Journal of Agromedicine

ISSN: 1059-924X (Print) 1545-0813 (Online) Journal homepage: http://www.tandfonline.com/loi/wagr20

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To cite this article: John M. Shutske, Daniel Schaefer, Rebecca Larson, Kevin Erb, Cheryl Skjolaas, Stephanie Leonard, Jeff Nelson, Elizabeth Binversie & Scott Rifleman (2018) Investigation of a Worker Death While Agitating Manure in a Non-enclosed Storage, Journal of Agromedicine, 23:1, 10-19, DOI: 10.1080/1059924X.2017.1397076

To link to this article: https://doi.org/10.1080/1059924X.2017.1397076

Accepted author version posted online: 25 Oct 2017.
Published online: 25 Oct 2017.

JOURNAL OF AGROMEDICINE
2018, VOL. 23, NO. 1, 10–19
https://doi.org/10.1080/1059924X.2017.1397076

PRACTICE/CASE HISTORY

Investigation of a Worker Death While Agitating Manure in a Non-enclosed Storage

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ABSTRACT
An in-depth investigation of an unusual, non-enclosed manure storage hydrogen sulfide-induced fatality on a Holstein beef production operation is presented. The case involved several factors that likely played a role in the young farmer's death. These included zero wind movement, a reported temperature inversion in the area, relatively cool late summer outdoor temperatures on the morning of the incident, higher outdoor temperatures the week prior, and a high by-product steer ration containing ingredients that contributed significant sulfur content to the stored manure. Recommendations are offered for future research to determine the combinations of conditions and inputs that have potential to increase human and animal risk around manure storage structures. Based on this case and others recently documented showing unsafe levels of hydrogen sulfide being released from similar outdoor storages, it is critical that agricultural industry experts and input suppliers continue to analyze risk and consequences associated with new management practices, processes, inputs (including feed ingredients and animal bedding), machines, and other technology developed to support animal agriculture. Production practice and educational guidance are also offered based on this case and published literature.

KEYWORDS
Death/fatality; hydrogen sulfide; manure storage; occupational hazard

Introduction

In August 2016, a young beef producer died while agitating slurry manure in a storage basin that adjoined a Holstein steer finishing feedlot in central Wisconsin. In addition, 16 cattle died in a pen close to where the victim died. This was the first known incident to be documented in Wisconsin in which a farm worker died from a "manure gas" exposure in a completely open outdoor environment. However, well-documented manure-storage fatality incidents have occurred in enclosed spaces throughout the United States.[1–4] A multidisciplinary team analyzed and investigated this case and examined factors connected to the person, setting, task, equipment, and connected weather and environmental conditions. Recommendations stemming from this unusual incident and additional pertinent literature are discussed.

The person

This manure gas fatality incident occurred on August 15, 2016. Information initially obtained about the incident by the authors was first acquired from newspaper and television accounts within one day of the event and was followed by conversations between the authors and first responders.[5,6] Those conversations also included phone calls with the coroner within 2 days of the incident, and with the parents of the decedent 2 weeks after the incident. There were also phone conversations and e-mail communication with a custom manure pumper and hauler who was on the scene shortly after the victim was discovered, and a more thorough and confirming site visit with family members was completed 6 weeks after the incident. The local University of Wisconsin Extension Agent, a technical college farm management instructor, and the

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/wagr.

county coroner also participated and provided information during the site visit.

The decedent was a 29-year-old farmer, reported by his parents to be in good health prior to and at the time of the incident. He grew up at the farm site where the incident occurred with three sisters. After graduating from a local high school, he was a successful participant in a local technical college's farm business management program and an enthusiastic partner in his family's farming business with his father and hired employees. He had interest in adopting precision agriculture technologies in the farm's cropping operations. He was active in many parts of the farm operation including operating field and farmstead equipment, cropping operations, caring for cattle, feeding animals, formulating and mixing diets, and working with animal manure including the agitating activities that led to this fatality.

