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.
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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$_2$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$_2$S emission released from movement of manure containing gypsum-based bedding. Gypsum (CaSO$_4$·2H$_2$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$_2$S release at farms using gypsum bedding, a manure amendment compound was identified that reduced H$_2$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$_2$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$_2$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$_2$S concentrations that were considered immediately dangerous to life and health (above 100 ppm). Increasing gypsum use significantly increased cumulative H$_2$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 H$_2$S gas emission concentrations. However, no scientifically-defensible evidence has linked gypsum bedding use with dangerous levels of H$_2$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)
Michael Hile
Davis Hill
Robert Meinen
Dennis Murphy
Robin Brandt
Hershel “Chip” Elliott
Vance Brown

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 H₂S 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 (H₂S) 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 H₂S 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, H₂S exposure inhibits respiration and can cause death according the Occupational Safety and Health Administration guidelines (OSHA, 2005). Physical effects for various H₂S exposure levels are summarized in Table 3-1.

Table 3-1: Physical effects of exposure to various levels of H₂S (ANSI, 1972)

<table>
<thead>
<tr>
<th>H₂S Concentration (ppm)</th>
<th>Physical Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13</td>
<td>Minimal perceptible odor</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 H₂S 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, desulfatomaculum, desulfo bacter, desulfococcus, 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>( \text{O}_2 \rightarrow \text{H}_2\text{O} )</td>
</tr>
<tr>
<td>Denitrification</td>
<td>( \text{NO}_3^- \rightarrow \text{N}_2 )</td>
</tr>
<tr>
<td>Manganese Reduction</td>
<td>( \text{Mn}^{4+} \rightarrow \text{Mn}^{2+} )</td>
</tr>
<tr>
<td>Iron Reduction</td>
<td>( \text{Fe}^{3+} \rightarrow \text{Fe}^{2+} )</td>
</tr>
<tr>
<td>Sulfate Reduction</td>
<td>( \text{SO}_4^{2-} \rightarrow \text{H}_2\text{S} )</td>
</tr>
<tr>
<td>Methanogenesis</td>
<td>( \text{CO}_2 \rightarrow \text{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, \( \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \)) as part of bedding material, provides an extra source of S and therefore creates potential for additional \( \text{H}_2\text{S} \) 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 \( \text{H}_2\text{S} \) generation, other biochemical, environmental and physical factors affect \( \text{H}_2\text{S} \) production.

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

3.4.1  Biochemical Factors

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

![Diagram](image)

**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.
Figure 3-2: H$_2$S concentration increase with increase in temperature. (Andriamanohiarisoamanana et al. 2015).

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$_2$S emissions based on types of manure storage structures and production facilities for the swine industry. Facility management practices may also influence H$_2$S emissions.

3.5 Need for Solution

The need for odor control and the prevalence of H$_2$S in the swine industry have prompted discussion and research endeavors regarding H$_2$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$_2$S and NH$_3$. 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$_2$S emissions by increasing the redox potential in the manure. The energy yield for reducing sulfate to H$_2$S is much less than the energy yields for these oxidizers. Thus, the presence of electron acceptors having higher energy yield inhibit H$_2$S emissions. Smith and Nicolai (2005) found that potassium permanganate and hydrogen peroxide oxidized H$_2$S into its elemental sulfur form and reduced H$_2$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$_2$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$_2$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$_2$S gas from manure. A substantial set of observations is first required for analysis. Biochemistry supports the conditions for H$_2$S production from gypsum mixed with manure. Dangerous levels of H$_2$S emissions occur due to a variety of factors. Environmental conditions, biochemical characteristics and even management practices can promote H$_2$S production. Yet, addition of products or thoughtful management practices can reduce H$_2$S emission at
manure movement and agitation. Understanding the factors beyond the conditions that generate H$_2$S is crucial to identifying solutions that reduce or eliminate hazardous conditions. Developing evidence for commercial amendments that mitigate H$_2$S 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 H$_2$S 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 H$_2$S 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 H$_2$S 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: H₂S 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: H₂S; CH₄; NH₃; carbon monoxide (CO); CO₂; O₂ 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 (H₂S) 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 H₂S 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 represent 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 H$_2$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 H$_2$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 H$_2$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 H$_2$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 H$_2$S concentrations. However, statistical analysis indicates that Vital™ Breakdown did not significantly (alpha = 0.05) reduce cumulative H$_2$S 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 H$_2$S 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 H$_2$S concentration, suggesting that H$_2$S emissions may be decreased using manure amendments.

Figure 5-4: General linear model regression line through cumulative H$_2$S 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$_2$S plume resulting in elevated cumulative H$_2$S concentrations close to the storage.

5.2 Operator Exposure

Personal monitors provided a way to measure operator exposure to H$_2$S during the observed 60 minutes of agitation. Recall that H$_2$S 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$_2$S during agitation. Operators that were considered safe, therefore not exposed to over 20 ppm H$_2$S, 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$_2$S 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$_2$S during agitation.*
Figure 5-6: Four operators were periodically exposed to over 50 ppm H₂S (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 H₂S) 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 H₂S 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 H₂S proximate to the storage. Table 5-1 lists maximum H₂S 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 H₂S 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 H₂S emissions) showed downwind conditions above 20 ppm H₂S.

Table 5-1: Maximum H₂S 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>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 meters from storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(lbs cow⁻¹ day⁻¹)</td>
<td>(ppm)</td>
<td></td>
</tr>
<tr>
<td>Non-gypsum (NG)</td>
<td>Ht F13 NG</td>
<td>0.0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cp F13 NG</td>
<td>0.0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cp S14 NG</td>
<td>0.0</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ht S14 NG</td>
<td>0.0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sh S14 NG</td>
<td>0.0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Gypsum (G)</td>
<td>Wr F13 G</td>
<td>5.1</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wr S14 G</td>
<td>5.1</td>
<td>11</td>
<td>prior agitation</td>
</tr>
<tr>
<td></td>
<td>We S14 G</td>
<td>0.6</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sr S14 G</td>
<td>0.3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>We F14 G</td>
<td>0.6</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sr F14 G</td>
<td>0.3</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Gypsum with treatment (GT)</td>
<td>Bl F13 GT</td>
<td>2.0</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bl S14 GT</td>
<td>3.4</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Br S14 GT</td>
<td>0.4</td>
<td>7</td>
<td>Multi-stage Manure Transfer</td>
</tr>
<tr>
<td></td>
<td>Cy S14 GT</td>
<td>1.2</td>
<td>11</td>
<td>Slurry Store™</td>
</tr>
<tr>
<td></td>
<td>Hr S14 GT</td>
<td>7.4</td>
<td>5</td>
<td>liquid manure, no crust</td>
</tr>
<tr>
<td></td>
<td>Hr F14 GT</td>
<td>7.4</td>
<td>170</td>
<td>liquid manure, no crust</td>
</tr>
<tr>
<td></td>
<td>Br F14 GT</td>
<td>0.5</td>
<td>2</td>
<td>Multi-stage Manure Transfer</td>
</tr>
<tr>
<td></td>
<td>Bl F14 GT</td>
<td>3.4</td>
<td>1000</td>
<td></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 H$_2$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 H$_2$S concentration of 42 ppm confirming anecdotal reports that some farms using gypsum bedding experience no problems with H$_2$S levels, but at other times encounter hazardous conditions. It seemed that frequent movement decreased H$_2$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 H$_2$S generated during transfer is lost to the atmosphere before reaching the long term concrete storage structure, thus reducing H$_2$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 H$_2$S escaped over the edge of the storage. Note though that H$_2$S at 10 m distant was measured at 11 ppm for the Cy farm during the spring 2014 agitation.

