection; **gas monitors** recommended.

Specific to gypsum bedding use

- **Under-barn manure storage**: Our unconditional recommendation is to not use gypsum bedding with under-barn manure storage. Potential is very high for release of extreme concentration of H\textsubscript{2}S when manure is moved or mixed, resulting in harm to barn workers and confined cattle.
- **Operator position during agitation**: During any manure movement or mixing, operator must be up above the ground and away from edge of a manure storage. Particularly with manure containing gypsum bedding material, H\textsubscript{2}S gas at lethal levels (>600 ppm) is quickly produced and undetectable by smell. Hydrogen sulfide is a heavy, ground-hugging gas.
- **Position work area** so operator:
  - Does not reach over the storage for routine practices
  - Does not work or need to adjust machinery near storage edge
  - Is not in a low-lying area
- **Wind Direction**: Hydrogen sulfide can settle in windless areas, shelterbelts or among buildings blocking airflow near a storage unit. Strong breezes will move H\textsubscript{2}S out and away from storage, diminishing risk. Operators should be positioned upwind.
- **Access during Agitation**: Once manure storage agitation begins, no one should be in the immediate area. Encourage casual onlookers to keep well away (minimum of 50 feet). Children, pets, calves, and resting cattle are more susceptible due to lower breathing zones. Low areas accumulate H\textsubscript{2}S so operators, other people and animals should avoid any nearby depressions.
• **Planning Layout:** Gases “throw” in the direction of a manure agitator nozzle, so be aware of dangerous impact on “downwind” animal or human occupied areas. Confined cattle in the area are at risk.

• **Confined storage:** Long ago it was discovered that confined spaces accumulated dangerous levels of manure gases (sumps; low areas; gutters; cross channels; pits; pump out access areas; underfloor manure storages). Dangerous gas levels are especially common during agitation of the manure. The addition of gypsum bedding makes this an even greater hazard with the potential for high H$_2$S levels.

### Chapter 7 Dissemination of Information: Penn State Extension

As a demonstration project, the information learned was made available to the dairy industry in many user-friendly formats. Nationwide and international meetings provided excellent opportunity to highlight the findings of this project and communicate the potential hazards of working around manure storages that contain gypsum products. This section provides the details and references for the information sessions, conference and poster presentations, webinars and Penn State Extension documents that were conducted as a part of this demonstration project. There have been numerous media articles about project outcomes, and more continue to be made available to the farming community. At least two web pages catalog resources related to demonstration findings.

The project successfully completed all deliverables:

1. A written *document* with recommendations on how project findings may be incorporated into NRCS technical guidelines [Appendix H]
2. *Training* of NRCS engineers in safety, air quality instrument use, and environmental issues associated with open-air manure storages [Table 7.1; Appendix E]
3. A non-technical *brochure* for delivery to farmers as NRCS personnel work with them on issues associated with gypsum bedding use and manure handling [Appendix H]
4. *Events* to attend included two webinars and on-farm field day with technical findings suitable for producers and professionals [Table 7.1; Appendix E; Appendix G]

**Information Sessions (deliverables 2 & 4):**

Table 7-1 provides a list of information sessions during which observations from this project were communicated to producers, manure haulers and engineers. The slide set from the most recent presentation (2015 North American Manure Expo, Chambersburg, PA) is included in Appendix E. This appendix also includes field day promotion and NRCS training information.
Table 7-1: Trainings, field days and expos for technical and professional audiences.

<table>
<thead>
<tr>
<th>Information Session</th>
<th>Date</th>
<th>Location</th>
<th>Approximate Number of Attendees</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRCS PA regional engineers technical training update</td>
<td>July 9, 2014</td>
<td>Livestock Evaluation Center - Penn State's Ag Progress days Site</td>
<td>20</td>
</tr>
<tr>
<td>Manure Hauler’s field day</td>
<td>August 6, 2014</td>
<td>Lebanon County, PA</td>
<td>80</td>
</tr>
<tr>
<td>International Society for Agriculture Safety and Health annual meeting</td>
<td>June 22 - 29, 2014</td>
<td>Omaha, NE</td>
<td>20</td>
</tr>
<tr>
<td>Ag Progress Days, Manure Haulers Training</td>
<td>August 12 and 14, 2014</td>
<td>Penn State Ag Progress Days site</td>
<td>60</td>
</tr>
<tr>
<td>On-farm Demonstration Day</td>
<td>August 28, 2014</td>
<td>Pleasant View Dairy Farms, Pine Grove, PA</td>
<td>70</td>
</tr>
</tbody>
</table>

Conference Oral Presentations and Papers:


**Conference Poster Presentations:**

A poster was developed for the 2015 Waste to Worth national meeting in Seattle, Washington. This is referenced below and a copy of this poster is provided in Appendix F.


**Webinars (deliverable 4):**

Two webinars were provided to a national audience. The references and link to these webinars are listed below. The slide set of the most recent webinar (Hile and Meinen, 2015) and overview of each webinar is provided in Appendix G.


**Written Documents (deliverables 1 & 3):**

Two Penn State Extension *fact sheets* were developed and are available on the Penn State Extension gypsum website (Penn State Extension, 2015) and are included in Appendix H.

1. A written *document* with recommendations on how project findings may be incorporated into NRCS technical guidelines:

2. A non-technical *brochure* for delivery to farmers as NRCS personnel work with them on issues associated with gypsum bedding use manure handling:

**News Articles:**

Table 7-2 lists the news articles that reference this work. Copies of these articles are also provided in Appendix I for convenient reference. Another Article has been drafted and approved for publication in a future issue of Hoard’s Dairyman.

<table>
<thead>
<tr>
<th>Title</th>
<th>Newspaper</th>
<th>Author</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>It's coming! Don't let it get you!</td>
<td>Farmshine</td>
<td>Dieter Krieg</td>
<td>9/5/2014</td>
</tr>
<tr>
<td>Manure handling field day focuses on hydrogen sulfide gas</td>
<td>Lancaster Farming</td>
<td>Dick Wanner</td>
<td>9/6/2014</td>
</tr>
<tr>
<td>Please be afraid of deadly hydrogen sulfide</td>
<td>Farmshine</td>
<td>Dieter Krieg</td>
<td>9/19/2014</td>
</tr>
<tr>
<td>Gypsum bedding—is it worth the manure safety risk?</td>
<td>Progressive Dairyman</td>
<td>Eileen Fabian-Wheeler</td>
<td>10/1/2014</td>
</tr>
<tr>
<td>Do not give the killer in the pit the benefit of the doubt</td>
<td>Farmshine</td>
<td>Dieter Krieg</td>
<td>10/10/2014</td>
</tr>
<tr>
<td>Empty it, maintain it, and above all, stay safe</td>
<td>Farmshine</td>
<td>Emily Dekar</td>
<td>10/17/2014</td>
</tr>
<tr>
<td>They're not just standing around!</td>
<td>Farmshine</td>
<td>Dieter Krieg</td>
<td>10/24/2014</td>
</tr>
<tr>
<td>Agricultural safety, sometimes forgotten</td>
<td>Industrial Hygiene</td>
<td>Mike Platek</td>
<td>12/1/2014</td>
</tr>
<tr>
<td>The invisible goon in the lagoon has been detected</td>
<td>Farmshine</td>
<td>Dieter Krieg</td>
<td>12/5/2014</td>
</tr>
<tr>
<td>This poisonous cocktail shows absolutely no mercy.</td>
<td>Farmshine</td>
<td>Dieter Krieg</td>
<td>12/5/2014</td>
</tr>
<tr>
<td>Gypsum linked to poison gas in manure storage</td>
<td>Lancaster Farming</td>
<td>Gruber, Philip.</td>
<td>2/21/2015</td>
</tr>
</tbody>
</table>

Given the numerous opportunities within the state of Pennsylvania and around the country, this work has been well received and has generated interest from a range of people in the industry including producers, haulers, engineers and county officials and fire departments. A nationally recognized manure management eXtension website has
early findings from this demonstration (eXtension, 2015). Continued communication of the observations collected from this project will prolong the discussion of manure storage safety, such as in articles generated from our fact sheets in farm.com (2015) and The Beef Site (2015).

Chapter 8 Cited References


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Appendix A. Manure Additives

Vital Breakdown

Benefits of Vital Break Down
- Controls odors
- Breaks down solids
- Fosters the building of humus
- Requires less agitation
- Retains high levels of Nitrogen

Recommendations for Use:

**LIQUID MANURE PITS AND SLURRY TANKS:**
- Initial Treatment: Apply 2 lbs. per 10,000 gallons of liquid.
- Subsequent Treatment: Apply 1/2 lb. for each additional 10,000 gallons of liquid.

**OR**
- For Dairy: 3/4 to 1 lb. per cow per year
- For Hog: 1 lb. per 5-12 head per year

"Important"
- Agitate for proper action to assure efficient biological action.
- If extra odor control is needed, do not hesitate to add more.

- Weekly application produces best results.

**DRY MANURE PADDY:**
- Treatment: 1/2 lbs. for 100 square feet
- Non-fibrous - Apply at every 3 inch depth
- Fibrous - Apply at every 5-6 inch depth

Distributed By:

Homestead Nutrition, Inc.
296 White Oak Road
New Holland, PA 17557
1-888-336-7876
www.homesteadnutritioninc.com
This chart shows the amount of Nitrogen retained in the total dry mass of the material after being treated with Vital Break Down. The chart reveals that the highest amount of retained Nitrogen occurred at the recommended rate of 1 lb. per cubic yard.

This data shows the amount of organic Nitrogen formed after treating the material with Vital Break Down. Organic Nitrogen is a more stable form of Nitrogen. The presence of organic Nitrogen confirms the fact that humus is being built, which is a very positive thing.

