GREAT PLAINS
Center for Agricultural Health
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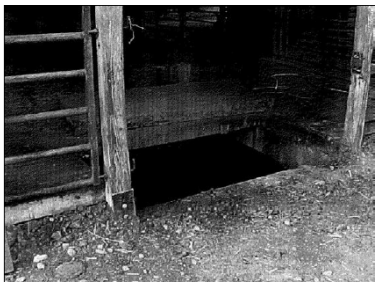
Manure Storage Pit Dangers: Identifying Hazardous Gases

Technical Guidance for Selection and Use of Monitors to Assess Air Hazards

People entering manure pits without taking proper precautions are at risk of dying from high exposures to hydrogen sulfide gas. Guidance on manure pit operations from ASABE specify the need to monitor these spaces prior to entry. This alert provides general guidance on why and how to monitor.



Access to manure pit where two died after entering a manure pit, Iowa FACE 2005 IA 024, 025.

Do not enter manure storage areas without ventilating and measuring gas concentrations.

Four Midwestern farmers died in July 2015 from gas exposures when entering manure pits:

- Palo Alto County, Iowa: Son entered manure pit to make repairs, and father entered to rescue him. Both died July 25, 2015. http://www.siouxlandmatters.com/story/d/story/palo-alto-co/38089/L8vsp-TP00OoWIs_n4MX-g
- Chippewa County, Wisconsin: Son entered manure pit to retrieve equipment, and father entered to rescue him. Both died July 2, 2015. http://www.jsonline.com/news/wisconsin/2-wisconsin-men-die-after-falling-into-manure-pit-b99532179z1-311646871.html

People cannot smell hazardous concentrations of hydrogen sulfide (H_2S) and methane (CH_4), but concentrations may be high enough to decrease oxygen or paralyze breathing. Concentrations change over time, and understanding how much gas is in the manure storage pit before each entry is important to prevent death. Monitors for measuring gas concentrations are available and should be used prior to entry into any manure storage area.

A monitoring plan should be incorporated into a confined-space program that identifies how to assess the air quality prior to entering a manure storage pit. This alert provides farmers with specific information on the hazards of manure gases, information on how to select monitoring equipment, procedures to use to safely monitor the air quality prior to entering spaces containing or previously containing manure, and how to interpret readings to ensure a safe entry. This alert *supplements* the brief hazard alert "Manure Storage Pit Dangers: Hazard Gas Awareness" to provide technical information to farmers to implement a monitoring program.

*This alert provides technical guidance to help agricultural workers understand how to **safely evaluate the air quality** in manure storage pits for safe entry into manure pits*.

Everyone who works in or around manure storage tanks /pits / lagoons should understand manure gas hazards.

Do not enter **manure storage areas until they are adequately ventilated and concentrations are verified to be safe.**

"Holding your breath" is not an acceptable strategy to safely enter into hazardous environments.

The following pages provide general guidance on how to select and use gas monitors to evaluate whether a manure pit is safe for entry.

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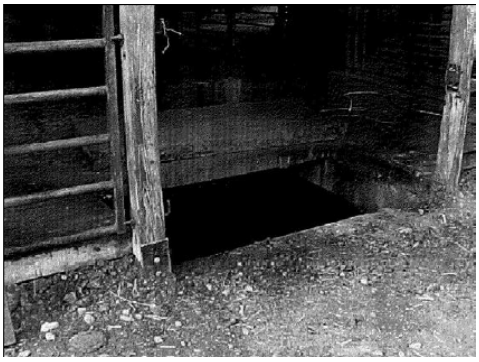
Technical Guidance for Selection and Use of Monitors to Assess Air Hazards

What are the hazards?

Methane and hydrogen sulfide gases are generated naturally in all anaerobic manure pits.

Hydrogen sulfide (H_2S) has a rotten egg odor at low concentrations, but as concentration increases, people can no longer smell this compound (olfactory fatigue). At and above concentrations of 100 ppm, severe eye and lung irritation begins and pulmonary edema (a potentially fatal lung condition) may occur. Most importantly, at high concentrations (800 ppm and above), the respiratory system is paralyzed and the exposed person loses consciousness, with typically fatal outcomes. Concentrations well above 1000 ppm have been measured during manure agitation (ASABE, standard EP470.1).