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

These results measuring H$_2$S 10 m (33 ft.) away from the manure storage provide additional support for concluding that gypsum promotes greater risk of H$_2$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 H$_2$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$_2$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$_2$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$_2$S concentrations.

Table 5-2: Manure characteristics, environmental parameters, manure handling practices and sulfur sources that were analyzed for effect on H$_2$S concentrations.

<table>
<thead>
<tr>
<th>Independent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure characteristics</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Environment parameters</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Storage engineering</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Manure handling</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Sulfur sources</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

None of the independent variables in Table 5-2 had a statistically significant effect on cumulative H$_2$S concentrations during manure agitation. Surprisingly, no temperature effect on H$_2$S cumulative concentration was found as this is a documented influence with greater temperature increasing H$_2$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 H$_2$S concentration was detected, however, it should be noted that wind direction could be a localized factor. Observation of highly elevated H$_2$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 H$_2$S production. Observations showed that repeated movement or mixing of the manure released H$_2$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 H$_2$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 H$_2$S gas. Findings include:

**6.1 Conclusions**

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

- Measurements collected before and after agitation show H$_2$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 H$_2$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 H$_2$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$_2$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$_2$S and reduce health hazards. Safety can be improved through awareness of conditions via personal gas monitors and, perhaps, manure amendments to lower H$_2$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$_2$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$_2$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$_2$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$_2$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$_2$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:

American Society of Agricultural and Biological Engineers. Reference No. 1893752.


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 7-2: Summary of news articles

<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**


Executive for Northern Ireland Health and Safety Authority, Ireland Available at: 


Appendix A. Manure Additives

Vital Breakdown

Benefits of Vital Break Down
- Controls odors
- Breaks down solids
- Fosters the building of humus
- Requires less agitation
- Retaining 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 lb. for each additional 10,000 gallons of liquid.

OR
For Dairy: 1/4 to 1 lb. per cow per year
For Hogs: 1 lb. per 5-10 head per year

**Important**
* Agitate for proper aeration to insure efficient biological action.
* If extra odor control is needed, do not hesitate to add more.
* Weekly application produces best results.

**DEV MANURE PAILS:**
Treatment: 1/2 lb. for 100 square feet
For-Horses - Apply at every 4 inch depth
For-Brush - Apply at every 6-8 inch depth.

Distributed By:
This data shows the amount of Nitrogen retained in the total dry matter of the manure 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 cow per year.

This data shows the amount of organic Nitrogen formed after treating the manure 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 as well as 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 sulfhydril group. The sulfhydril 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 326,000 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 tank mixed with most liquid fertilizers, herbicides, insecticides and fungicides. Use in conjunction with a good soil test and soil fertility program. Always perform a compatibility test prior to mixing any chemicals. Application should be made within 24 hours after dilution.

This product is intended as a supplement or addition to regular fertility, not a replacement of fertility.

LIMITED WARRANTY
Manufacturer and seller make no warranty, expressed or implied concerning the usefulness of this product, and shall not be liable for any injury or damage occurring from misuse or mishandling. Buyer assumes all responsibilities other than stated label guarantees. Manufacturer or seller's obligation is limited to replacement for the quantity of defective materials only.

KEEP OUT OF REACH OF CHILDREN
SHAKE WELL BEFORE USE
PROTECT FROM FREEZING

RECOMMENDED APPLICATIONS
COLLECTION PONDS - LAGOONS AND REINTRODUCTIONS:
Spray 8 to 12 ppm over surface using water as a carrier for uniform coverage, or add at several locations, depending on solids.

STOCK PONDS - FISH CULTURE PONDS:
Use 1 to 3 ppm. If excessively muddy or very high algae is present, repeat application in three to four days. After pond has been stabilized, repeat application of 1 to 3 ppm every two to three weeks as needed.

FEED LOTS - BARN AREAS:
Spray 4 to 6 ounces per 1,000 square feet of surface area. Use sufficient amount of water for uniform coverage.

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

HOESE SEPTIC SYSTEMS:
Use 1 quart every 30 days by flushing into system. To aid in clearing pipes and drains, use 1 fluid ounce weekly in each commode, wash basin and drain. Follow application by either 1 flush for commodes or 1 gallon of water for drains.

Manufactured by:
PRO-SOIL AG SOLUTIONS, INC.
P.O. BOX 1537-HAWKINS, TX 75755
903-799-5081

Net Content 2.5 gallons (9.4L)
20.85 U. S. lbs (9.45 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.):

2nd 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 A-1: Farm characterization summary