This chart compares the amounts of total Nitrogen, organic and non-organic, after the application of Vital Break Down. Again, the best results were obtained from applying the 1 pound rate, which is our suggested rate of application.
Pro Soil OK-1000

OK-1000 is a product that is designed to abate mal-odors and reduce solids for animal waste byproducts. This technology uses a proprietary enzymatic process that works through the acceleration of the natural biodegradation process and includes enzymes and biological catalysts but also specific micronutrients all of which are non-hazardous, non-toxic and environmentally friendly. This process molecularly transforms mal-odors into benign species. In waste byproducts, mal-odors are generated by the anaerobic digestion of biomass. Hydrogen sulfide and mercaptans, which are generated as by-products of anaerobic digestion, are strong correlates to the mal-odor industry. OK-1000 enzyme mal-odor abatement protocol proceeds in three stages. In the first stage, the mal-odor species generated by the decaying of biomass are captured. This is facilitated by the enzymes and bio-chemical reactions with a number of the micro constituents in the catalyst solution. The second stage, involves the aerobic respiration of the in situ and added microbes. This process consumes the Biomass, releasing carbon dioxide, water and energy. The third stage, involves the propagation and growth of the microbial populations. Mal-odor and toxic emissions species, such as hydrogen sulfide, mercaptans, ammonia, amines and other nitrogen or sulfur hetero-atom containing organic materials are converted into a benign species, becoming part of the building blocks of new cell structure. Hydrogen sulfide are suppressed by the use of the product. When hydrogen sulfide is present, this proprietary bio-catalyst enzyme captures the hydrogen sulfide and cleave the sulphhydryl group. The sulphhydryl group winds up in a sulfur containing amino acid or mercaptans when incorporated into animal manure or municipal sludge that is maintained aerobically. It is also effective in treating solid waste streams and waste water, both the in situ and air to air phases. Ammonia emissions are suppressed by a bioenzyme/catalytic process. Any ammonia captured is bound into the enzymatic process. The ammonia is then used to build amino acids, primarily aspartic. These then support the healthy propagation of the aerobic bacteria populations. Instead of the ammonia winding up in the air, the nitrogen source stays contained in the biomass, organically bound and enhances the fertilizer value of the manure. Recommended application rates are 1 gallon to 325,000 gals of manure.
OK-1000 is a non-toxic, biodegradable bioenzyme mixture with micro-nutrients and waste digestant designed for a multitude of uses.

**DIRECTIONS FOR USE**
Mix with sufficient water to allow uniform coverage. Can be used mixed with most liquid fertilizers, herbicides, inositol and hormones. Use in conjunction with good soil test and soil fertility program. Always perform compatibility test prior to mixing any chemicals. Application should be made within 24 hours after dilution.

This product is intended as a supplement or additive to current fertility and NOT a replacement of fertility.

**LIMITED WARRANTY**
Manufacturer and seller makes no warranty, expressed or implied, concerning the use of this product and shall not be liable for any injury or damage accruing from misuse or misapplication. Buyer assumes all responsibilities other than stated label guarantees. Manufacturer or seller obligations are limited to replacement for the quantity of defective material only.

**KEEP OUT OF REACH OF CHILDREN**

**SHAKE WELL BEFORE USE**

**PROTECT FROM FREEZING**

**RECOMMENDED APPLICATIONS**

**COLLECTION PONDS - LAGOONS AND POND NUTRITION**
Spray 8 to 15 psi over surface using water as a carrier for uniform coverage, or add as several locations, depending on solids.

**STOCK PONDS - PIGS, CULTURAL PONDS**
Use 1 to 3 gpm. In excessively muddy or very high algae problems, repeat application in three to four days. After pond has been stabilized, repeat application of 1 to 3 gpm every two to three weeks as needed.

**FEEDLOT - BARN AREAS**
Spray 4 to 5 ounces per 1,000 square feet of surface area. Use sufficient amount of water for uniform coverage.

**ANIMAL ISSUE**
Use 3 ounces per quart of water. Spray liberally onto animal. Can be repeated every 24 hours.

**HOME SEPTIC SYSTEMS**
Use 1 quart every 30 days by flushing into system. To add to existing pipes and drain, use 1 fluid ounce monthly in each commode, wash basin and drain. Follow application by either 1 flush for commodes or 1 gallon of water for drain.

Manufactured by:
PRO-SOIL AG SOLUTIONS, INC.
P.O. BOX 1537 - HAWKINS, TX 75773
903-769-5573

Net Content 2.5 gallons (9.4L)
20.85 U.S. lbs. (9.5 kg)
Appendix B. Dairy Farm Background Characterization

NRCS CIG Demo Gypsum, Additives & Dairy Manure Gas

Farm Name or Owner

Date and note taker name: ____________ ________________

Farm contact person
Phone #s
Email
Address

Driving Directions

Type of dairy for our demonstration: ___gypsum; ____ with additive; ___no gypsum

Barn Description(s) that contribute manure to storage
General: # stall rows; feeding aisle; shape

Primary barn dimensions (L, W, H) and description (natural ventilation, bedded pack; freestall; etc.):

2\textsuperscript{nd} barn dimensions (optional):

Site plan sketch (on back) with compass north
House age and builder
Cleanliness/ condition of note

Barn Manure Management
Type of handling system (slurry, liquid, etc.)

Barn cleanout schedule (daily-approx. time; 2xdaily, etc.)
Cleanout technique (scraper, skid steer, gutter cleaner, etc.)

General conditions
(temperature, odor, moisture, quantity of feed waste, water spill, etc.)

Type and use of manure additives

Notes:
Manure Storage Description
- Geometry and maximum manure depth
- Design and construction contractors
- Size (dimensions, gallons, etc.)
  - Material (concrete, steel, earthen)
  - Intended capacity (6 months, etc.)
  - Loading design (push off onto top, bottom, etc.)

Unloading design

Notes relevant (% buried; surface water encroachment, etc.)

Manure Storage Management
- Agitation schedule
  - Type (top discharge; tractor PTO, etc.)
  - Frequency/ duration
  - Notable criteria

Manure and other materials (check-off and estimated amounts, where available)
- Dairy manure  Y / N
- Heifer manure  Y / N
- Dry cow manure  Y / N
- Silage leachate  Y / N
- Milkhouse washwater  Y / N
- Barnyard runoff  Y / N
- Other additions  Y / N

Notes:

Cow Management
- Milk supplied to ________________________
- Milk cow population ________________  Breed _____________
  - Groups (hi, lo)
  - Average cow weight
  - Milk production
  - Number milking/day

Population contributing to manure storage
- Heifers
- Dry cows
- Other animals contributing to manure storage
Feeding Schedule, type of feeders, total tonnage, daily feed consumption
Lighting Schedule, type and amount
Type of waterers; consumption if available
Feed analysis (get papers from nutrition consultant?)
  DDGs fed?
Special Production strategies (cooling for feed consumption etc.)

Notes:

**Bedding**
Type
Amount
Cost
Amendment (description and amount)
Gypsum use(d)
  Amount
  Cost

Notes:

************************************************************************
Site visit #1 Farm Name/owner _____________________
Date
Personnel present
Observations today:
  Temperature range
  Humidity
  Wind velocity and direction
  Precipitation
  Weather-clouds etc.
  Notes

Manure storage
  Crust? Depth & description
  Last agitation. Date and describe

Notes:

************************************************************************
Site visit #2 Farm Name/owner _____________________
Date
Personnel present
Observations today:
   Temperature range
   Humidity
   Wind velocity and direction
   Precipitation
   Weather-clouds etc.
   Notes

Manure storage today
   Crust? Depth & description
   Last agitation. Date and describe

Notes:
<table>
<thead>
<tr>
<th>Sampling Season</th>
<th>Farm</th>
<th>Cumulative H₂S Concentration (ppm)</th>
<th>Gypsum Application Rate (gal 6 month⁻¹)</th>
<th>Storage Structure</th>
<th>Manure Transfer</th>
<th>Storage size (gal)</th>
<th>Thickness of Bottom Solids (inches)</th>
<th>Surface Coat (inches)</th>
<th>Sulfur Sources (Aside from Gypsum) (gal)</th>
<th>Somatic Cell Count (%)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2013 (F13)</td>
<td>Bl F13 GT</td>
<td>1250.8</td>
<td>2.0</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
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<td>36</td>
<td>45</td>
<td>12</td>
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<td>0</td>
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<td>36</td>
<td>480</td>
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<td>Hv S14 NG</td>
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<td>36</td>
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<td>Sh S14 NG</td>
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<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
<td>1,500,000</td>
<td>24</td>
<td>100</td>
<td>12</td>
<td>0</td>
<td>0</td>
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<td>Scrape - Topload</td>
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<td>Scrape to Sump - Gravity Flow</td>
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<td>6</td>
<td>100</td>
<td>2</td>
<td>600</td>
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<td>N Q</td>
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<td>3.4</td>
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<td>0</td>
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<td>50</td>
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<td>1040</td>
<td>N Q</td>
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<td></td>
<td>Cr S14 GT</td>
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<td>1.2</td>
<td>Aboveground Steel</td>
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<td>0</td>
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<td>Hr S14 GT</td>
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<td>Subgrade Concrete</td>
<td>Scrape to Sump - Gravity Flow</td>
<td>850,000</td>
<td>60</td>
<td>100</td>
<td>12</td>
<td>600</td>
<td>5.07</td>
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<td>Sr F14 G</td>
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<td>24</td>
<td>80</td>
<td>12</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>

Notes: Season codes are F13 = fall 2013, S14 = spring 2014 and F14 = fall 2014.
Treatment codes are NG = non-gypsum, G = gypsum and GT = gypsum with treatment.
N Q = Distiller's grains are used in diet but we are not quantified.
Appendix C. Gas monitor information sheets

MX6 iBrid Brochure and specification sheet (Industrial Scientific, Pittsburgh, PA)
Don’t Buy Gas Detectors
Subscribe to Gas Detection as a Service

It gives you help from The Gas Detection People.
Let us handle your gas detection program. Gas detection is probably not core to what you do. But, it’s all that we do. It’s what we love to do.

It gives you cost savings.
The list price is only part of a gas detector’s total cost. You have to maintain it. You have to wait for it to be serviced. iNet eliminates unnecessary ownership and maintenance costs.

iNet Compatible for Increased Safety, Cost Savings and Productivity

iNet is a software-based service that manages your fleet of gas detectors. iNet solves the most common gas detection problems. For example, iNet keeps people safe by providing visibility into alarms, exposure and usage. It keeps gas detectors working without costly and time-consuming maintenance. And with iNet, you won’t have to buy the MX6. So why do it?

How Does iNet Work?