The setting

The operation included approximately 800-head of Holstein beef steers being raised for regional markets and 1500 acres of production cropland. The manure storage structure was a large, outdoor, in-ground 400-foot × 150-foot concrete basin with sloped sidewalls. It was approximately 15-feet deep at its deepest point. The basin collected and stored manure, rainwater, and other runoff from adjoining concrete pads where cattle were located. Cattle had access to feedlot pads, but they could also walk and lie in nearby open-sided sheds. Inside the sheds, steers had access to cornstalk bedding for animal comfort. In the winter months, solid manure and used bedding were scraped and collected periodically and spread onto fields. The basin was approximately two-thirds full at the time of the incident. There was a crusted top surface ranging in thickness from 6 to 12 inches. The operation had harvested a wheat crop from nearby acreage 2 weeks prior, and there was a desire to pump and apply manure from the basin to be applied onto these 85 harvested acres before fall alfalfa seeding. The basin had last been pumped in mid-April 2016. At that time, approximately 2.5 feet of manure solids remained in the bottom of the basin. Figure 1 shows the feedlot, adjacent animal housing, feed storage, and residence of the victim's parents. The approximate elevation at the northwest corner of the basin where this incident occurred was 1201 feet (above sea level). This was the elevation across the entire western side of the basin. Feedlot surfaces to the north, northeast, and east were approximately 4–6 feet higher than elevations on the west side.

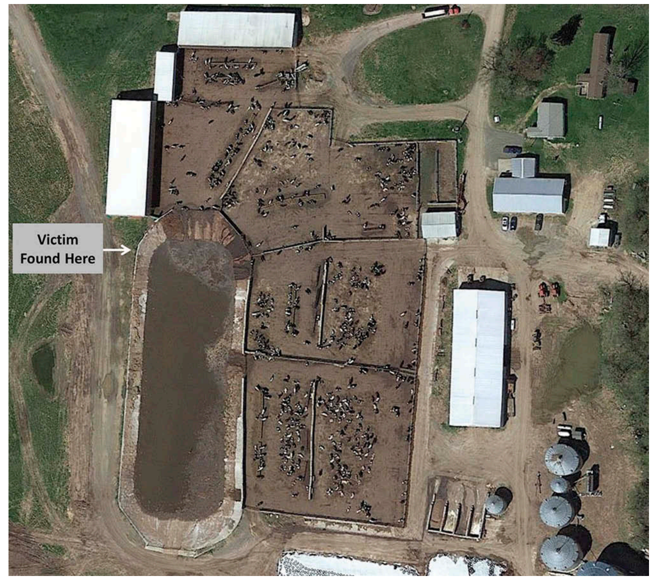

Figure 1. Farm workplace, feedlot, and residence—Amherst, WI (photo: Google Earth).

The task and equipment

Agitation is done routinely in livestock and dairy manure storage systems to attempt to resuspend solid materials and create a more homogenous mixture to be pumped and spread onto crop land. Agitation provides for a more consistent mix of liquid and solid content. This can reduce operational issues, and it makes the nutrient content of each pumped-out load more consistent to aid in accounting for nutrient application rates applied on crop land.[7] It is also common in other situations to agitate manure stored in deep pits located underneath livestock housing buildings, though a very different agitator design is used as compared to the one involved in this case.

The towed manure agitator unit used at this site was 42-feet long. The machine was backed up by the tractor into the slurry, and the far end (that included a propeller and pump) was then submerged into the contents of the basin. In situations like this, as the agitator is backed up onto a crusted surface, its weight breaks through the crust and settles down inside of the liquid slurry. This agitator had a large spray gun that remained approximately 6 inches above the top surface. A large tractor's (235 horse power engine) power takeoff operating at 540 rpm served as the agitator's power unit. Agitation action was accomplished via the large propeller at the end of the agitator structure, along with an aggressive 6-inch pump that lifted and sprayed liquid waste outward and to the sides and above the surface of the liquid to help break up crusted surfaces. The agitation and pumping were controlled with levers that actuate hydraulic valves on the agitator unit. Those controls were mounted on the front of the agitator and accessed from ground level. Figures 2 and 3 show the agitator structure and controls, with the agitator having been pulled out of the storage basin after the

Figure 2. Agitator unit after the incident.

Figure 3. Agitator controls.

Figure 4. Manure agitation in process at educational field day.

incident. Figure 4 shows an example of a typical agitation process occurring during an educational field day. Manure pumping and spreading contractors often depend on the agitation to be started prior to their arrival, which allows the contractor's crew to begin hauling immediately.