<table>
<thead>
<tr>
<th>Sampling Season</th>
<th>Farm</th>
<th>Cumulative H2S Concentration</th>
<th>Gypsum Application Rate</th>
<th>Storage Structure</th>
<th>Manure Transfer</th>
<th>Storage size (gal)</th>
<th>Thickness of Bottom Solids (% DM) (inches)</th>
<th>Surface Coat</th>
<th>Sulfur Sources (Aside from Gypsum)</th>
<th>Somatic Cell Count</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fall 2013 (F13)</strong></td>
<td>BF 13 GT</td>
<td>1250.8 2.0</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
<td>1,300,000</td>
<td>36</td>
<td>45</td>
<td>12</td>
<td>0</td>
<td>0</td>
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<tr>
<td></td>
<td>Wf 13 G</td>
<td>1326.1 5.1</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
<td>415,000</td>
<td>12</td>
<td>100</td>
<td>12</td>
<td>2400</td>
<td>0</td>
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<td>HH 13 NG</td>
<td>150.2</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
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<td>48</td>
<td>100</td>
<td>36</td>
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<td></td>
<td>Cyp 13 NG</td>
<td>145.7</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
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<td>36</td>
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<td>36</td>
<td>480</td>
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<td>HH 14 NG</td>
<td>91.4</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
<td>365,000</td>
<td>36</td>
<td>100</td>
<td>36</td>
<td>0</td>
<td>0</td>
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<tr>
<td></td>
<td>Sh 14 NG</td>
<td>66.5</td>
<td>Subgrade Concrete</td>
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<td>1,500,000</td>
<td>24</td>
<td>100</td>
<td>12</td>
<td>0</td>
<td>0</td>
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<tr>
<td></td>
<td>Wf 14 G</td>
<td>982.9 5.1</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
<td>415,000</td>
<td>36</td>
<td>55</td>
<td>12</td>
<td>2400</td>
<td>0</td>
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<td></td>
<td>We 14 G</td>
<td>2828.8</td>
<td>Subgrade Concrete</td>
<td>Scrape to Sump - Gravity Flow</td>
<td>850,000</td>
<td>6</td>
<td>100</td>
<td>2</td>
<td>600</td>
<td>5.07</td>
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<td></td>
<td>Sr 14 G</td>
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<td>Earth Lagoon</td>
<td>Scrape - Topload</td>
<td>160,000</td>
<td>NA</td>
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<td>12</td>
<td>0</td>
<td>NQ</td>
</tr>
<tr>
<td></td>
<td>WS 14 GT</td>
<td>3054.5 3.4</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
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<td>60</td>
<td>35</td>
<td>12</td>
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<td>0</td>
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<tr>
<td></td>
<td>Bh 14 GT</td>
<td>60.6</td>
<td>Subgrade Concrete</td>
<td>Scrape to sump - Two Transfer Sump Pumps</td>
<td>370,000</td>
<td>12</td>
<td>50</td>
<td>0</td>
<td>1040</td>
<td>NQ</td>
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<td></td>
<td>Cy 14 GT</td>
<td>1888.2</td>
<td>Abovegrade Steel</td>
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<td>12</td>
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<td>7.94</td>
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<td>Ws 14 GT</td>
<td>5203.3</td>
<td>Lined Earth Lagoon</td>
<td>Scrape to Sump - Gravity Flow</td>
<td>250,000</td>
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<td>0</td>
<td>150</td>
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<tr>
<td></td>
<td>We 14 G</td>
<td>3124.3</td>
<td>Subgrade Concrete</td>
<td>Scrape - Topload</td>
<td>850,000</td>
<td>60</td>
<td>100</td>
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<td>600</td>
<td>5.07</td>
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<td>Sr 14 G</td>
<td>727.5</td>
<td>Earth Lagoon</td>
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<td>100</td>
<td>12</td>
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<td>NQ</td>
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<td></td>
<td>Ws 14 GT</td>
<td>2983.4</td>
<td>Lined Earth Lagoon</td>
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</tr>
<tr>
<td></td>
<td>Bh 14 GT</td>
<td>127.2</td>
<td>Subgrade Concrete</td>
<td>Scrape to sump - Two Transfer Sump Pumps</td>
<td>370,000</td>
<td>24</td>
<td>100</td>
<td>2</td>
<td>1000</td>
<td>NQ</td>
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<td></td>
<td>Wf 14 G</td>
<td>11076.5</td>
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<td>Scrape - Topload</td>
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<td>24</td>
<td>80</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
</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.
NQ = 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 a safer workplace.

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.

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.
THE MX6 iBRID COLOR DISPLAY
Enhanced Visibility – Expanded Functionality

The MX6 clearly shows real-time readings in PPM or % by volume.

An intuitive menu provides easy access to features and setup.

Data trends and direct readings can be viewed graphically.

Calibration progress and results are shown for each sensor.

A “calibration due” warning appears for each relevant sensor.

Bright red numerals and a flashing backlight show alarm conditions.

Alarms shown with “Go/No Go” text and flashing backlight.

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

INDUSTRIAL
Scientific
www.indsci.com
## ORDERING INFORMATION

<table>
<thead>
<tr>
<th>MX6 BASE UNIT</th>
<th>SENSORS OPTIONS</th>
<th>BATTERY OPTIONS</th>
<th>VERSION OPTIONS</th>
<th>AGENCY CERTIFICATIONS</th>
<th>LANGUAGE OPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combustible Gases: LEL (Pentane), CO, H2, O2, NOx, NO, N2</td>
<td>Li-ion</td>
<td>Diffuser</td>
<td>UL/CSA</td>
<td>English, Portuguese</td>
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<tr>
<td></td>
<td>Volatile Organic Compounds: PID</td>
<td>Li-ion Ext., Range Pump</td>
<td>ATEX/EXe</td>
<td>French, Indonesian</td>
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<tr>
<td></td>
<td>Toxic Gases: H2S, O3, SO2, CO, CO2, HCl, NOx, H2O, NH3, CO, PhPh, OH, NO2</td>
<td>Alkaline</td>
<td>GOST/R</td>
<td>German, Russian</td>
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<td></td>
<td></td>
<td>Alkaline</td>
<td>EX/CS</td>
<td>Italian, Czech</td>
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<td></td>
<td></td>
<td>Alkaline</td>
<td>KOSHA</td>
<td>Dutch</td>
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<td>Alkaline</td>
<td>China CPC</td>
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</table>

### COMMON INSTRUMENT CONFIGURATIONS

<table>
<thead>
<tr>
<th>Part NO.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MX6-L</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump</td>
</tr>
<tr>
<td>MX6-L2000</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump Petrol Priming</td>
</tr>
<tr>
<td>MX6-K</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump Extr.</td>
</tr>
<tr>
<td>MX6-K2000</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
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<tr>
<td>MX6-K2000</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
</tr>
<tr>
<td>MX6-M</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner</td>
</tr>
<tr>
<td>MX6-M2000</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump</td>
</tr>
<tr>
<td>MX6-M2000</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump Petrol Priming</td>
</tr>
<tr>
<td>MX6-M2000</td>
<td>LEL (Pentane), CO, H2, O2, NOx, NO, N2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
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</table>