1. Operators dock gas detectors owned by Industrial Scientific.
2. Docking Stations - perform bump tests, calibrations and record-keeping.
3. iNet Control provides visibility into your gas detection program via the Web.
4. iNet e-mails real-time alerts and status reports.
5. When iNet detects a problem, Industrial Scientific rushes a replacement gas detector to you.

On average, gas detectors go into high alarm once every ten days. How many high alarms did your facility have? iNet gives you information and tools to fix problems before they happen.
**THE MX6 iBRID COLOR DISPLAY**

Enhanced Visibility – Expanded Functionality

<table>
<thead>
<tr>
<th>O2</th>
<th>PID</th>
<th>H2S</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

- The MX6 clearly shows real-time readings in PPM or % by volume.
- An intuitive menu provides easy access to features and setup.

- Display trends and data readings can be viewed graphically.
- Calibration progress and results are shown for each sensor.

<table>
<thead>
<tr>
<th>O2</th>
<th>NO2</th>
<th>H2S</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

- A “calibration due” warning appears for each relevant sensor.
- Bright red numerals and a flashing backlight show alarm conditions.

### Bump Test Results

- OK
- LOW

Alarms shown with "Go/No Go" text and flashing backlight.

- Color-coded text shows test or calibration results at a glance.

Visit www.indsci.com for more information.
SP6 MOTORIZED SAMPLING PUMP

CHARGER / DATALINK
- Instantly download event logs and datalog data while instrument battery charges
- Quickly and easily configure instrument settings.

MULTI-UNIT CHARGER

CHARGER

LEATHER CASES

TRUCK MOUNT CHARGER

MX6 CONFINED SPACE KIT

Cylinder shown with iGas Card Reader

Choice of MX6 monitor, universal charger, nylon carrying case, belt clip, calibration gas, vent stack, maintenance tool, manual, quick start guide, calibration tubing, dust filter/water trap (with pump), calibration filling (with pump), sample filling (with pump), calibration gas (appropriate mix) with regulator, spare replaceable cell, lithium battery pack, rugged Pelican case.
### Specifications

**INSTRUMENT WARRANTY:**
Warranted for as long as the instrument is supported by Industrial Scientific Corporation.

**CASE MATERIAL:**
Luminescent Stainless Steel submersible rubber overmold.

**DIMENSIONS:**
133 mm x 77 mm x 43 mm (5.2" x 3.0" x 1.7") — without pump
167 mm x 77 mm x 56 mm (6.6" x 3.0" x 2.2") — with pump

**WEIGHT:**
420 g (14.8 oz) typical — without pump
311 g (10.9 oz) typical — with pump

**DISPLAY/READOUT:**
Color Graphic Liquid Crystal Display

**POWER SOURCES/RUN TIMES:**
Rechargeable Lithium-ion (Li-ion) Battery Pack (24 hours) — without pump
Rechargeable, Extended Range Lithium-ion (Li-ion) Battery Pack (36 hours) — without pump
Replaceable AA Alkaline Battery Pack (10.5 hours) — without pump

**OPERATING TEMPERATURE RANGE:**
-20°C to 50°C (-4°F to 122°F)

**OPERATING HUMIDITY RANGE:**
15% to 95% non-condensing (continuous)

### Measuring Ranges

<table>
<thead>
<tr>
<th>MEASURING RANGES:</th>
<th>RANGE</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SENSOR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CATALYTIC BEAD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combustible Gas</td>
<td>0-100% LEL</td>
<td>1%</td>
</tr>
<tr>
<td>Methane</td>
<td>0-5% vol</td>
<td>0.1%</td>
</tr>
<tr>
<td><strong>ELECTROCHEMICAL</strong></td>
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<tr>
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<tr>
<td>Carbon Monoxide (High Range)</td>
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<tr>
<td>Carbon MonoxideHydrogen Mix</td>
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<td>Chlorine</td>
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<td>Chlorine Dioxide</td>
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<td>Oxygen</td>
<td>0-30% vol</td>
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<td>Phosphorus</td>
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<td>Hydrocarbons</td>
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<td>Methane (CCH)</td>
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<tr>
<td>Methane (C2H6)</td>
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<tr>
<td>Carbon Dioxide</td>
<td>0-10% vol</td>
<td>0.1%</td>
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</table>

### Certifications

- **UL:** Class I, Groups A,B,C,D,T4; Class II, Groups F,S,T4; ATEX ia IIC T4
- **CSA:** Class I, Groups A,B,C,D,T4; Ex d ia IC T4
- **ATEX:** Ex ia IC T4 Ga Ex d-IIa T4b Pd IP64; Equipment Group and Category: AEx ia IIC T4 (ia iIC T4)
- **IECEx:** Ex ia IC T4 1Ga Ex d IIa T4b IP64; Ex ia IC T4 1Ga Ex d IIa T4b IP64
- **ANZEEx:** Ex ia IC 1Ga Ex d IIa T4b IP65; Ex ia IC 1Ga Ex d IIa T4b IP65
- **IMETEX:** Ex ia IC T4 Ge
- **DEKRA:** Ex ia IC T4 Ge
- **KOSHA:** Ex ia IC T4 Ge
- **China Ex:** Ex ia IC T4 Ge

*These specifications are based on performance estimates and may vary by instrument.*
**Tango TX1 specification sheet (Industrial Scientific, Pittsburgh, PA)**

---

**SINGLE GAS MONITOR**

### INSTRUMENT SPECIFICATIONS

**INSTRUMENT WARRANTY:**
Three year warranty which does not include battery, sensors and filters.*
CO and H₂S sensors are warranted for 3 years from the initial purchase date.
All other sensors are warranted for 2 years from the initial purchase date.

**DISPLAY:**
Segment liquid crystal display (LCD)

**KEYPAD:**
Two buttons

**CASE MATERIALS:**
- Case: Polypropylene with protective rubber overmold
- Case inserts: Conductive polyethylene

**ALARMS:**
- Three strobe/warning visual alarms (two red, one blue)
- 180 audible (98) audible alarms at a distance of 15 cm (6", 3") vibration alarm

**DIMENSIONS:**
- 58 x 11 x 36 mm (2.3" x 4.3" x 1.4")

**WEIGHT:**
- 135 g (4.8 oz)

**TEMPERATURE RANGE:**
- -40°C to +80°C (-40°F to +122°F)

**HUMIDITY RANGE:**
- 15% to 95% non-condensing (continuous)

**SENSORS:**
- CO, CO₂, H₂S, O₂, NO, NO₂ - Electrochemical sensor technology

**SENSOR MEASURING RANGES:**
- Carbon Monoxide (CO): 0 to 1,000 ppm in 1 ppm increments
- Carbon Monoxide (CO₂): 0 to 1,000 ppm in 1 ppm increments
- Hydrogen Sulfide (H₂S): 0.1 to 2,000 ppm in 0.1 ppm increments
- Nitrogen Dioxide (NO₂): 0.1 to 1,000 ppm in 0.1 ppm increments
- Sulfur Dioxide (SO₂): 0.1 to 100 ppm in 0.1 ppm increments

**BATTERY:**
- 3.6 V Primary Lithium-ion batteries (2 x 3.0V) 1.5A, 200A) replaceable: non-rechargeable, allows up to 2 year use time depending on operating conditions

**DATA LOGGING:**
- 2 months at 30 second intervals

**EVENT LOGGING:**
- 4 alarm events

**CERTIFICATIONS:**
- UL, CSA, INMETRO

**INGRESS PROTECTION:**
- IP86, IP87

**OPERATING TEMPERATURE:**
- -40°C to +50°C (-40°F to +122°F)

**OPERATING HUMIDITY:**
- 15% to 95% non-condensing

---

**ACCESSORIES**

- 100005120-00C DSS™ Fitting Station for Tango™ TX1
- 100005111-00C Soft case, black
- 100005108-00C Soft case, orange
- 100005099-00C Carrying case, black
- 100005082-00C Carrying case, orange
- 100005073-00C Carrying case, grey
- 100005107-00C Belt clip
- 100005106-00C Black armband
- 100005105-00C Safety armband
- 100005095-00C Belt armband
- 100005094-00C Clip armband
- 100005093-00C Snap armband
- 100005092-00C Snap armband
- 100005091-00C Clip armband
- 100005090-00C Snap armband
- 100005089-00C Belt armband

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**INDUSTRIAL SCIENTIFIC**

www.indsci.com

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**AMERICAS**

Phone: +1-412-795-4353
Fax: +1-412-795-7787
info@indsci.com

**ASIA PACIFIC**

Phone: +852-8385-9261
Fax: +852-8385-9260
info@ap.indsci.com

**EMEA**

Phone: +33 (0) 1 53 87 92 81
Fax: +33 (0) 1 53 87 92 87
info@eu.indsci.com
Appendix D. Manure Characterization and Environmental Parameters
NRCS CIG Demo Gypsum, Additives & Dairy Manure Gas

On-Farm measurements

Manure surface temperature: IR thermometer
Manure sample ORP (oxidation reduction potential): hand-held meter (starting spring 2014)
Gas concentration:
  - Hydrogen sulfide
  - Ammonia
  - Carbon dioxide
  - Carbon monoxide
  - Methane (%LEL)
Oxygen
Weather (one location):
  - Air temperature
  - Relative humidity
  - Wind velocity
  - Wind direction

Manure analysis from Ag and Analytical Services Lab (Penn State)
  - 3 Samples drawn: Before agitation, near top and near bottom of storage and After agitation.