The incident

The decedent went out early in the morning (around 3:00 AM) to use the agitator to aggressively break up and stir the manure that had a natural crust of organic, plant-based material about 6–12 inches thick on the top surface. He and his father had scheduled a contractor to arrive on the site later that morning to pump manure from the basin into large mobile tanks to be hauled (by truck) from the basin's perimeter and spread onto nearby fields that day. The agitation and activities to break up the crusted surface were done in preparation for that pumping, hauling, and field application activity.

The agitation activity was started by the victim sometime after 3 AM. The last known contact was via a social media post that he sent to friends from his smartphone while at the worksite shortly after 4:10 AM after his work had commenced. More than 2 hours later, at approximately 6:30 AM, the victim's body was found by a hired employee of the farm who had arrived by truck to the scene to begin assisting work. The decedent's body was located outside of the manure storage. Based on his position, it was assumed that he had become incapacitated, and fell backward in the direction of the manure. His body was found where the tractor and agitator were parked and running, behind and to the right side of the tractor. He was unresponsive, on his back, at the edge of the slurry.

Within moments of the employee finding the victim, a member of the contracted manure pumping crew also arrived at the scene. He made the official 911 call at 6:32 AM to the sheriff's office. A county sheriff's deputy arrived within minutes and notified the county coroner at 6:50 AM. Soon after his arrival on the scene, the coroner pronounced the victim dead.

No other unusual local conditions were noted at the immediate scene at the time of the incident. Ground and nearby grass and concrete working surfaces were not wet or slippery. Machinery and equipment was fully functional, and it appeared that the task had been progressing as planned. After the coroner left the site, a neighbor who had come to the scene to provide assistance noticed a steer in a nearby pen that struggled to stand. Upon further investigation by a family member, the group found 13 steers each weighing nearly 1400 pounds deceased and another three head of steers that showed signs of distress. The three animals were unable to stand or walk and were later euthanized. Because the affected animals were found relatively near the victim's location, the coroner was notified by telephone about these additional findings. This follow-up call resulted in further investigative action by the coroner, which is reported in a later section.

Weather and environmental conditions

Weather conditions from the morning of the incident were obtained and examined from the nearby Stevens Point, Wisconsin airport, located 11.5 miles from the farm.[8] Wind conditions recorded in the window of the time of the event and throughout that morning were still/calm—wind speed was reported as 0 mph. Outdoor temperatures at 4:15, 5:15, and 6:15 AM were 54.5°F (12.5°C), 53.6°F (12.0°C), and 52.9°F (11.6°C), respectively. Relative humidity levels during this period ranged between 97% and 100%. The high temperature on the previous day (August 14) was 80°F (26.7°C), and the highest recorded temperature in the prior 1-week period (August 7–13) had been 87°F (30.6°C). Overall, the prior week's daily average temperature ran 10°F (5.6°C) warmer than the normal historical weekly average (80°F versus 70°F as a weekly average). In the days immediately after the incident, reports in several media outlets characterized the incident as having been caused by methane and a "deadly dome of air."[9]

In news accounts, airport observers had reportedly cited a temperature inversion as a potential contributing factor.[10] On the day of the incident, the county coroner had contacted the National Weather Service's Green Bay office, which confirmed a "strong temperature inversion in the area," stating that the air at 1000–1300 feet above ground level had been warmer than at ground level. During temperature inversions, a layer of colder and denser air exists near ground surface, with a warmer layer of air above. Temperature inversions reduce convective air movement and can trap gases and pollutants near the earth's surface.[7]

Investigation findings

In the days that followed, because of the combination of both a human death and animal impacts, the county coroner's office sought technical assistance from a University of Wisconsin–Madison Extension farm safety expert (one of the coauthors), who suggested that the investigation look beyond the media-reported methane exposure to consider potential hydrogen sulfide H_2S exposure. Following his initial examination (no autopsy was performed), the coroner sent blood specimens out of the state for laboratory toxicology testing. Test results were returned 23 days after the incident. They confirmed elevated blood levels of thiosulfate, a commonly referenced sulfur metabolite and indicator of H_2S exposure. The tests showed a blood thiosulfate concentration of 9.2 μg/mL, a level found in past cases to be indicative of a lethal H_2S exposure.[11] The coroner indicated that the victim showed no other signs of external trauma that might have resulted from contact or entanglement with moving equipment or from a fall. Further pathology testing was not performed on the cattle, but the animal deaths were assumed to be attributable to H_2S exposures.