### COMMON INDUSTRY CONFIGURATIONS

<table>
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<tr>
<th>Part NO.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MX6-K2000</td>
<td>LEL, CO, O2, CO2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
</tr>
<tr>
<td>MX6-K2000</td>
<td>LEL, CO, O2, CO2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
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<td>LEL, CO, O2, CO2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
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<td>MX6-K2000</td>
<td>LEL, CO, O2, CO2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
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<td>MX6-M2000</td>
<td>LEL, CO, O2, CO2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
</tr>
<tr>
<td>MX6-M2000</td>
<td>LEL, CO, O2, CO2, Ext. Liner, Lnh. Liner, Pump Extr. Petrol Priming</td>
</tr>
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<td>MX6-M2000</td>
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### ACCESSORIES

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<th>DESCRIPTION</th>
</tr>
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<tr>
<td>MX6917-0000211</td>
<td>MX6 Kit - PEI Extended Liner, with pump</td>
</tr>
<tr>
<td>MX6917-1232111</td>
<td>MX6 H2S Pump, 4 pump with pump</td>
</tr>
<tr>
<td>MX6917-1233111</td>
<td>MX6 H2S Pump, 4 pump with pump</td>
</tr>
</tbody>
</table>

DSX Docking Station

The DSX Docking Station easily maintains the gas detectors that keep your people safe in hazardous environments.

- Know that your gas detectors are ready for use every day, every shift, without the burden of manual maintenance routines.
- Stop worrying about calibration gas and let the DSX monitor and order replacement gas cylinders when you need them.
- Effortlessly manage your fleet, data, and software updates from any web-enabled device.
INSTRUMENT WARRANTY:
Warranted for as long as the instrument is supported by Industrial Scientific Corporation

CASE MATERIAL:
Lacquered Stainless Steel with protective rubber overmold

DIMENSIONS:
133 mm x 77 mm x 43 mm (5.3" 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:
450 g (16.1 oz) typical - without pump
511 g (18.0 oz) typical - with pump

DISPLAY INTERFACE:
Color Graphic Liquid Crystal Display

POWER SOURCE/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:
10% to 95% non-condensing (continuous)

MEASURING RANGES:

<table>
<thead>
<tr>
<th>SENSOR</th>
<th>RANGE</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustible Gas</td>
<td>0-100% LEL</td>
<td>1%</td>
</tr>
<tr>
<td>Methane</td>
<td>0-5% vol</td>
<td>0.05%</td>
</tr>
</tbody>
</table>

ELECTROCHEMICAL:

<table>
<thead>
<tr>
<th>SENSOR</th>
<th>RANGE</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>0-500 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>0-1,500 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Carbon Monoxide (High Temp)</td>
<td>0-1,500 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Water/Oxygen</td>
<td>0-10,000 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0-200 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0-1 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>0-1,500 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Hydrogen Sulfide (CO2)</td>
<td>0-100 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0-200 ppm</td>
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</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>0-200 ppm</td>
<td>0.1</td>
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<tr>
<td>Hydrogen Sulfide</td>
<td>0-200 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>Nitric Oxide</td>
<td>0-500 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0-150 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0-30% vol</td>
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</tr>
<tr>
<td>Phosphates</td>
<td>0-1 ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>Phosphates (High Range)</td>
<td>0-1,000 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Sulphur Dioxide</td>
<td>0-150 ppm</td>
<td>0.1</td>
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</tbody>
</table>

INFRARED:

<table>
<thead>
<tr>
<th>SENSOR</th>
<th>RANGE</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (g/m³)</td>
<td>0-100% LEL</td>
<td>1%</td>
</tr>
<tr>
<td>Methane (vol%)</td>
<td>0-100% vol</td>
<td>1%</td>
</tr>
<tr>
<td>Methane (% LEL)</td>
<td>0-100% LEL</td>
<td>1%</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>0-5% vol</td>
<td>0.05%</td>
</tr>
</tbody>
</table>

PHOTOIONIZATION:

<table>
<thead>
<tr>
<th>SENSOR</th>
<th>RANGE</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOC</td>
<td>0-5,000 ppm</td>
<td>0.1</td>
</tr>
</tbody>
</table>

CERTIFICATIONS:

UL: Class I, Groups A,B,C,D, T4; Class II, Groups F,G,H,T4
CSA: Class I, Groups A,B,C,D, T4, T6
ATEX: Ex ia IIC T4 Ga / Ex ia IIC T4 db IP65
IECEx: Ex ia IIC T4 Ga / Ex ia IIC T4 X
KOSHA: Ex ia IIC T4 Ga / Ex ia IIC T4 X

** These specifications are based on performance averages and may vary by instrument.

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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>Farm</th>
<th>Sampling Season</th>
<th>Ambient Temperature</th>
<th>Surface Before Agitation</th>
<th>1 Foot Below Crust Before Agitation</th>
<th>Bottom Before Agitation</th>
<th>Middle After Agitation</th>
<th>pH Bottom Before Agitation</th>
<th>Middle After Agitation</th>
<th>Average Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL F13 GT</td>
<td>Fall 2013</td>
<td>14.8</td>
<td>13.7</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.5</td>
</tr>
<tr>
<td>WR F13 G</td>
<td></td>
<td>14.7</td>
<td>7.6</td>
<td>N/A</td>
<td>N/A</td>
<td>15.2</td>
<td>11.5</td>
<td>15.1</td>
<td>6.46</td>
</tr>
<tr>
<td>Ht F13 NG</td>
<td></td>
<td>18.0</td>
<td>16.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>6.42</td>
<td>6.77</td>
</tr>
<tr>
<td>CP F13 NG</td>
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<td>4.1</td>
<td>2.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>SH S14 NG</td>
<td>Spring 2014</td>
<td>12.5</td>
<td>9.5</td>
<td>15.2</td>
<td>14.8</td>
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<td>6.8</td>
<td>4.3</td>
<td>7.2</td>
<td>11.5</td>
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<td>10</td>
<td>2</td>
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<td>SH S14 NG</td>
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<td>19.7</td>
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<td>-39</td>
<td>-57</td>
<td>-23</td>
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<td>0.3</td>
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<td>6.1</td>
<td>-13</td>
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<td>-21</td>
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<td>WE S14 G</td>
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<td>10.1</td>
<td>-2.7</td>
<td>2.8</td>
<td>5.4</td>
<td>6.6</td>
<td>18</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>Sr S14 GT</td>
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<td>3.4</td>
<td>-0.8</td>
<td>8.8</td>
<td>8.0</td>
<td>11.0</td>
<td>-4</td>
<td>-10</td>
<td>7</td>
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<tr>
<td>BL S14 GT</td>
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<td>7.5</td>
<td>2.7</td>
<td>4.9</td>
<td>7.0</td>
<td>5.5</td>
<td>-3</td>
<td>-7</td>
<td>-6</td>
</tr>
<tr>
<td>BR S14 GT</td>
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<td>16.7</td>
<td>15.5</td>
<td>9.1</td>
<td>8.6</td>
<td>9.0</td>
<td>-13</td>
<td>-7</td>
<td>-11</td>
</tr>
<tr>
<td>Cy S14 GT</td>
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<td>21.8</td>
<td>15.3</td>
<td>11.7</td>
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<td>-13</td>
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<td>-8</td>
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<td>Hr S14 GT</td>
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<td>3.6</td>
<td>1.6</td>
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<td>6.8</td>
<td>-13</td>
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<td>19.5</td>
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<td>Sr S14 GT</td>
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<td>20.5</td>
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<td>11</td>
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<tr>
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<td>-28</td>
<td>-34</td>
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<td>15.2</td>
<td>14.7</td>
<td>13.6</td>
<td>16.2</td>
<td>14</td>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>