Solids %
Total Nitrogen (N)
Ammonium N (NH4-N)
Calculated organic N
Total Phosphate (P2O5)
Total Potash (K2O)
Total Calcium (Ca)
Total Magnesium (Mg)
Total Sulfur (S)
Total Copper (Cu)
Total Zine (Zn)
Total Manganese (Mn)
Total Iron (Fe)
Total Sodium (Na)
Total Aluminum (Al)
pH
Ash %
Volatile %
P Source Coefficient
Table A-2: Summary of field measurements

<table>
<thead>
<tr>
<th>Sampling Season</th>
<th>Farm¹</th>
<th>Ambient Temperature²</th>
<th>Manure Temperature</th>
<th>Oxidation-Reduction Potential (ORP)</th>
<th>pH</th>
<th>Average Wind Speed³</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Surface Before Agitation</td>
<td>1 Foot Below Crust Before Agitation</td>
<td>Bottom Before Agitation</td>
<td>Middle After Agitation</td>
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</table>

Notes:
1F13, S14 and F14 represent Fall 2013, Spring 2013 and Fall 2014, respectively
2NG, G and GT represent non-gypsum, gypsum and gypsum with treatment, respectively
3Surface temperature were averaged from measurements collected using an infrared thermometer
4Ambient temperature was averaged from Kestral weather station data.
5Wind Speeds were average over first 60 mins of agitation from data collected from Kestral weather station at one location
6N/A cells represent dates that kestral data was not measured or recovered. MCl meter
7Fall 2013 observation did not include manure temperature, pH or ORP at depth because the field meter was not available for these field collection dates
8Temperature for shaded cells are from Fall 2013
<table>
<thead>
<tr>
<th>Sampling Season</th>
<th>Farm</th>
<th>Cumulative H₂S Concentration</th>
<th>Gypsum Application Rate</th>
<th>pH</th>
<th>PSC</th>
<th>Solids (% dry weight)</th>
<th>Total Nitrogen (% dry weight)</th>
<th>Sulfur (% dry weight)</th>
<th>Calcium (% dry weight)</th>
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<tbody>
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</tbody>
</table>

Notes: ¹ 33, 53 and 51 represent Fall 2013, Spring 2013 and Fall 2014, respectively
² NG, G and GT represent non-gypsum, gypsum and gypsum with treatment, respectively
Appendix E. Example Oral Presentation Slides


---

**Dairy Manure-gas Agitation Risks-Field Day**

**Thursday August 28, 2014**
**10:30 AM – 12:30 PM**

**2.0 Continuing Education Credits (CECs) for Act 49 Haulers and Brokers**
**No Registration. No Charge. No meal provided.**

Penn State Extension, in conjunction with USDA-NRCS, is conducting an educational program at an actual manure gas measurement event at a dairy farm. This one event is part of a larger project that is exploring Hydrogen Sulfide emissions during agitation at a number of manure storage structures. A number of recent dangerous or deadly incidents related to toxic gas levels at dairy farms has increased interest in working safely around manure storages. Farms participating in the study either bed with gypsum, bed with gypsum but use a manure pit additive, or do not gypsum for bedding.

Educational discussions and presentations will include: manure storage practices and risks; safety instruments and protective gear; emergency response actions; gases released at agitation; gypsum bedding benefits and risks; observations of agitation during field demonstration. Personal safety gas monitors will be available to try. Supplier of instruments available for questions.

**Wolfe Dairy**
**181 Wolfes Road**
**Pine Grove, PA 17963**

10:30-Explore the demonstration site of gas monitors surrounding the manure storage with Extension researchers
11:00 - Agitation begins
   Actions for safe mixing.
   Impact of stall bedding, including gypsum.
   Gas level detection instruments for personal use.
   Safety tips.
12:00 - Field day discussion of dairy manure storage agitation with instruments and safety practices demonstrated.
   Actions useful in an emergency response.
   Observation of gas monitor changes during agitation of both stationary monitors and those worn by workers.
12:30 Finish
NRCS Safety & Air Quality Training
Penn State Extension
July 9, 2014  9:30 AM – 1:30 PM
114 Agricultural Engineering Building, University Park campus

1. Welcome & introductions

2. Environmental issues associated with open-air manure storages
   a. Toxic gas levels observed during data collection-Mike Hile/Eileen Fabian
      i. Measurement and observation results
   b. Makeup of “normal” air and factors that affect the air we breathe-Mike Platek
      i. Chart of oxygen levels
      ii. H2S-Source and levels
      iii. NH3-Source and levels
      iv. CO2-Source and levels
      v. CH4-Source and levels
   c. Using instruments to measure unsafe atmospheres-Mike Platek
      i. Selection, use, calibration and care of gas detection equipment

3. Creating and encouraging a safety culture with manure storages-Dave Hill
   a. Restricted areas during agitation
   b. Training of family & employees
   c. Signage & barriers
   d. PPE
   e. Developing an on-farm manure storage safety program-farm info kit

4. Next steps and discussion

5. Adjourn
PENNAG INDUSTRIES ASSOCIATION
MANURE HAULER/APPLICATOR FIELD DAY

Wednesday, August 6, 2014

Lebanon Convention Expo Center & Fairgrounds
80 Rocherty Road, Lebanon, PA 17042 (Enter through Main Expo Building Doors)

FIELD DAY PARTICIPATION = 2 NUTRIENT MANAGEMENT CREDITS AND 4 MANURE HAULER/BROKER CREDITS

Preliminary Agenda:
8 a.m. - 9 a.m. Registration
9 a.m. - 10 a.m. Manure Gas Emissions / Equipment Update / Monitoring Instruments - Eileen Fabian, Mike Hill & Dan Hardesty, PSC
10 a.m. - 10:30 a.m. Regulatory Review - Mike Aucin, SCC & Robb Meinan, PSU
10:30 a.m. - 11 a.m. Recordkeeping - Mike Aucin, SCC
11 a.m. - 12 p.m. Application Compliance - Roundtable Discussion - Mike Aucin, SCC; Steve Tagliang, DEP; Robb Meinan, PSU & Others
12 p.m. - 1 p.m. Lunch
1 p.m. - 2 p.m. Live Action Spill Response Demonstration - Discussion and Demonstration
2 p.m. - 2:30 p.m. Council Meeting

Questions? Contact Mindy Fleetwood at mfleetwood@pennag.com or 717-651-5920.

2014 MANURE HAULER/APPLICATOR FIELD DAY REGISTRATION

Registration Fee: $15 PennAg Members, $25 Non-Members
(Registration includes presentations and lunch. Registration fee will be collected at event. Cash or check only)

Name(s): ____________________________
Company: ____________________________
Address: ____________________________
Phone: ____________________________ Email: ____________________________

COMPLETE AND RETURN (OR CALL 717-651-5920) BY WEDNESDAY, JULY 23 TO GUARANTEE LUNCH RESERVATION.

PennAg Industries Association • 2215 Forest Hills Dr., Suite 39 • Harrisburg, PA 17112
Phone 717.651.5920 • Fax 717.651.5926 • mfleetwood@pennag.com • www.pennag.com

NOTE: RSVP by emailing mfleetwood@pennag.com, calling (717-651-5920) or faxing (717-651-5926) the below information. Registration fee will be collected at event. Cash or check only.
What is Gypsum

Calcium Sulfate
- CaSO₄·2H₂O (Hydrous)
- CaSO₄ (Anhydrous)

Naturally occurring mineral and coal plant byproduct

Manufacturing And Construction Waste

Gypsum is used to produce drywall for construction. Manufacturing rejects and construction waste is collected and recycled.

Manufacturing And Construction Waste Is Processed And Sold For Use In Agriculture

Agricultural benefits – improves soil

- Improves soil structure (porous, light soil)
- Water is more mobile in soil
- Improves root development
- Provides store of secondary crop nutrients (Ca and S)
Agricultural benefits – ideal bedding for dairy cows

As bedding
- Moisture absorption
- Low bacteria counts
- Neutral pH

Gypsum bedding provides a sulfate source within the manure storage that reduces to form H₂S

Hydrogen Sulfide Creates A Dangerous Environment Heavier Than Air

<table>
<thead>
<tr>
<th>Exposure Unit</th>
<th>H₂S Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permissible Exposure Limit (PEL) or Ceiling</td>
<td>10</td>
</tr>
<tr>
<td>Immediately Dangerous to Life and Health (IDLH)</td>
<td>100</td>
</tr>
</tbody>
</table>

Manure gases escape during agitation

Numerous reports of:
- REALLY strong smell
- Dead livestock
- Employees/workers overcome
- Some haulers would not haul from gypsum farms

Child Found Unresponsive Here (2011)
May 2012 – 3 PA Workers Die In MD Manure Storage

Dairy Farmer’s Boys Have Close Call With Manure Gas

Farm bedded with Gypsum

Penn State Extension

METHODS: Three farm categories were observed in the fall and spring:
1. Gypsum
2. Gypsum with treatment
3. Non-gypsum

Penn State Extension

Unresponsive but breathing 500-600 ppm H₂S

150 ppm H₂S

Penn State Extension

Barn 30 feet away (30-60 ppm H₂S)

Penn State Extension

50 feet away (50 ppm H₂S)

Inside free stall (35 ppm)

Penn State Extension
METHODS: \( H_2S \) concentrations were measured during agitation events using portable meters.

METHODS: Temperature, wind speed and wind direction were recorded during data collection.

METHODS: Manure was characterized

- Samples were collected and analyzed for % solids, Ca, S, Total N, pH, ORR, PSC and temperature.

Physical Characteristics
- Crust thickness, Bottom sediments,
**Change in wind direction increased H\textsubscript{2}S concentrations**

Max H\textsubscript{2}S concentration = 580 ppm

**Personal monitoring devices provide effective awareness of exposure**

**Best management practices lower exposure risk**

<10 ppm H\textsubscript{2}S

Operators with two highest H\textsubscript{2}S readings were close to agitation

>300 ppm H\textsubscript{2}S

**Conclusions: H\textsubscript{2}S Concentrations**

- Increased gypsum use increases cumulative H\textsubscript{2}S concentrations.
- Treatments did not significantly reduce cumulative H\textsubscript{2}S concentrations, but more research could show otherwise.
- Manure moving-mixing-agitation creates safety concerns related to high gas levels.
- Safety practice’s lower risk of exposure.
- Risk of exposure present even at 10 meters downwind from storages that contain gypsum.
Open Air Manure Storage Safety
- Non-enclosed manure storages can still meet the definition of a confined space in terms of occupational safety and health:
  - Is large enough that a worker can enter and perform work,
  - Has limited or restricted means for entry or exit, and
  - Is not designed for continuous human occupancy.

“Easy in: Hard to get out!”

Confined Spaces
- Do not enter them!
- Gases can cause loss of consciousness and death.
- Always assume there are gases present.