Because this seemed to be an unusual incident, university staff also followed up with the victim's father and mother by telephone 10 days after the incident. More information about the decedent was obtained as well as additional details about the operation. Nothing out of the ordinary was noted in terms of feedlot design, manure storage, or animal housing. Several months prior to the incident, the owner told researchers that a University of Wisconsin agricultural engineer and University of Wisconsin Extension Agent had visited the farm at the owner's request to make recommendations on animal housing, handling, and rainwater management on the feedlot site. During the investigative call, authors asked specific questions about the past or recent use of gypsum bedding, known from recent studies in other states to be associated with higher levels of H_2S release from dairy manure storage facilities.[12] Gypsum was not ever used on this farm and is *not considered* to be a contributing factor to this incident.

An in-person follow-up site visit was conducted 6 weeks (September 26, 2016) after the incident by university staff at the invitation of the family. Information about the diet fed to the herd was reported by the owner in the spring and summer months leading up to the incident. The feed ingredients are shown in Table 1.

The high inclusion of vegetable by-products (whole plant, ensiled sweet corn, and potatoes) was attributed to the proximity of nearby vegetable processors that sell processing by-products that can be fed to ruminants. The distiller's syrup was purchased as a by-product from a corn ethanol production facility. The owner indicated that he had been advised by a beef cattle nutritionist to feed his steers additional thiamine, because excess sulfur consumed through the distiller's syrup has a high potential to cause polioencephalomalacia, a neurological impairment in ruminants that is associated with high sulfur intake.[13]

Laboratory test results of the diet dated September 16, 2016, were also obtained during the site visit. The total mixed ration contained 0.44% sulfur on a dry matter basis. For feedlot cattle that are fed a high concentrate diet, animal nutrition sources cite that sulfur concentration in the diet should not exceed 0.3%. Amounts half that (0.15%) are recommended for adequate diet concentration.[14] On the date of the September 2016 site visit, a sample of distiller's syrup from the same batch as had been fed in the spring and summer of 2016 was collected, sealed tightly, stored in a refrigerator, and later tested in a commercial laboratory. That sample's sulfur concentration was found to be 1.53% of the dry matter content.

Manure samples were previously laboratory-tested in April 2015 and November 2015 (the latest was 9 months prior to the incident). Manure test results showed total sulfur levels of 9.7 lbs and 6.9 lbs per 1,000 gallons in the spring and early winter samples, respectively. Normally observed liquid and slurry beef manure laboratory samples at the University of Wisconsin analysis laboratory had average values of 1.6 pounds per 1,000 gallons from 1998 to 2012.[15]

An additional summary of this case has been reported and published by the Centers for Disease Control to rapidly alert local public health, medical, and emergency response professionals as well as the media to this seemingly unusual case.[16] Additional discussion provides further analysis, commentary, and specific recommendations for further research and safety.

Table 1. Daily feed rations per animal.

Feed product	Daily quantity fed per animal (lbs./animal/day)
Dry, baled hay	2–3
Whole plant sweet corn	18–20
Potatoes/potato cull products	20–30
Distiller's syrup	15–20

Discussion

The workplace dangers associated with manure gases that result from the anaerobic breakdown of organic materials have been well known for decades and even centuries.[4] Agricultural producers and those who provide products, services, and technical information to farm operators who handle and store manure are urged to learn more about the health/safety hazards and risk associated with manure storage and handling from the array of existing technical and practical safety resources that exist. This recommendation for future education and professional development is also directed toward extension educators, local health professionals, first responders, emergency service personnel, forensic toxicologists, and others who examine these types of incidents.