Notes:
1 F13, S14 and F14 represent Fall 2013, Spring 2013 and Fall 2014, respectively
2 NG, G and GT represent non-gypsum, gypsum and gypsum with treatment, respectively
3 Surface temperature were averaged from measurements collected using an infrared thermometer
4 Wind Speeds were average over first 60 mins of agitation from data collected from Kestral™ weather station at one location
N/A cells represent dates that kestral data was not measured or recovered. MX1 meter
Fall 2013 Observation did not include manure temperature, pH or ORP at depth because the field meter was not available for these field collection dates
Temperature for shaded cells are from
### Table A-3: Summary of laboratory analytical results

<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>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fall 2013</strong></td>
<td>Bl F13 GT</td>
<td>1251</td>
<td>2.0</td>
<td>7.18</td>
<td>7.12</td>
<td>7.1</td>
<td>0.22</td>
<td>0.11</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Wr F13 G</td>
<td>3162</td>
<td>5.1</td>
<td>7.5</td>
<td>7.38</td>
<td>7.55</td>
<td>0.19</td>
<td>0.15</td>
<td>0.16</td>
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<td></td>
<td>Hr F13 NG</td>
<td>150</td>
<td>0.0</td>
<td>7.88</td>
<td>7.96</td>
<td>7.82</td>
<td>0.35</td>
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<td></td>
<td>Co F13 NG</td>
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<td>7.8</td>
<td>7.86</td>
<td>7.88</td>
<td>0.25</td>
<td>0.13</td>
<td>0.31</td>
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<tr>
<td><strong>Spring 2014</strong></td>
<td>Co S14 NG</td>
<td>263</td>
<td>0.0</td>
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<td>7.12</td>
<td>7.13</td>
<td>0.36</td>
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<tr>
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<td>0.43</td>
<td>0.39</td>
<td>0.52</td>
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<tr>
<td></td>
<td>Sr S14 NG</td>
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<td>0.0</td>
<td>7.52</td>
<td>7.83</td>
<td>7.43</td>
<td>0.36</td>
<td>0.14</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Wr S14 G</td>
<td>983</td>
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<td>7.79</td>
<td>7.69</td>
<td>7.89</td>
<td>0.29</td>
<td>0.17</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>We S14 G</td>
<td>983</td>
<td>5.1</td>
<td>7.79</td>
<td>7.69</td>
<td>7.89</td>
<td>0.29</td>
<td>0.17</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Sr S14 G</td>
<td>208</td>
<td>0.3</td>
<td>7.19</td>
<td>7.09</td>
<td>7.42</td>
<td>0.64</td>
<td>0.65</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Br S14 GT</td>
<td>3645</td>
<td>3.4</td>
<td>7.57</td>
<td>7.42</td>
<td>7.31</td>
<td>0.42</td>
<td>0.15</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Bl S14 GT</td>
<td>66</td>
<td>0.0</td>
<td>7.52</td>
<td>7.83</td>
<td>7.43</td>
<td>0.36</td>
<td>0.14</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Fall 2014</strong></td>
<td>We F14 G</td>
<td>2829</td>
<td>0.6</td>
<td>7.01</td>
<td>6.73</td>
<td>6.99</td>
<td>0.7</td>
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<td>0.66</td>
</tr>
<tr>
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<td>Sr F14 G</td>
<td>208</td>
<td>0.3</td>
<td>7.19</td>
<td>7.09</td>
<td>7.42</td>
<td>0.64</td>
<td>0.65</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Hr F14 GT</td>
<td>208</td>
<td>0.3</td>
<td>7.19</td>
<td>7.09</td>
<td>7.42</td>
<td>0.64</td>
<td>0.65</td>
<td>0.62</td>
</tr>
</tbody>
</table>

**Notes:**
1. 13, 14 and F14 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


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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-Souce 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 / Gypsum Research Update / Monitoring Instruments - Flock
Eileen Fabric, Mike Hill & Dan Hofstetter, FSC
10 a.m. - 10:30 a.m. Regulatory Review
Mike Aucott, SCC & Robb Meiner, PSU
10:30 a.m. - 11 a.m. Recordkeeping
Mike Aucott, SCC
11 a.m. - 12 p.m. Application Compliance – Roundtable Discussion
Mike Aucott, SCC, Steve Taglang DEP, Robb Meiner 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.

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.

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
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 Limit</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
Farm bedded with Gypsum

Dairy Farmer’s Boys Have Close Call With Manure Gas

Unresponsive but breathing
500-600 ppm H₂S
150 ppm H₂S

Barn 30 feet away (30-60 ppm H₂S)

50 feet away (50 ppm H₂S)
Inside free stall (35 ppm)

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

Treated With OK-1000
**METHODS**: Temperature, wind speed and wind direction were recorded during data collection.

**Penn State Extension**

**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

**Increase in gypsum application rate significantly increases cumulative H2S concentrations, Treatments are not significant.**

Cumulative H2S Concentration for First 60 Minutes of Agitation vs. Gypsum Application Rate

Graph showing the relationship between gypsum application rate (lbs cow^-4 day^-1) and cumulative H2S concentration.
Change in wind direction increased H$_2$S concentrations

Personal monitoring devices provide effective awareness of exposure

Best management practices lower exposure risk

Operators with two highest H$_2$S readings were close to agitation

Conclusions: H$_2$S Concentrations
- Increased gypsum use 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 storages that contain gypsum.