Invest in the Insurance of a Monitor
- Test atmosphere:
  - Oxygen deficiency
  - Combustibles
  - Toxic gases
- Multiple gas vs single gas—cost and ease of use will be a factor
- Most reliable way of "seeing" the invisible

Gases 'throw' in the direction of manure agitator nozzle, so be aware of dangerous impact on 'downwind' animal- or human-occupied areas

Operator Position – up and away
- Position operator work area so that a person:
  - Does not reach over the storage for routine practices
  - Does not work or need to adjust machinery near storage edge
  - Is not in a low-lying area. (Remember H.5 is a heavy, ground-hugging gas)

Choose up-wind position

Gypsum bedding should not be used with under-barn manure storage
Unconditional recommendation against under-barn manure storage when gypsum bedding is used.
**Body Alarms!!!**

- Dizziness
- Wobbly knees
- Feeling hot and clammy
- Lack of attention to details
- Loss of motor skills/ fatigue
- Anxiety
- Severe eye irritation/ decrease in sight
- Irregular/fast heartbeat

*Pay attention to your body. Take action if there are signs of gas exposure. Get to fresh air!

---

**Acknowledgment and Thank You to the supporters of this project.**

*Penn State Investigators*

- Eileen Fabian-Wheeler, Michael Hile, Davis Hill, Dennis Murphy, Robin Brandt, Hershel Eliott, Robert Meiners

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**Industrial Scientific**

*110 Gas Detection People*
Appendix F. Poster

Appendix G. Example Webinar Slides (deliverable)

GYPSUM BEDDING
RISKS AND REWARDS

February 2015

Penn State Extension

GYPSUM BEDDING Introduction
Benefits and Use

What is gypsum and where does it come from
Uses in agriculture and benefits
Risk in manure storages – demonstration results

Penn State Extension

What is Gypsum

Calcium Sulfate
• CaSO₄·2H₂O (Hydrous)
• CaSO₄ (Anhydrous)

Naturally occurring mineral and coal plant byproduct

Penn State Extension

Manufacturing And Construction Waste

Gypsum is used to produce drywall for construction.
Manufacturing rejects and construction waste is collected and recycled.

Penn State Extension

Manufacturing And Construction Waste Is Processed And Sold For Use In Agriculture

Penn State Extension
Agricultural benefits – improves soil

- Water retention improves soil permeability and structure
- Reduces surface crusting
- Improves soil structure
- Retains nutrients, especially phosphates, improving crop yields
- Reduces odor, eliminates odors
- Provides a sun-sterilized soil environment (Es and E)

Agricultural benefits – ideal bedding for dairy cows

- As bedding:
  - Moisture absorption
  - Low bacteria counts
  - Neutral pH

Gypsum bedding provides a sulfate source within the manure storage that reduces to form H₂S

- Sulfate (SO₄²⁻)
- Hydrogen sulfide (H₂S)

Hydrogen Sulfide Creates A Dangerous Environment Heavier Than Air

<table>
<thead>
<tr>
<th>Exposure Level</th>
<th>LEL Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permissible Exposure (8-hour TWA) at 100%</td>
<td>200</td>
</tr>
<tr>
<td>Immediately Dangerous to Life and Health (IDLH)</td>
<td></td>
</tr>
</tbody>
</table>

General Industry: 200 ppm (200 parts/million).

Manure gases escape during agitation

Numerous reports of:

- REALLY strong smell
- Dead livestock
- Employees/workers overcome
- Some haulers would not haul from gypsum farms
METHODS: Three farm categories were observed in the fall and spring:
1. Gypsum
2. Gypsum with treatment
3. Non-gypsum

METHODS: H$_2$S concentrations were measured during agitation events using portable meters

METHODS: Temperature, wind speed and wind direction were recorded during data collection

METHODS: Manure was characterized
Field and Lab Analysis
- Samples were collected and analyzed for % solids, Ca, S, Total N, pH, ORP, PSC, and temperature

Physical Characteristics
- Crust thickness, Bottom sediments,

METHODS: Farm practices were documented
- Storage Design
  - Type of structure, volume
- Manure Handling
  - Loading, sulfate inputs
Change in wind direction increased H₂S concentrations.

Personal monitoring devices provide effective awareness of exposure.

14 out of 18 operators did not exceed 20 ppm H₂S exposure.

Best management practices lower exposure risk.

4 out of 18 operators were exposed to H₂S above 20 ppm.

Operators with two highest H₂S readings were close to agitation.
**Conclusions:**

- Elevated H$_2$S concentrations were observed at farms that use gypsum.

**Conclusions:**

- **H$_2$S Concentrations**
  - Increased gypsum application rate significantly increases cumulative H$_2$S concentrations.
  - Treatments did not significantly reduce cumulative H$_2$S concentrations, but more research could show otherwise.
  - Manure moving-mixing-agitation creates safety concerns related to high gas levels.
  - Safety practice's lower risk of exposure.
  - Risk of exposure present even at 10 meters downwind from storage that contain gypsum.

**Conclusions:**

- **Environmental Effects**
  - Wind speed and direction affect H$_2$S.
  - Temperature affects CH$_4$ but not H$_2$S.

**Conclusions:**

- **Gypsum Benefits**
  - Users and manufacturers claim gypsum retains plant available nitrogen — however, measurements did not confirm this claim.
  - Phosphorus retention increases with increasing gypsum application rate, but not at building rates less than 1% to gypsum per cow per day.

**Additional Project Findings**

- Low concentrations of methane were observed at non-gypsum and gypsum farms during manure agitation.

- Corrosion of metal lenses and building components was observed at multiple farms that used gypsum.

- Gypsum storage tanks reported by users to have increased odors.

---

**SUMMARY**

**On-Farm Demonstration Study**

**QUESTIONS?**
Practical Thoughts for Manure Handlers

Robert Reineke, Senior Extension Associate
Penn State Department of Animal Sciences
University Park, PA
reineke@psu.edu
(814) 865-1816

Gypsum and Liquid not needed

- All manures are organic material in a state of microbial degradation.
- Gases are a by-product of microbial respiration.

\[ H_2S \]

- Many people can detect it <1 ppm
- Can deaden sense of smell at 100 ppm
- Deadly 600 ppm

Gases

- Some are odorless
- Most (all) are colorless
- Some are explosive
- Some sink (e.g., \( H_2S \))
- Some rise

Open Air Manure Storage Safety

- Non-enclosed manure storages can still meet the definition of a confined space in terms of occupational safety and health:
  - Is large enough that a worker can enter and perform work;
  - Has limited or restricted means for entry or exit, and
  - Is not designed for continuous human occupancy.

“Easy in. Hard to get out!”

Confined Spaces

- Do not enter them!
- Gases can cause loss of consciousness and death.
- Always assume there are gases present!
What is your responsibility?
Everyone has an obligation to design, supply, buy, operate and maintain manure storage and handling systems that are safe for workers, visitors and children.

Invest in the Insurance of a Monitor
Test atmosphere
- Oxygen deficiency
- Combustibles
- Toxic gases
Multiple gas vs single gas—cost and ease of use will be a factor
Most reliable way of “seeing” the mobile

Open Air Manure Storage Safety
Safety tips include:
- No naked flame
- No smoking, open flames or sparks
- If equipment malfunctions shut it off and remove it before servicing
- If feeling unwell or uncomfortable, back out, contact someone and remove the situation before proceeding
- Be prepared to call 911 if an emergency happens…
- Have a buddy, designating the buddy a specific direction to take at the sign of an emergency

Tips for Operators
- Use a monitor
- Observe agitation from a distance. Consider remote control kill switches
- The first hour of agitation is probably the worst, but never let your guard down
- H₂S is a heavy gas—higher is better
- Remember health of nearby livestock
- This is one time when the Agricultural Work Ethic can backfire

Observed gas behavior
Gases “throw” in the direction of manure agitator nozzle, so be aware of dangerous impact on ‘downwind’ animal- or human-occupied areas

Operator Position – up and away
Position operator work area so that a person:
- Does not reach over the storage for routine practice
- Does not work or need to adjust machinery near storage ridge
- Is not in a low-lying area. (Remember H₂S is a heavy, ground-hugging gas
Choose up-wind position
Gypsum bedding should **not be used** with under-barn manure storage.

Unconditional recommendation against under-barn manure storage when gypsum bedding is used.

---

**WARNING**

**DURING AGITATION**

**DEADLY GASES POSSIBLE**

---

**New NRCS Warning Sign**

---

**Penn State Extension**

**Body Alarms!!!**

- Dizziness
- Wobbly knees
- Feeling hot and clammy
- Lack of attention to details
- Loss of motor skills
- Fatigue
- Anxiety
- Severe eye irritation
- Decrease in sight
- Irregular/rapid heartbeat

Pay attention to your body. Take action if there are signs of gas exposure. Get to fresh air!

---

**Learn More at the North American Manure Expo**

- Data collection demonstrations (July 14 Tour Day)
- Highlighted education on manure gas issues

**Chambersburg, PA**

- **Tour Day - July 14**
- **Main Event - July 15**

[manureexpo.org](http://manureexpo.org)

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**Penn State Extension**

**Manure Gas Risks Associated with Gypsum Bedding at Dairy Farms**

Penn State Investigators

- Eileen Fabian-Wheeler
- Mike Hile
- Davis Hill
- Dennis Murphy
- Robin Brandt
- Hershel Elliott
- Mike Platek
- Robert Melvin

[www.manurepitsafety.psu.edu](http://www.manurepitsafety.psu.edu)

**Video Presentations:**
- Reducing Entry Risk: Solid Floor Storages
- Reducing Entry Risk: Slotted Floor Storages

**Fact Sheets:**
- E 51: Confined Space Manure Storage Hazards
- E 52: Confined Space Manure Gas Monitoring
- E 53: Confined Space Manure Storage Ventilation System Design
- E 54: Confined Space Manure Storage Emergencies
- Open Air Manure Storage Safety Tips

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More information on issues surrounding handling manure with gypsum bedding

* Agricultural Safety web site
  - extension.psu.edu/business/gysafety
* Gypsum bedding and manure handling
  - site.psu.edu/news/2014/gypsum-bedding-is-it-worth-the-risk
* Commercial Manure Hauler and Broker Certification Program
  - www.agriculture.state.pa.us
* North American Manure Expo
  - manureexpo.org

SUMMARY
Practical Thoughts for Manure Handlers

QUESTIONS?
Appendix H. Fact Sheets (deliverables)
Written document for NRCS technical guidelines & non-technical brochure for NRCS personnel

SAFETY RISK FROM MANURE STORAGES OF DAIRY COWS BEDDED WITH GYPSUM

Michael Hile and Eileen Fabian-Wheeler, Agricultural and Biological Engineering

Human and cattle deaths have prompted investigation into what is causing dangerous conditions during otherwise routine manure handling procedures on farms. This brochure provides background and findings from on-farm monitoring of dairies using gypsum as stall bedding where a link has been found to highly toxic levels of hydrogen sulfide gas during manure movement and agitation.