Specific manure gas safety recommendations and practices have been well described by the National Institute for Occupational Safety and Health in 1990, and the first, consensus-based engineering-practice safety standard was published by the American Society of Agricultural and Biological Engineers in 1992.[17,18] More recent summary and technical information has appeared in the literature.[2–4] For readers unfamiliar with manure gases, the above references contain excellent technical information and citations that document the primary hazards of concern: hydrogen sulfide, ammonia, carbon dioxide (CO2), and methane. In addition to the toxic nature of H_2S and ammonia, the potential accumulation of methane, CO_2 (and other gases) can also create extreme danger by displacing oxygen to a level below 19.5%—the level below which is immediately dangerous to life and health.[19] Methane is also highly explosive at certain concentrations.

Some states within the United States having active extension and outreach programs in agricultural safety and health also have translated research literature and case investigations into actionable educational information designed to be useful to the agricultural producer community and their employees.[20–23] These materials have often referenced pits, tanks, and other structures considered to be confined spaces. Only recently has there been extensive discussion about dangers associated with outside, non-enclosed manure storages. Penn State authors Meinen and Hill warn of specific hazards in non-enclosed storages, "such as earthen, lined and concrete manure pits, ponds and above ground tanks."[24] Other recent articles provide specific instruction to reduce risk connected with agitation and pumping manure in outdoor facilities, largely informed by the findings in the case described herein.[7,16]

The findings from this case and others that reference potentially dangerous levels of H_2S in non-enclosed manure storages warrant further discussion. This was the first known case in which a Wisconsin fatality occurred in a totally outside setting that would not be envisioned as a more typical confined space. However, the recent work at Penn State describes high levels of measured H_2S adjacent to outdoor dairy farm manure storage units that received manure that included calcium sulfate or "gypsum" bedding.[12] They reported operators being at "risk during activities in close proximity to the manure storage during agitation, and conditions 10 m away from the storage were above the 20 parts per million (ppm) H_2S threshold on some farms using gypsum bedding." These authors also state that while H_2S "rose to dangerous levels, only 2 of 18 operators were exposed to >50 ppm H_2S during the first 60 min of manure storage agitation."

The gypsum-related article cites a Pennsylvania news account in which two children playing adjacent to an outdoor manure storage basin were incapacitated by gases, but later recovered.[25] It is not known if other documented outdoor fatalities in the United States or other countries have been attributed to manure gases from non-enclosed structures. Another news article from Maryland describes a case in which three operators lost their lives in a similar basin, though it appears that they first may have become entangled in the agitator propeller that extended out into the manure; details are unclear.[26] Obviously, these accounts and the case described in this article heighten concern about the potential risk near these outdoor structures.

Gypsum is not the only input product associated with higher levels of H_2S in stored manure. Andersen warns that, "Sulfur content in manure has increased over the past ten years from three pounds per 1,000 gallons to nine pounds per 1,000 gallons in swine manure because of increased use of distiller's dried grains with solubles (DDGS) and improved water conservation."[21] Any addition of sulfur into an animal production system has the potential to influence the production of H_2S including well water with high sulfur concentrations consumed by animals or used during cleaning processes. Recently, copper sulfate-containing footbaths intended to improve animal health have also been suggested as a potential source of additional sulfur that can enter manure storages.[27] Hydrogen sulfide evolution from solution is pH dependent. As the pH of the manure decreases, more of the dissolved sulfide is in the form of gaseous H_2S.[7]

As animal production practices change, including changes in inputs and structures (such as feed, bedding, manure storage/processing technologies, handling equipment), it seems crucial that we do more to analyze the safety risks that could impact human and animal health. Further, H_2S and other sulfur-containing compounds are also a contributor to odor which has received growing societal scrutiny in the last two decades.[28]

Research recommendations from this case

This single case might seem unusual as it occurred outside and involved a high sulfur environment, still wind, and a possible inversion effect. But, it seems prudent to consider this and other recent incidents as a potential bellwether calling for a deeper examination of evolving farming practices that could elevate risk for human and animal health and safety. Specific areas that warrant further examination include:

- How do H_2S releases and worker exposures vary with crusted manure versus non-crusted and other types of covers on stored manure during key activities including agitation, pumping, and field application? How does risk change as a function of crust thickness, density, and composition?
- How do risk levels change (positively or negatively) as the industry develops new animal bedding, housing, and manure handling, processing, application, and storage systems?
- How does worker exposure to H_2S and other gases in manure change as feed ingredients and feeding practices change?
- How do manure nutrient percentages, manure temperature, and other system characteristics influence risk and worker safety during times when potential exposure occurs?
- What are the impacts and relationships of local weather conditions and manure gases on health risk including, but not limited to, ambient air temperature, relative humidity, wind speed/direction, past weather conditions, and other phenomena?
- How do nearby structures (buildings, fences, feed storage, silage bags, grain bins, windbreaks, etc.) influence manure gas movement, dissipation, and associated worker risk?
- What are the specific, measured impacts of practices connected to manure agitation, pumping, and spraying of manure on the release of toxic gases, and which best practices should inform these activities?
- Which components of the manure system impose the greatest gas exposure risk (e.g., manure storage, manure processing, agitation, pumping, application, etc.) and which practices increase risk?

Outdoor storage: Practice and educational recommendations from this case

While further research is needed, in the meantime, we provide additional recommendations for outside, non-enclosed, manure storage basins, ponds, and lagoons that are warranted because of this case and other cited information found throughout this article. This list is relatively specific to this case, yet the previously cited references must be considered:

- Do NOT agitate, pump, or move slurry or liquid manure from outdoor manure storage during periods of no-wind or low wind or during times of closely connected weather phenomena that may be linked to increased risk such as temperature inversions and fog. Until more research is complete, it is impossible to predict and communicate a safe wind speed or setback distance to ensure worker safety. Risk is likely to be dependent on a host of other localized weather factors such as temperature of the manure and surrounding air, relative humidity, and thermally caused air layering effects as well as non-weather factors such as topography and vegetation (including windbreak shelters).
- Since hydrogen sulfide is heavier than air, always avoid setting up and operating pumping and agitation equipment in lower lying areas or any area where moving air might settle or collect in dead spots or eddies.
- Even during times when significant wind is present, wind direction is critical. Wind must be blowing away from workers, yet, operators of agitators, pumps, and other equipment must also be fully cognizant of potentially high risk levels to animals and people in the downwind areas as well as to themselves.

- Even with seemingly adequate wind speed, authors urge the use of a portable, battery powered, direct-reading gas monitor. Single gas monitoring units are available at lower cost, but the authors strongly recommend a four-gas monitor that can provide an alarm (audible and visual) for H_2S, inadequate oxygen levels, flammable/explosive gas (generally methane in this case), and at least one other gas. The fourth gas sensor chosen will depend on the type of farming operation and potential hazard exposures. Regular calibration, bump-testing before each use, and other maintenance of these devices is extremely critical to their safe use as well as training, planning, and protocols to follow when environmental conditions are changing rapidly.
- Other manure safety recommendations that have been cited that were first developed with confined space entry in mind provide additional measures of protection even for outdoor, non-enclosed storage facilities. These include: technical training and demonstration for all workers in a language they will understand with clarity; written and administrative protocols and procedures for completing work tasks; working in teams of qualified individuals; use of (or access to) self-contained breathing apparatus; notifying local emergency response professionals of all pending high-risk farm tasks; and worker use of lifelines, harnesses, and other emergency retrieval systems. The impact of ventilation fans in outside settings requires additional investigation. In outdoor situations fans may have limited impact on risk mitigation, though ventilation is considered an important part of enclosed confined space entry.
- While the cost efficiency of production often drives producer decisions for feeding and other production practices, the authors encourage equal emphasis on human health and safety in the future. Producers and livestock/dairy nutritionists must evaluate products that contain sulfur levels above what is required by animals, as excess sulfur ends up in livestock manure, potentially increasing H_2S levels in storage. Producers and agricultural industry suppliers must consider how all alternative and novel inputs, practices, machines, and technologies alter farmer and employee risk. This mindset will also be increasingly important as we continue to see more automation, increased use of sensors, and changes in the demographics, experience levels, and skills of agricultural workers. Careful evaluation and analysis of these changes have potential to impact other aspects of agricultural health and safety as well.
- Engineers who design agitation systems like the one that was used in this case should investigate the potential use of engineered safety systems and safeguarding devices that would supplement warning labels and other information displayed on the product or in operator's manuals.
- While the topic of manure gas safety would seem to be a mature topic, the agricultural industry must remember that there are always new generations of farmers, farm employees, and others involved in the industry and in rural communities who may have limited or zero knowledge of the risks and hazards that exist. Even with farming practices, and machines that have been around for 20 or more years, not all farm hazards are immediately evident to those unfamiliar with the industry. Thus, continuous education must be offered including through the media; meetings attended by farmers and agricultural industry suppliers, service people, and technical support people; and through all who provide products, services, consultation, and information to members of the agricultural community. The same is true for rural health professionals, educators, emergency medical personnel, fire departments, coroners, forensic examiners, and others.