Elevated H$_2$S concentrations (50 to >500 ppm) were observed at farms that use 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

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 practices
- Does not work or need to adjust machinery near storage edge
- Is not in a low-lying area. (Remember H2S is a heavy, ground-hugging gas)

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 Hille, Davis Hill, Dennis Murphy, Robin Brandt, Hershel Elliott, Robert Meinen

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**PLEASE BE AWARE OF DEADLY HYDROGEN SULFIDE**

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**Questions**
Appendix F. Poster

Appendix G. Example Webinar Slides (deliverable)


Waste to Worth Preview:
Gypsum Bedding Risks and Rewards
February 27, 2015
2:30 pm (eastern), 1:30 pm (central), 12:30 pm (mountain), 11:30 am (pacific)

A preview of the useful topics that will be discussed and presented via posters and informational sessions at the Waste to Worth Conference in Seattle, a group of professors and extension professionals present about the use of gypsum in dairy bedding. Gypsum recycled from dry wall is used to supplement traditional bedding materials with agronomic, milk quality, and cow health benefits. But once in the manure storage, gypsum bedding is a source of sulfur that leads to increased hydrogen sulfide gas production. This toxic gas is commonly found at deadly levels in enclosed manure pits, though dangerous levels are found even around outdoor open-air storages during agitation of manure. An application for continuing education credits for Certified Crop Advisors (CCAs) and members of the American Registry of Professional Animal Scientists (ARPAS) has been submitted.

Robb Meinen is a Senior Extension Associate in the Department of Animal Science at Penn State University. His main duty is to coordinate education for the PA Commercial Manure Hauler and Broker Certification Program. Additional duties include education in Nutrient and Odor Management and service to the swine industry. Meinen co-instructs the Nutrient Management course at Penn State. He is involved in long-term Manure Expo planning and is Co-Chair of the 2015 North American Manure Expo in Chambersburg, PA on July 14-15. Be sure to attend the Manure Expo. It promises to provide Manure than you can Handle.

Phone: (814) 865-5986. Email: rm124@psu.edu

Dr. Joe Harrison is a faculty member of the Department of Animal Sciences at Washington State University and has been conducting research and demonstration projects related to feed management and whole farm nutrient management since the early 2000’s. His projects include: precision nitrogen feeding, effect of potassium on milk fat in the early lactation cow, capture of phosphorus for off-farm transport, and efficiency of capture of manure nitrogen in crops as affected by manure source and method of application. Phone: (253) 445-4638. Email: jharrison@wsu.edu

Mike Hile is a Ph. D. Candidate in the Department of Agricultural and Biological Engineering at Penn State University. His research focuses on gas emissions from manure storage, processing and handling in the agricultural industry. As one of the members of the Penn State Odor Assessment Laboratory (PSOAL), Mr. Hile has evaluated the efficacy of manure additives and technological solutions to reducing odors for biosolids and animal manures. Field and laboratory experience enables Mr. Hile to be a key member of projects that involve measuring greenhouse gases, ammonia and hydrogen sulfide.

Phone: (814) 865-1783. Email: mlh144@psu.edu

How Do I Participate?
On the day of the webcast, go to www.extension.org/58813 to download the speaker’s power point presentations and connect to the virtual meeting room. First time viewers should also follow the steps at: www.extension.org/3924.

For More Information
* Waste to Worth - http://wastetoworth.org/
* Gypsum Bedding - Risks and Recommendations for Manure Handling - www.extension.org/6760

The LPE Learning Center is a project dedicated to the vision that individuals involved in public policy issues, animal production, and delivery of technical services for confined animal systems should have on-demand access to the nation’s best science-based resources. See our website at: http://www.extension.org/animal+manure+management.
GYPSUM BEDDING
RISKS AND REWARDS

FEBRUARY 2015

Michael L. Lea
Associate Professor
Department of Agricultural Engineering

Robert Shew
Professor
Department of Animal Science

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 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**
- Improves soil structure (aerates tight soils)
- Water is more readily in soil
- Improves soil development
- Improves soil nutrients
- Reduces phosphorous runoff
- Reduces pathogen population
- Provides source of secondary crop nutrients (Ca and Mg)

**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 H$_2$S**

<table>
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<td>100</td>
</tr>
</tbody>
</table>

**General Industry: 20-PPM (8-Hour Time Weighted Average) -** Exposures shall not exceed 20 ppm (time-weighted average) with the following exception. If no other measurable exposure occurs during the 8-hour work shift, exposures may exceed 20 ppm, but not more than 50 ppm (peak), for a single-time period up to 10 minutes.

**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
Farm bedded with Gypsum

Dairy Farmer’s Boys Have Close Call With Manure Gas
Unresponsive but breathing 500-600 ppm H₂S
150 ppm H₂S

Barn 30 feet away (30-60 ppm H₂S)

50 feet away (50 ppm H₂S)
Inside free stall (35 ppm)
METHODS: Three farm categories were observed in the fall and spring:

1. Gypsum
2. Gypsum with treatment
3. Non-gypsum

METHODS: H₂S 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 \( \text{H}_2\text{S} \) concentrations.

Personal monitoring devices provide effective awareness of exposure.

14 out of 18 operators did not exceed 20 ppm \( \text{H}_2\text{S} \) exposure.

Best management practices lower exposure risk.

4 out of 18 operators were exposed to \( \text{H}_2\text{S} \) above 20 ppm.

Operators with two highest \( \text{H}_2\text{S} \) readings were close to agitation.
Conclusions: H₂S Concentrations
- Increased gypsum application rate significantly increases cumulative H₂S concentrations.
- Treatments did not significantly reduce cumulative H₂S 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 H₂S
- Temperature affected CH₄ but not H₂S.

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 bedding rates less than ½ lb gypsum per cow per day.
PbC = Phosphorus source coefficient

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

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

Gypsum storages were reported by some users to have increased odors.
Practical Thoughts for Manure Handlers

Robert Moore
Senior Extension Associate
Penn State Department of Animal Science
University Park, PA.
Email: rmoore@psu.edu
Phone: (814) 865-1064

Gypsum and Liquid not needed

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

H₂S

- 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., H₂S).
- 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 invisible.

---

**Open Air Manure Storage Safety**

Safety tips include:

- No horseplay
- No smoking, open flames or sparks
- If equipment malfunctions shut it off and remove it before servicing
- If feeling unsure or uncomfortable, stop back, contact someone and review the situation before proceeding
- Be prepared to call 911 if an emergency happens
  - As soon as possible, describing the incident, number of victims, and giving specific directions to the site of the 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 practices
- Does not work or need to adjust machinery near storage edge
- 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.