GYPSUM – ANIMAL WELFARE AND AGRONOMIC IMPROVEMENT

Gypsum recycled from manufacturing and construction waste provides a bedding source for the dairy industry. Gypsum can be used as 100% of the bedding or as a bedding additive to traditional bedding materials. Advantages to its use include the following:

<table>
<thead>
<tr>
<th>Bedding</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorbs moisture</td>
<td>Low carbon</td>
</tr>
<tr>
<td>Low bacteria</td>
<td>Adds sulfur</td>
</tr>
<tr>
<td>Neutral pH</td>
<td>Adds calcium</td>
</tr>
<tr>
<td>Improved udder health</td>
<td>Reduced phosphorus runoff</td>
</tr>
</tbody>
</table>

GYPSUM AND MANURE GAS HYDROGEN SULFIDE

Gypsum is calcium sulfate (CaSO₄·2H₂O) so it provides a source of sulfate, which under anaerobic conditions can be microbially converted to hydrogen sulfide (H₂S) gas. Anaerobic conditions (without oxygen) exist in dairy manure slurry within many short-term and most long-term storages. Hydrogen sulfide is heavier-than-air. It therefore settles in low areas such as in pits, near storages, and in the breathing zones of calves and children. When present, H₂S is released in bursts that are dangerous to nearby humans and cattle during manure movement or agitation.

Personal Monitoring to Save Lives

Portable gas instruments detect and indicate hazardous situations. Audible, vibration, and visual alarms are set to alert the user of dangerous gas concentrations that are not otherwise detectable. It is recommended that farm operators working around manure storages with gypsum bedding wear a hydrogen sulfide personal gas monitor. Single gas monitors (right) are about the size of a cell phone and cost under $300. Units can provide multi-year battery life, display of gas level, and a second backup sensor. For professional dairy manure haulers a four-gas monitor offers additional safety from methane, low oxygen level in a confined space, carbon monoxide (exhaust) from equipment operation, in addition to hydrogen sulfide protection for gypsum-using farms.

Photo Source: Industrial Scientific

Hydrogen sulfide is immediately dangerous to life and health above 100 ppm. Lower concentrations of 10 to 20 ppm can be tolerated for periods of time, such as a part of a workday. Hydrogen sulfide gas has a familiar “rotten egg” odor to a healthy human nose. Unfortunately, this distinctive odor goes undetected at dangerous levels or after extensive exposure. Because of this, instruments are needed to detect H₂S concentrations to avoid dangerous conditions.
MONITORING MANURE AGITATION GAS RELEASE

Three types of farms were monitored based on their bedding management: 1) conventional dairy stall bedding; 2) gypsum bedding, and 3) gypsum bedding with a manure additive treatment. Instruments placed around the perimeter of the outdoor open-air manure storages recorded gas concentration immediately prior to and for up to two hours after manure agitation began. Findings are from ten farms during 19 events:

- The use of gypsum bedding increased H$_2$S gas release during manure agitation to levels that were dangerous near the storage (see graphs).
- Almost no H$_2$S was found near the non-gypsum dairy manure storages.
- Some additive-treated manure and crust-free manure reduced H$_2$S emissions during agitation.
- Operators with highest H$_2$S exposure were very close to agitation.
- The first 30 to 60 minutes of agitation is the most dangerous even near open-air outdoor manure storages.

REDUCING RISKS FROM GYPSUM-MANURE STORAGE

1. Gypsum bedding adds sulfur to manure that can lead to dangerous levels of hydrogen sulfide gas emission at agitation; but not all farms with gypsum bedding have safety problems.
2. Keep non-essential people away during agitation, especially children who are at increased risk as H$_2$S is typically at higher concentration close to the ground. Nearby cattle are also at risk.
3. Secure storage from entry; provide rescue and fall protection; gas monitors recommended.
4. Manure moving mixing agitation creates highest gas levels for the first hour. Leave the area.
5. Crust-free manure and additives seem to allow continuous H$_2$S release lowering agitation risk.
6. Gypsum benefits for cow bedding and agronomic values must be balanced against the potential gas hazard.

ACKNOWLEDGEMENTS: We are thankful that this demonstration of manure amendment is possible with the partnership of Penn State Extension with USA Gypsum, Industrial Scientific (gas detection) and Pennsylvania State Conservation Commission. This material is based upon work supported by the Natural Resources Conservation Service, U.S. Department of Agriculture; under number 69-2037-13-673. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Additional Information: Mike Hite 814-865-1783; mhill144@psu.edu. Eileen Fabian (Wheeler) 814-865-3552; fabiani@psu.edu

Penn State College of Agricultural Sciences research and extension programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

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Manure Storage Design and Safety Considerations with Gypsum Bedding

Eileen Fabian-Wheeler, Professor of Agricultural Engineering
Mike Hile, Post-Doc, Agricultural and Biological Engineering

Surprise! Open-air, outdoor manure storages pose dangers even with all that fresh air around. A number of recent human tragedies in the vicinity of mixing and cleanout of outdoor manure storages raised concern. A series of investigations by farmers, manure haulers, Penn State Extension personnel and industry leaders identified that gypsum-laced manure was capable of creating deadly levels of gas emissions, specifically hydrogen sulfide gas \(H_2S\). The gypsum, a.k.a. calcium sulfate, was a residual in the manure from its use as a beneficial bedding material in the dairy barn. This fact sheet outlines practical design considerations of manure storages and management for safely working during manure agitation events on dairy farms using gypsum bedding.

**Under-barn Manure Storage**

Our unconditional recommendation is to not use gypsum bedding with under-barn manure storage. Potential is very high for release of extreme concentration of \(H_2S\) when manure is moved or mixed, resulting in harm to barn workers and confined cattle.

**Operator Position During Agitation**

During any manure movement or mixing, operator must be up above the ground and away from edge of a manure storage. Particularly with manure containing gypsum bedding material, \(H_2S\) gas at lethal levels (>600 ppm) is quickly produced and undetectable by smell. Hydrogen sulfide is a heavy, ground-hugging gas.

**Position Work Area so Operator:**
- Does not reach over the storage for routine practices
- Does not work or need to adjust machinery near storage edge
- Is not in a low-lying area

**Wind Direction**

Hydrogen sulfide can settle in windless areas, shelterbelts or among buildings blocking airflow near a storage unit. Strong breezes will move \(H_2S\) out and away from storage, diminishing risk. Operators should be positioned upwind.

**Access During Agitation**

Once manure storage agitation begins, no one should be in the immediate area. Encourage casual onlookers to keep well away (minimum of 50 feet). Children, pets, calves, and resting cattle are more susceptible due to lower breathing zones. Low areas accumulate \(H_2S\) so operators, other people and animals should avoid any nearby depressions.
PLANNING LAYOUT

Gases “throw” in the direction of a manure agitator nozzle, so be aware of dangerous impact on “downwind” animal or human occupied areas. Confined cattle in the area are at risk.

CONFINED MANURE STORAGE

Long ago it was discovered that confined spaces accumulated dangerous levels of manure gases (sumps; low areas; gutters; cross channels; pits; pump out access areas; underfloor manure storages). Dangerous gas levels are especially common during agitation of the manure. The addition of gypsum bedding makes this an even greater hazard with the potential for high H₂S levels.

Take home points are:

1. Manure movement and mixing will almost certainly cause dangerous levels of H₂S gas release from manure that contains gypsum bedding.
2. Avoid being anywhere near the manure storage during agitation events and consider impact on occupants of nearby surroundings.
3. Up and away. Operators positioned above surrounding topography and at a distance from the storage area at reduced risk for experiencing dangerous H₂S gas levels versus operators positioned nearby at ground-level. Operators should be positioned upwind.

May 2015

Contact Information

Department of Agricultural and Biological Engineering
249 Agricultural Engineering Building
University Park, PA 16802

ACKNOWLEDGEMENTS: An evaluation of conditions for farms using and not using gypsum bedding was possible with the partnership of Penn State Extension with USA Gypsum, Industrial Scientific (gas detection) and Pennsylvania State Conservation Commission. This material is based upon work supported by the Natural Resources Conservation Service, U.S. Department of Agriculture; under number 69-2D37-13-673. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

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Appendix I. News Articles

Krieg, Dieter. It’s coming! Don’t let it get you! Farmshine - September 5, 2014.

Manure Handling Field Day Focuses on Hydrogen Sulfide Gas

DICK WANNE

FIRE GROVE, Pa. — It was almost like standing next to a pond full of spring peepers. Peep-peep-peep.

But the noise wasn’t coming from tiny frogs. It was coming from hydrogen sulfide monitors hanging from a chain-link fence encircling a 12-foot-deep liquid manure pit on Eric and Amy Wolfe’s dairy farm here in Schuylkill County.

Many of the 40-onlookers wandering around the pit were also wearing monitors that contributed to the din.

The Wolfs were the hosts for a liquid manure handling field day designed to emphasize the need for safety awareness around manure pits.

The demonstration project was also expected to provide some insight into the effectiveness of additives that might reduce the presence of hydrogen sulfide — H2S — in liquid manure.

The project was the result of an agri-business effort involving a tractor-powered agitator that drew material from the bottom of the 12-foot-deep pit and sprayed it through a nozzle onto the top.
Field Day

Continued from p.1

An unusual alliance of government, academia and industry, according to Eileen Fabian-Wheeler, a Penn State professor of agricultural and biological engineering.

It was also one of the few such projects ever to receive a hefty grant from the USDA’s Natural Resources Conservation Service. Here’s the way Fabian-Wheeler described that alliance:

NRCS sponsored Penn State doctoral candidate Mike Hille’s demonstration project with a $30,000 grant. Matching support of the same amount came from Penn State, USA Gypsum, the Pennsylvania State Conservation Commission and Industrial Scientific.

Terry Weaver, president of USA Gypsum, covered the field day expenses for lunches and beverages, fuel and oil for the Wooleys.