Conclusion

Agriculture is changing rapidly and the livestock industry will continue to evolve with new practices, processes, inputs, machines, and other future developments. These changes will confound old, existing, and previously studied agricultural safety and health issues including manure gas exposure along with other known hazards. This case represents the dilemma that exists—hydrogen sulfide is a seemingly well-known livestock farm hazard, but the conditions that led to the fatality described in this case need to be better understood. The interaction of feeds, feeding practices, weather conditions, work practices, and understanding of safety practices, needs, and risks will all need continued attention going forward. Hopefully the research, practice and educational recommendations presented here will serve to prevent similar, future incidents.

Acknowledgments

Special thanks and gratitude go to the family so deeply affected by this incident and to the community members, leaders, and industry personnel who provided needed information. Special thanks to the UW-Madison College of Agricultural and Life Sciences and University of Wisconsin Extension for support of travel, time, and other activities associated with this work.

References

1. Beaver RL, Field WE. Summary of documented fatalities in livestock manure storage and handling facilities: 1975–2004. *J Agromedicine*. 2007;12(2):3–23. doi:10.1300/J096v12n02_02.
2. Issa SF, Cheng Y-H, Field W. Summary of agricultural confined-space related cases: 1964–2013. *J Agric Saf Health*. 2016;22(1):33–45. doi:10.13031/jash.22.10955.
3. Murphy DJ, Manbeck HB. Confined space manure storage and facilities safety assessment. *J Agric Saf Health*. 2014;20(3:199–210.
4. Riedel SM, Field WE. Summation of the frequency, severity, and primary causative factors associated with injuries and fatalities involving confined spaces in agriculture. *J Agric Saf Health*. 2013;19(2:83–100.
5. Press A, News F. *Coroner: Gas Fumes Killed Wisconsin Farmer; Death Accidental*. Green Bay, WI; 2016. http://fox11online.com/news/state/coroner-gas-fumes-killed-wisconsin-farmer-death-accidental.
6. Mueller C. Coroner: farmer killed by manure fumes in Amherst. Stevens Point Journal – USA Today Network – Wisconsin. Stevens Point, WI: 2016. http://www.stevenspointjournal.com/story/news/2016/08/17/coroner-farmer-killed-fumes-amherst/88889352/.
7. Larson R, Aguirre-Villegas H, Shutske J, et al. *Reducing Risks from Manure Storage Agitation Gases*. A4131-06. Madison, WI: University of Wisconsin – Extension; 2017. https://learningstore.uwex.edu/Assets/pdfs/A4131-06.pdf.
8. Underground W. *Weather History for Stevens Point, WI – August 15, 2016*. San Francisco, CA: The Weather Company, LLC; 2016. https://www.wunderground.com/history/airport/KSTE/2016/8/15/DailyHistory.html.
9. Moye D. *Farmer and 16 Cows Die from 'Deadly Dome' of Manure*. New York, NY: Huffington Post; 2016. http://www.huffingtonpost.com/entry/manure-tragedy-michael-biadasz_us_57b60fdfe4b00d9c3a165f1a.
10. Thornton E. *Expert Explains Deadly Dome of Air Leaving 1 Farmer, 16 Steer Dead*. LaCrosse, WI: WXOW Television; 2016. http://www.wxow.com/story/32784538/2016/08/Wednesday/expert-explains-deadly-dome-of-air-leaving-1-farmer-16-steer-dead.
11. Kage S, Kashimura S, Ikeda H, Kudo K, Ikeda N. Fatal and nonfatal poisoning by hydrogen sulfide at an industrial waste site. *J Forensic Sci*. 2002;47(3):652–655.
12. Fabian-Wheeler EE, Hile ML, Murphy D, et al. Operator exposure to hydrogen sulfide from dairy manure storages containing gypsum bedding. *J Agric Saf Health*. 2017;23(1):9–22. doi: 10.13031/jash.11563.
13. Amat S, Olkowski AA, Atila M, O'Neill TJ. A review of polioencephalomalacia in ruminants: is the development of malacic lesions associated with excess sulfur intake independent of thiamine deficiency? *Vet Med Anim Sci*. 2013;1(1):1. doi:10.7243/2054-3425-1-1.
14. National Academies of Sciences Engineering and Medicine. *Nutrient Requirements of Beef Cattle*. Washington, DC: National Academies Press; 2016.
15. Laboski C, Peters J. *Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin*. A2809. Madison, WI: University of Wisconsin Extension; 2012. http://learningstore.uwex.edu/assets/pdfs/A2809.pdf.
16. Shutske J, Larson R, Schaefer D, Binversie L, Rifleman S, Skjolaas C. Death of a farm worker after exposure to manure gas in an open air environment—Wisconsin, August 2016. *MMWR Morb Mortal Wkly Rep*. 2017;66(32):861–862. doi:10.15585/mmwr.mm6632a6.
17. National Institute of Occupational Safety and Health (NIOSH). NIOSH alert: preventing deaths of farm workers in manure pits. 90–103. 1990. https://www.cdc.gov/niosh/docs/90-103/. Accessed August 31, 2017.
18. ASABE. *Manure Storage Safety – ASABE Engineering Practice Standard ASAE EP470.1 Oct2011*. St. Joseph, MI: American Society of Agricultural and Biological Engineers (ASABE); 2016.
19. Occupational Safety and Health Administration (OSHA). Permit-required confined spaces. 3138-01r. 2004. https://www.osha.gov/Publications/osha3138.pdf. Accessed August 30, 2017.
20. Andersen D. *Hydrogen Sulfide Safety – Manure Agitation*. AE-3604. Ames, IA: Iowa State University Extension and Outreach; 2017. https://store.extension.iastate.edu/product/15107.
21. Andersen D. *Hydrogen Sulfide Safety – Monitoring*. AE-3603. Ames, IA: Iowa State University Extension