---

**Body Alarms!!!**
- Dizziness
- Wobbly knees
- Feeling hot and clammy
- Lack of attention to details
- Loss of motor skills/satigue
- 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!*
More information on issues surrounding handling manure with gypsum bedding

- Agricultural Safety web site
  - extension.psu.edu/business/ag-safety
- Gypsum bedding and manure handling
  - site.psu.edu/news/2013/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

Penn State Extension

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>Absorb 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.

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.

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
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 Hile 814-865-1783; mh144@psu.edu; Eileen Fabian (Wheeler) 814-865-3552; fabian@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.

Where trade names appear, no discrimination is intended, and no endorsement by Penn State Extension is implied.

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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 \( \text{H}_2\text{S} \). 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 \( \text{H}_2\text{S} \) 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, \( \text{H}_2\text{S} \) gas at lethal levels (\( \geq \)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 breeze will move \( \text{H}_2\text{S} \) 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 \( \text{H}_2\text{S} \) 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 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 level 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 are at reduced risk for experiencing dangerous H₂S gas levels versus operators positioned nearby at ground-level. Operators should be positioned upwind.

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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 WANNER
Reporter

PINE 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 50 or so observers 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 AGRIP.FIELD.DAY, page A2

Photo by Dick Wanner

A tractor-powered agitator drew material from the bottom of the 12-foot-deep pit and sprayed it through a nozzle onto the top.
Field Day

Continued from A1

usual 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 manure projects to ever receive a hefty grant from the USDA's Natural Resources Conservation Service. Here's the way Fabian-Wheeler described the alliance:

NCRS sponsored Penn State doctoral candidate Mike Hile's demonstration project with a $70,000 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 snacks and beverages, fuel and time for the Wolves.

Penn State Extension coordinated the 10 farms used in Hile's project, and prepared and presented the program at 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. 28, 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 before hauling the contents out to the field for spreading.

But the Wolves weren't planning on spreading. They just agreed to stir up their pit so folks could watch and see what happened.

About 11 a.m., Eric Wolfe climbed into the seat of a tractor hooked up to an agitator that took material from the bottom of the pit and blew it onto the crust that had formed on the top.

A needle swayed from side to side, distributing stirred-up material evenly across the surface. About 11:05, the monitors started beeping.

Fabian-Wheeler said some of the monitors were designed to detect multiple gases, hydrogen sulfide being among them. Others were designed for H2S alone.

Hydrogen sulfide in the air at 100 parts per million is considered an

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 agitation 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 insidious. It is heavier than air, which has a molecular weight, when dry, of about 29 grams per mole. Hydrogen sulfide weighs in at 34 grams.

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

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

Mike Hile'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 limestone-rich formulation made by Homestead Nutrition in New Holland, Pa.

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

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

“My interest is in safety of farm families,” Weaver said. “We have had a handful of tragic incidents in the past few years, some involving gypsum, some not.

Full protection is first and foremost a safety issue for many farmers. It's also about reducing odors. The solution is to use additives in the pit, which reduces the amount of hydrogen sulfide released into the atmosphere.
Gypsum bedding offers benefits to cows, comfort, milk quality and low bacterial growth in the pH-neutral mineral-enhancing animal welfare through improved udder health. Fabian and Eileen's research has led to the conclusion that gypsum bedding can be broken down and disposed of safely, reducing odor and bacterial growth. The research was published in Progressive Dairyman on October 1, 2014.
animal manure and any dairy bedding material. But recent observations raise the need for concern even at outdoor open manure storage during agitation. A second project feeding is encouraging in that use of manure additives that break down the stored manure seem to reduce hydrogen sulfide gas levels at agitation on farms using gypsum bedding.

We also found that the first 30 to 60 minutes of manure storage agitation are the most dangerous. Stay away during this time. Or wear a gas monitor that warns of risky gas level. Personal gas monitors are already larger than a cell phone and cost less. The farmers in our 10 demonstration sites each wore a personal gas monitor during manure storage agitation so we could observe exposure and increase their safety.

Operators with highest hydrogen sulfide exposure during our project were very close to the manure being agitated or had leaned over the storage fence line to adjust or maintain equipment. Operators who stayed in tractor cab or were otherwise well away from gas plumes coming off the manure were at lower risk.

It is virtually impossible for an individual to get themselves out of a manure storage accident. Every recent incident in the northeastern U.S. (except two young boys in Pennsylvania who were overcome by gas and found unconscious at the edge of an in-ground open storage during agitation) involved people who were found unresponsive in a manure storage with no means of rescue or recovery in place. The fatalities involved farms using gypsum bedding and those that do not. We will never know if the people were overcome by gas or simply fell into the storage, as there were no surviving witnesses. These tragic reminders point to the importance of providing a life line (harness and rope, for example) and a plan that does not endanger those attempting rescue.

This leads to two strong recommendations for any and all dairy manure storages. One is to stay clear of manure being agitated for the first half hour when most gas is released: more than an hour is even better. This includes not leaning over or within the storage container. Secondly, keep nonessential people away during agitation, especially children.

Gypsum bedding offers benefits to cow comfort, milk quality and agronomic features. These benefits should be weighed against the risk of elevated levels of hydrogen sulfide gas. Hydrogen sulfide is likely to be dangerous in locations in breezy areas and around outdoor open manure storage during agitation prior to wind application when gypsum bedding is used. Be aware. 

Eileen Fabian-Wheeler is an agricultural and biological engineering professor with Penn State University. Email her at eww23@psu.edu.

Three manure storage safety tips

1. If you must go into the fenced area of the open manure storage, wear a safety harness with life line attached to a safely located solid object or anchor to enhance your chances of rescue.
2. Never work alone. The second person's role is to summon help in an emergency and assist with rescue without entering the storage.
3. If you feel unsure or uncomfortable with what you are getting ready to do near the open manure pit, step back, contact someone and review the situation before proceeding.

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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 22.2 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.
INDUSTRIAL HYGIENE

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 278 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 "sift" 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.

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What’s on the OH&S Site this Month

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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

from page 12

d eos

David Hill, a Penn State farm safety specialist, had plenty to say at the field day. He warned that a respiratory illness (which is what H₂S inhalation causes) will affect a person quickly but, if you can get quickly to fresh air, it will cause a quick reversal of negative effects caused by H₂S.

Hydrogen sulfide gas is heavier than air, Hill pointed out, which makes it so extremely dangerous. It’s right at your level, especially if you’re down. On the other hand, methane—another dangerous gas—is lighter than air and will usually go off fairly quickly. But not so with H₂S. It stays low to the ground and if the weather is hot and humid, it’s worst of all.