Penn State Extension coordinated the 10 farms used in Hille’s project, and prepared and presented the program on the Wolfe farm.

Industrial Scientific donated about $15,000 worth of gas monitors to the project, and those monitors will continue to be used in other demonstrations, extension education and research.

Aug. 25, the day of the program, was clear, windy and on the cool side of normal for late summer. It was a perfect day for agitating a manure pit, Hille said.

We have seen some promise for additives under these controlled conditions and in some previous, controlled lab-scale work,” Fabian-Wheeler said.

Weaver’s interest in Hille’s work was sparked by the fact that gypsum bedding had dramatically increased the amount of hydrogen sulfide in liquid manure. His company, US Gypsum, is a major supplier of gypsum bedding, which is made from recycled wallboard and other gypsum-rich building products.

“Many of the many farms said the gypsum bedding was the secret to their high-quality bedding,” Fabian-Wheeler said.

Hille, a doctoral agricultural engineering student at Penn State, is shown with two H2S monitors, one mounted near the ground, one at chest level. That difference in height can mean the difference between a safe and deadly level of the heavier-than-air gas.

“Hydrogen sulfide in the air at 100 parts per million is considered an acceptable level,” Hille said. “A concentration of 20 ppm is considered safe.”

A concentration of 20 ppm is considered safe. The field day monitors were set to go off at 10 ppm. It was possible to track the position of the agitator nozzle by the monitor beeps. As the nozzle swung across the surface, it created a plume of gas with considerably elevated concentrations of H2S.

Hydrogen sulfide smells like rotten eggs, and it can be deadly. And, in livestock housing, it is heavier than air, which has a molecular weight of 34 ppm.

It can creep out of a manure pit and fill the ground to an invisible, deadly carpet a foot or two thick, where a farmer’s kids can be riding their bicycles while the farmer is breathing good air several feet above the ground.

This actually happened two years ago in Montour County, and fortunately, the boys’ father dragged them to safety just in time.

Mike Hille’s doctoral thesis will focus on the effectiveness of additives intended to reduce the presence of hydrogen sulfide in manure pits. The additive used on the Wolfe farm is Vital Breakdown, a nitrogen-rich formulation made by Homestead Nutrients in New Holland, Pa.

“We have seen some promise for additives under these controlled conditions and in some previous, controlled lab-scale work,” Fabian-Wheeler said.

Weaver’s interest in Hille’s work was sparked by the fact that gypsum bedding had dramatically increased the amount of hydrogen sulfide in liquid manure. His company, US Gypsum, is a major supplier of gypsum bedding, which is made from recycled wallboard and other gypsum-rich building products.

Although gypsum bedding can increase the presence of deadly H2S, by and large, farmers have to know how to deal with it. “You can do anything from a daily basis,” Weaver said.

Heavily gassed areas are something they have to be careful about — like football solutions — but they say the advantage of gypsum bedding is that it’s less toxic than other bedding materials.

They work with about 180 farms, mostly Holstein producers, with a few Barrows, Whiteface, Jerseys and even one Jersey.

“This cow is clean and dry. They’re comfortable. We have a policy that we have a dense room in front of the barn where we keep the cows in a 15 x 40-foot room, and we switch to a different paddock every day,” Weaver said.

“We’re going to stick with gypsum.”
Gypsum bedding: Is it worth the manure safety risk?

Elann Fabian-Wheeler for Progressive Dairyman

Recent deaths of farmers and cattle have raised awareness of the all-too-common dangers of working around manure storage facilities. People “being overcome” or feeling dizzy around manure storage areas is not uncommon. Headlines often list the reason as asphyxiation or toxic gas. Many times, the toxic gas is hydrogen sulfide, with most deaths associated with below-ground, enclosed storages. More recent investigations indicate that hydrogen sulfide is also present in outdoor open storages, particularly on dairy farms where gypsum is used as bedding material.

Recent measurements at 10 dairy farms confirm highly elevated hydrogen sulfide gas concentrations surrounding open manure storages during agitation prior to manure removal for land application. A link to gypsum bedding seems clear. A big concern is the everyday risk of working near any stored manure, particularly when agitating.

Gypsum bedding has become popular in regions with an affordable supply, such as in Pennsylvania. It is obtained from recycled construction waste, such as drywall board. Bedding products range from a four powder to granular material to pelletized wall-board chunks. All versions seem comfortable to the cows, offering increased moisture absorption and low bacteria growth in the pit-ceiling material, enhancing animal welfare through improved odor control and cow cleanliness.

Farmers are keen on gypsum bedding due to the soil benefits. Manure from gypsum-bedded cows has reduced carbon to be broken down once land-applied versus wood chips and sawdust bedding. Plus gypsum manure provides additional sulfate to soil while reducing phosphorus runoff through improved phosphorus source coefficient (PSC).

Thus, there are many good reasons for the use of gypsum as dairy cow bedding. The question now is how to raise awareness that safe manure-handling practices are just as important, if not more so, when handling manure containing gypsum or with any manure source.

One might ask how a bedding material source could influence risk during manure handling months later. Gypsum is calcium sulfite (CaSO4·2H2O) that under anaerobic (no oxygen) conditions in manure storage is microbially converted to hydrogen sulfide gas. This makes it very likely that hydrogen sulfide will be produced in dairy manure collection pits and manure storages. Some will recognize hydrogen sulfide by its “rotten egg” smell.

Hydrogen sulfide gas is particularly tricky as it is heavier than air. It can settle in low spots near manure storage. Children breathing at their level are more susceptible to hydrogen sulfide plumes. Equally tricky is that hydrogen sulfide overcomes the sense of smell, and no longer smells like rotten eggs at dangerous levels (100 ppm). Then, at higher levels (500 ppm or more), it quickly arrests the ability to breathe properly, resulting in death by asphyxiation. At extremely high levels (approximately 1,000 ppm) breathing ceases quickly.

Gypsum bedding offers benefits to cow comfort, milk quality, and agronomic features, but its use should be weighed against the risk of elevated levels of hydrogen sulfide gas in manure storages.

Hydrogen sulfide and other gases of concern are released in bursts during manure movement and agitation. These bursts are often accompanied by a metallic odor. During our measurements from a USDA Natural Resources Conservation Service-funded demonstration project, we found several factors of interest. One is with gypsum-bedded cows, the manure during agitation released hydrogen sulfide levels that were immediately dangerous to life and health (at 300 ppm or higher). This raises obvious concern. Plumes of this gas have been known to be present in dangerous levels in below-ground, enclosed storages with any species of

Continued on page 925.
Gypsum bedding: Is it worth the manure safety risk? cont’d from page 131

Three manure storage safety tips

Outdoor dairy manure storage ponds are open to the atmosphere and still need the definition of a confined space in terms of danger from toxic gases and drowning.

1. Never work alone. The first answer a person’s role is to summon help in an emergency and assist with rescue without entering the storage.

2. If you must go into the fenced area of the open manure storage, wear a safety harness with a life line attached to a safely located anchor or anchor will enhance your chance of rescue.

3. Find more useful information in the publication from which these three tips were taken. Open Air Manure Storage Safety Tips, Penn State Extension. By D.J. Murphy, R. Kline, and D.E. Hill, 2014.

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Eileen Frostie-Wheeler is an agricultural and biological engineering professor with Penn State University. Email her at efw2@psu.edu
Agricultural Safety, Sometimes Forgotten

There must be ongoing education of farmers, their families, and hired hands on the dangers of gases on farm properties.

BY MIKE PLATEK

One industry in the United States that many people take for granted is the farming industry. Agriculture and agriculture-related industries contributed $75.8 billion to the U.S. Gross Domestic Product in 2012, a 4.8 percent share. Of that amount, American farms contributed $166.9 billion, or about 1 percent. That translates into 16.5 million full- and part-time jobs, accounting for about 9.2 percent of total U.S. employment. More than 2.6 million of those jobs are directly connected to U.S. farms.

Why all the stats? Agricultural deaths in 2012 totaled 475, making the death rate 21.2 per 100,000 full-time workers. And to make matters worse, in 2013, the number of deaths climbed to 479 and the rate increased to 22.3 deaths per 100,000 workers. These numbers shouldn't be accepted by anyone.

Having spent time on farms, I have seen several unsafe acts involving different age groups. On family farms, the "young ones" are always helping out, from driving tractors and combines to working closely with the animals.

Of the many safety hazards that exist on a farm, the atmospheric hazards often go unaccounted for or are simply forgotten. This is due to either lack of caring or just being unaware of the potential gas hazards on a farm. Because of this, an increasing number of farmers and their family members are dying from gas exposures.

Areas in a farm that should be of concern are silos, outbuildings, barns, and manure pits. The most hazardous of these locations, by far, is manure pits. Some of the gases that can be found on a farm are hydrogen sulfide (H₂S), nitrogen dioxide (NO₂), methane (CH₄), chlorine (Cl₂), and ammonia (NH₃). In addition to these hazardous gases, another threat is the depletion of oxygen (O₂), which is a very common problem. The areas where these gases appear on a farm's property are numerous. For example, ammonia is used as a fertilizer, while nitrogen dioxide can be found when corn and other crops along with silage are stored in silos, while methane and hydrogen sulfide are present in manure pits. The list goes on.

Manure Pit Gas Hazards

As mentioned, the most hazardous area on a farm is the manure pit. Look at any fatality report regarding farming, and you'll see that the manure pit generally gets top billing as one of the most dangerous locations. Why are manure pits so dangerous? A typical dairy cow that produces approximately 2,000 gallons of milk per year also produces more than 7,000 gallons of liquid manure. The manure requires storing and overall managing by the farmers.

The Agricultural and Biological Engineering group of Penn State University is currently conducting a research project on hydrogen sulfide releases from manure pits, with a focus on farms using gypsum products as bedding for dairy cows.

The Agricultural and Biological Engineering group of Penn State University is currently conducting a research project on hydrogen sulfide releases from manure pits, with a focus on farms using gypsum products as bedding for dairy cows. The gypsum bedding is being used for the animals' welfare in that it improves the dairy cows' living conditions. The gypsum absorbs moisture better, reducing the bacteria count, and it is pH neutral. As a result, the cows are healthier. Later, as the manure is spread on the fields, the effects on the soil are low carbon additions with added sulfur.