and Outreach; 2017. https://store.extension.iastate.edu/Product/15106.
22. Petrea C. Manure storage safety. eXtension; 2016. http://articles.extension.org/pages/19943/manure-storage-safety.
23. Steel J, Murphy D, Manbeck H. *Confined Space Manure Storage Hazards*. College Station, PA: The Pennsylvania State University College of Agricultural Sciences; 2017. https://extension.psu.edu/confined-space-manure-storage-hazards.
24. Meinen R, Hill DE. *Open Air Manure Storage Safety Tips*. College Station, PA: Pennsylvania State University College of Agricultural Sciences; 2017. https://extension.psu.edu/open-air-manure-storage-safety-tips.
25. Torres C. *Dairy Farmer's Boys Have Close Call with Manure Gas*. Ephrata, PA: Lancaster Farming; 2012. http://www.lancasterfarming.com/news/main_edition/dairy-farmer-s-boys-have-close-call-with-manure-gas/article_81a6333f-a687-5edf-a3eb-02060fae3e17.html.
26. Alexander L. *Asphyxia Cause of Death for 3 Found in Maryland Manure Pit*. Lancaster, PA: LNP Media Group; 2012. http://lancasteronline.com/news/asphyxia-cause-of-death-for-found-in-md-manure-pit/article_84f27f7d-6533-58ba-8861-bd7f55d3cbf9.html.
27. Janni K. *Manure Safety: Hydrogen Sulfide*. St. Paul, MN: University of Minnesota Extension; 2017. https://www.extension.umn.edu/agriculture/dairy/manure/manure-safety-hydrogen-sulfide/index.html. Accessed September 20 2017.
28. Wing S, Horton RA, Marshall SW, Thu K, Tajik M, Schinasi L, Schiffman SS. Air pollution and odor in communities near industrial swine operations. *Environ Health Perspect*. 2008;116(10):1362. doi:10.1289/ehp.11250.