Rob Meier, from Penn State’s Department of Animal Sciences, described the signs of lung poisoning, which include headache, dizziness, and a reduced sense of smell. He referred to the symptoms as “body alterations” and declared that anyone working with manure should be aware of the danger symptoms and pay attention to them.

“I recognize the farmer’s work ethic,” he noted sympathetically. “You want to get the job done even though there’s pain and discomfort. But don’t do it in this case. Listen to your body alarms!”

As information was being shared at a safe distance from the pit, someone would check the monitors from time to time and report the findings. Where the PPM reading might have been 50, it had shot up to 300 and even higher as agitation of the pit’s contents continued vigorously. Inside the concrete storage facility, the PPM reading shot up to 900. A level of 300 and higher is considered lethal.

The group of attendees, which kept growing throughout the event, included people from as far away as Pen Yan, N.Y. Henry Martin and his son, Daryl, among four men from the Finger Lakes Region to make the trip. Why? They wanted answers. They wanted to see first-hand and above all, they’re interested in manure management safety.

Don Weaver, owner of Homestead Nutrients in New Holland, was also among the visitors. Like everyone else, his main interest for being there was to help promote safety around the pit. He has a simple message: “It’s like a gas. Stay clear of it.”

Safety awareness is the big deal in all of this. The word needs to get out.”

Eric Wolfe, dairy farm owner and custom manure hauler, watches and listens as the results come in.

Transitioning cows is topic of Technology Tuesday program

UNIVERSITY PARK, Pa. – Transitioning cows from the dry period into and through early lactation is the subject of the next "Technology Tuesdays" webinar on December 9, produced by the Penn State Extension dairy team.

Transitioning cows has a huge effect on the overall production and health of the entire herd. The way we house and manage the dry and pre-fresh cows ultimately determines the level of production she can achieve. The webinar will look at animal behavior aspects of this transition period as well as housing and management options. The discussion will be led by John Tyson, ag engineer, Penn State Extension Dairy Team.

Registration for the Technology Tuesdays webinar is free of charge, but you must pre-register for the first session that you wish to attend. Pre-register online at www.surveymonkey.com/s/TechnologyTuesdays1114 no later than noon the day preceding the session. Prior to the webinar sessions, you will receive an email that confirms your registration and contains the webinar URL. You need only register once; the same URL is used for all sessions.
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 stalls, increases hydrogen sulfide levels in manure storage, and new research supports that belief. Penn State Extension Associate said Feb. 10 during a Technology Tuesday webinar.

Gypsum, or calcium sulfate, occurs naturally and as 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 easy to make bedding for cattle," Hile said.

As a soil additive, gypsum acts as fertilizer and improves root development. It reduces phosphorus runoff, retains plant-available nitrogen, and supplies calcium and sulfur, Hile said.

Unfortunately, when gypsum sandy 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," 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, an Extension associate.

"As the concentration increases, actually your olfactory senses deaden a little bit, and you simply don't recognize that rotten egg smell, and you can actually still be in that dangerous environment without even realizing it," Hile said.

Hydrogen sulfide is released when various manure is agitated, Hile said.

For years, there have been cases of farmers being overwhelmed 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 Davis Hill, an Extension ag safety associate.

"We've heard of some manure banks that have made a policy that they're refusing to host manure from farmers that use gypsum bedding," Hile said.

In May 2015, two Pennsylvania workers died in a manure storage on a Maryland farm that used gypsum bedding.

"Later that year, two farmers in Montour County were found unconscious next to a manure storage after agitation," Hile said.

"Their father drove them to safety just in time," Hile 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 50 parts per million. The boys probably ingested a glance of up to 600 parts per million or their breath, Hile said.

Hydrogen sulfide often occurs in barns. Meinen said.

Hile told people that 30 feet was safe distance, but even at that distance he found elevated levels of hydrogen sulfide on the Montour farm.

"Even inside the foal stall barn we were kind of grabbing some samples just above that 20 mark," Hile said.

Those findings prompted Hile to determine whether gypsum was indeed producing the deadly gas.

Hile positioned gas monitoring devices around manure pits on a number of farms to measure hydrogen sulfide levels during agitation. He also tested the manure and noted environmental conditions like wind direction.

The farms that used gypsum indeed had high levels of hydrogen sulfide. Hile found 64 parts per million even 30 feet downwind of the storage. The farms that did not use gypsum stayed under five parts per million, he said.

The farmers who agitated the manure also wore monitors, and most of them stayed below hazardous levels of exposure.

"Those who were first on the agitator from the cab of their tractor with the doors closed. The tractor elevated them above the pit, Hile said.

"Those who were exposed to more gas worked outside the tractor often at the edge or even leaning over the storage wall," Hile said.

Some farmers reported corrosion of fences and buildings components, he said.

Environmental conditions can change the risk. A storm was rolling in during one agitation. The wind was blowing hydrogen sulfide directly into the foal barn, where the trapped gas topped 300 parts per million.

"It was actually higher than my meters would go," Hile said.

For now, safety precautions are the best way to reduce the risk from manure gas exposure. Treatments claimed to reduce hydrogen sulfide did not perform as advertised in Hile'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 30 feet away from the storage, said Edger Fabian, a Penn State engineering professor.

"It's helpful to be aware of where's around the storage," Hile said.

Hydrogen sulfide is heavier than air and tends to intensify at the few feet above ground. "You might be good while you're standing. When you bent over you might be in trouble," Meinen said.

Children are at particular risk because they are short enough to breathe in the hydrogen sulfide's manure and become toxic faster.

Meinen remembers being at the North American Manure Expo a few years ago.

"Every time there was a hole or a confined space, the kids were the first ones to walk in and look in there and get close," he said.

Penn State Extension found that 10 percent of manure gas deaths were children, Meinen said.

Most manure gas deaths happen during warm months when microbial activity is great. August accounted for a quarter of the deaths in the Perdue 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 storage came off, he said.

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

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

Meinen said people near manure storage need to pay attention to their "body alarms" just as they would feel a smoke detector.

"If you feel like you just walked up three or four flights of stairs and you really didn't exert yourself, that's your body telling you," 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.

Carrying a gas detector can minimize your risk. "The first hour of agitation is probably the worst, but never let your guard down," he said.

Farmin, the engineer, "unconditionally recommends that gypsum be used with aeration manure storage. The chance of exposure is just too great," she said.

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