(3th study was principally funded by a grant from the USDA-Natural Resources Conservation Service [USDA-NRCS]. It is being conducted by Mike Hile, a Ph.D. candidate at Penn State University, and overseen by Eileen Fabian Wheeler, professor, Air Quality. They are located in University Park, Pa., and can be contacted as follows: Mike Hile, mh14@psu.edu; Eileen Wheeler, efw2@psu.edu.)

Before gypsum was introduced to the dairy industry, there needed to be an understanding of the working of the manure pits and the dangers associated with them. The cow manure is moved from the barn into
a manure pit either by a built-in conveyor system or manually by the farmer, depending on the size of the dairy operation. For example, one farm included in the research study has 279 dairy cows and a 1 million-gallon manure pit. The pit is emptied twice a year, with the manure spread over the fields for fertilizer. Typically this is done in late fall after the crops have been harvested and then again in the spring before the crops are planted.

This long storage time of the manure allows it to go anaerobic (without oxygen) and allows the bacterial action to produce hydrogen sulfide. Sometimes a "crust" forms on the top of the manure, acting as a lid trapping the gases. The danger occurs when the farmer needs to "stir" the manure pit to prepare for the disposal or spreading of the manure. The stirring releases the hydrogen sulfide, along with any methane. The presence of these gases also can contribute to low-oxygen atmospheres. There are numerous accidents on record of farmers and members of their families who have been overcome by these deadly gases.

While gypsum benefits the welfare of cows, it increases the presence of hydrogen sulfide. Gypsum is a sulfur-based ore. Also known as calcium sulfate, CaSO₄, it provides a sulfate source within the manure storage that reduces to form H₂S. The Penn State research is focused on the use of gypsum as bedding and its contribution to the increased levels of H₂S. When farms using gypsum were studied, H₂S was detected at life-threatening levels.

OSHA has a PEL of 20 ppm that is stated as the ceiling level, with an Immediately Dangerous to Life or Health level of 100 ppm. When the manure pits containing gypsum were stirred, levels as high as 300 ppm were encountered. A breath or two at these levels could have serious effects on a farmer, including respiratory distress and/or unconsciousness, potentially leading that farmer to fall into the manure pit. This could lead to higher gas exposures, asphyxiation, and even drowning.

One farm visited during the study experienced a very close call related to the safety of the family's two young boys. Playing slightly downhill from the manure pit one day during a stirring process, the boys were observed by their father to be lying next to their bikes. Thinking the boys were just playing, he continued his work. A short time elapsed and he noticed the boys were in the same position. They had been overcome by hydrogen sulfide. He immediately attended to the boys and was able to revive them. No long-term damage occurred, but the younger boy was kept overnight at the hospital for observation.

There must be ongoing education of farmers, their families, and hired hands on these gas dangers on farm properties.

Mike Platek is a Gas Detection Specialist at Industrial Scientific Corporation.

REFERENCES
2. Centers for Disease Control (CDC) NIOSH Publication NIOSH 2000-001
3. Occupational Safety & Health Administration (OSHA) News Release: 13-1921-NAT (234)

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2. Centers for Disease Control (CDC) NIOSH Publication NIOSH 2000-001
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Krieg, Dieter. The invisible goon in the lagoon has been detected. Farmshine – December 5, 2014.
Krieg, Dieter. This poisonous cocktail shows absolutely no mercy. Farmshine – December 5, 2014.
Manure management safety

As information was being shared at a safe distance from the pit, a monitor would check on the monitors from time to time and report the findings. Where the PPM reading might have been 30, it had shot up to 400 and even higher as a result of the pit’s contents coming into the air. Inside the concrete storage facility, the PPM reading shot up to 600. A level of 300 and higher is considered lethal.

The group of attendees, which kept growing throughout the event, included people from far away as Pen Yan, N.Y. Henry Marie and his son, Deryl, were among four men from the Finger Lakes Region to make the trip. Why? They wanted to see the results and learn all they're interested in manure management safety.

Don Weaver, owner of Homestead Nourished at New Holland, was also among the visitors. Like everyone else, he was interested in having the opportunity to buy it. Don has a simple message: "It's also got a Stay close of it."

Safety awareness is the big deal in all of this. The word needs to get out," concluded Penn State’s Mike Hile.

More information to be shared in an upcoming edition. Please stay tuned.

Transitioning cows is topic of Technology Tuesday program

UNIVERSITY PARK, Pa. — Transitioning cows from the dry period into and through early lactation as the subject of the next “Technology Tuesdays” webinar on December 9, produced by the Penn State Extension Dairy Team.

Registration for the Technology Tuesdays Webinar Series is free and open to anyone interested in learning more about technology and management updates in the dairy industry. The discussion will be led by Luke Tyson, an extension specialist, Penn State Extension Dairy Team.

The webinar will look at animal behavior aspects of this transition period as well as housing and management updates. The discussion will be held by Luke Tyson, an extension specialist, Penn State Extension Dairy Team. Registration for the Technology Tuesdays Webinar Series is free of charge.
Krieg, Dieter. Do not give the killer in the pit the benefit of the doubt. Farmshine – October 10, 2014.
Dekar, Emily. Empty it, maintain it, and above all, stay safe. Farmshine – October 17, 2014.
Krieg, Dieter. They’re not just standing around. Farmshine – October 24, 2014.
Gypsum Linked to Poison Gas in Manure Storage

Philip Gruber
Staff Writer

A soft mineral that makes a good dairy bedding can also make manure storage more dangerous.

Researchers have suspected for some time that gypsum, the main material used in dairy-walls, increases hydrogen sulfide levels in manure storages, and new research supports that belief. Penn State Extension Associates said Feb. 10 during a webinar in Lancaster County.

Gypsum, or calcium sulfate, occurs naturally and is a byproduct of burning coal. The gypsum used on farms is made using waste from drywall manufacturing, said Mike Hile, a Penn State graduate student who conducted the research.

When used as a bedding for dairy cows, gypsum absorbs moisture and helps keep bacteria low. It has a neutral pH, so “it’s really ideal bedding,” he said.

As a soil additive, gypsum improves soil quality, holds water more easily and improves root development. It reduces phosphorus runoff, retains plant-available nitrogen, and supplies calcium and sulfur, Hile said.

Unfortunately, when gypsum winds up in manure storage, it tends to break down and produce hydrogen sulfide, a poisonous and explosive gas that is dangerous even at low concentrations.

“Industry doesn’t like to see workers exposed to above 20 parts per million,” and the gas is immediately threatening at 100 parts per million, Hile said.

Most people can smell hydrogen sulfide at extremely low concentrations, said Rob Meinen, Penn State Extension associate.

“The concentration increases, actually your olfactory senses deaden a little bit and you all of a sudden don’t recognize that rotten-egg smell,” and you can actually still be in the dangerous environment without even realizing it,” Hile said.

Hydrogen sulfide is released when covered manure is digested, Hile said.

For years, there have been cases of farmers being overcome by manure gases, but over the past few years, more stories have surfaced of “manure-smelling really, really strong,” dead livestock, and employees collapsing, said David Hill, an Extension ag safety associate.

“We’ve heard (of) some manure handlers that have made a policy that they’re refusing to load manure from farmers that use gypsum bedding,” Hill said.

In May 2012, three Pennsylvania workers died in a manure storage on a Maryland farm that used gypsum bedding.

Later that year, two little boys in Montour County were found unconscious next to a manure storage after it was exposed to gas.

Their father moved them to safety just in time, Hill said.

Usually, hydrogen sulfide makes up 10-20 parts per million of the air around a manure pit during agitation. But at the Montour site, the levels were 1/50 parts per million. The boys probably managed to survive at levels of 500-600 parts per million, Hile said.

“Gypsum fugitive gas listed in safety handbooks,” Hill said.

Environmental conditions can change the risk. A storm rolling in can cause a gas plume to blow hydrogen sulfide directly into the barrier barn, where the trapped gas topped 500 parts per million.

“Hydrogen sulfide is actually higher than my meters would measure,” Hill said.

For now, safety precautions are the best way to reduce the risk, researchers say.

Treatments claimed to reduce hydrogen sulfide did not perform as advertised in Hill’s test.

Some additives have been promising in lab research, but more farm-scale research needs to be done, Hile said.

Once agitation starts, everyone should stay at least 50 feet away from the storage, said Ed Fabbri, a Penn State engineering professor.

“It’s helpful to be aware of who’s around: children, animals, other workers that aren’t necessarily working right at the perimeter,” Hile said.

Hydrogen sulfide is heavier than air and tends to stay at the lowest point. “You might be good while you’re standing, but if you bend over you might be in trouble,” Meinen said.

Children at particular risk because they are short enough to breathe in the hydrogen sulfide’s plume and because they’re naturally curious.

Meinen remembers being at the Washington County Fair a few years ago.

“Every time there was a hole in a confined space, the kids were the first ones to walk through,” he said.

Purdue University found that 10 percent of manure gas deaths were children, Meinen said.

Most manure gas deaths happen during warm months when microbial activity is greatest. August accounted for a quarter of the deaths in one study, Meinen said.

Presumably, the farmers emptied the storage in the spring, the moisture accumulated while crops were growing in the summer, and they started to spread again when silage came off, he said.

It is best to have a second person to at least get help, not necessarily rescue, someone working in manure storage. “We could avoid many deaths if we employed a buddy system,” Hill said.

If help is far away, the second person may need to perform a rescue, but this is risky. “For every four people that went unconscious, another person died trying to rescue them,” Meinen said.

Meinen said people near manure storages need to pay attention to their “body alarms.”

“Tend to walk up a stair or four flights of stairs and you really didn’t exert yourself, but your body is feeling off,” Meinen said.

Meinen said a manure handler who visited the Maryland farm said his exposure was so bad he could barely see a manure tank 20 yards away.

Wearing a gas detector can minimize your risk. The “first hint of agitation is probably the worst, but never let your guard down,” he said.

Fabbri, the engineer, “unconditionally recommends” that gypsum bedding not be used with earthen manure storage. The chance of exposure is just too great, he said.

Hydrogen sulfide is only one of more than 200 manure gases, but farmers still need to weight the toxic value of gypsum bedding against the danger of the gas it creates.