Access to manure pit where two died after entering a manure pit, Iowa FACE 2005 IA 024, 025 (http://www.public-health.uiowa.edu/face/Reports/PDF-Reports/2005IA024-025.pdf)

Methane (CH_4) is also generated in manure pits. It cannot be smelled, but can be released in manure pits in concentrations that are combustible. When methane concentrations are between 5% (50,000 ppm) and 15% (150,000 ppm) and an ignition source is present (such as a pilot light, cigarette, shorting electrical wires, open torches), an explosion can occur. At these high concentrations, there is also a risk of reduced oxygen in the air: for every increased 4% of methane, the percent oxygen decreases by approximately 1%. When oxygen levels reduce from 20.9 to 19.5% (at sea level), people will not have enough oxygen. In oxygen-deficient atmospheres, a worker's pulse and breathing rate may increase and they may begin to feel nauseous. Impaired thinking, reduced coordination, and fatigue develop, and workers may faint: these safety hazards may lead to death in a manure pit.

How do know if these gases are present?

Workers should presume that these gases are present at hazardous concentrations in all manure pits. If entry into the pit is needed, a specific plan for entering is needed. This plan is referred to as a "confined space entry" program, which identifies the risks of entering a manure pit and outlines the steps for a safe entry.

See the following web sites for chemical-specific hazard information on gases common to manure pits:

Oxygen deficiency:
http://www.airproducts.com/~/media/Files/PDF/company/safetygram-17.pdf
LEL:
http://www.fireengineering.com/articles/2010/08/hazmat-atmospheric-monitors.html
Carbon monoxide:
http://ephtracking.cdc.gov/showCoRisk.action
https://www.osha.gov/Publications/3282-10N-05-English-07-18-2007.html
Hydrogen sulfide:
https://www.osha.gov/SLTC/hydrogensulfide/hazards.html
https://www.osha.gov/Publications/hydrogen_sulfide.html
Carbon dioxide:
http://www.epa.gov/ozone/snap/fire/co2/appendixb.pdf

Examples of a written confined space programs are provided at the end of this alert, for reference.

Monitors are available to test the air quality inside the manure pit. Monitors are available to measure a single gas or to measure multiple gases at the same time ("multi-gas monitors"). Identifying the presence of oxygen is important as well as identifying whether the methane is at explosive concentrations. The best monitor to select is a multi-gas monitor that has sensors for oxygen (O_2), hydrogen sulfide (H_2S), and methane or explosion (LEL or Lower Explosive Limit). Since these monitors typically have the capability for monitoring four gases at once, we recommend farmers select carbon monoxide (CO) as the fourth gas sensor, which comes in handy in the winter when gas-fired heaters may generate hazardous concentrations in livestock buildings. Ammonia (NH_3) sensors are also available, but these are expensive to purchase and calibrate, and a separate single-gas monitor is recommended for testing ammonia.

Inexpensive monitors can detect gases and indicate dangerous concentrations.

How does the monitor measure methane?

Direct reading monitors specific for combustible gases are available to measure whether methane gases are present in the air. These devices can be expensive ($600-1200 each), and units require calibration to ensure accurate readings. You should select a meter that is "intrinsically safe" so that it does not introduce a spark that might ignite the methane in the area you are testing. Rental companies (details at end of alert) can provide calibrated monitors, but it make take several days to receive rented monitors: plan to secure monitors before undertaking activities that might release methane. These meters provide readouts that will indicate the presence of methane (as LEL) to let you know if the indoor environment has a problem. Evacuate the building if you see %LEL increase when wearing / using these monitors.

If you are using an LEL monitors with catalytic (or "pellistor") sensors, oxygen is required for the LEL sensor to work properly. If there is insufficient oxygen, the LEL sensor will underestimate the risk of explosion. *If oxygen is lower than 20.9%*, presume that the *LEL risk is higher* than the monitor indicates, and do not enter the area.

What does %LEL mean?

The reading on most combustion meters indicate the gas concentration relative to its ability to combust or explode. Meters indicate the gas concentration in percent of the lower explosive limit (%LEL). Normal air should read 0% LEL.

Combustion monitors provide readings in terms of %LEL. At 100% LEL, the concentration of the gas is at the lower explosive limit. If the gas is methane, the

Using Gas Monitors – Methane as % LEL (Lower Explosive Limit)

1. There must be sufficient oxygen in the environment for an LEL monitor to read correctly, so a multi-gas monitor that also reads oxygen is recommended.
2. Gas monitors should be calibrated, at least as frequently as is specified by the manufacturer's directions. Follow calibration procedures in a safe area, where concentrations are anticipated to represent clean air.
3. To make sure the sensors are working before needing to rely on them to protect you, bump test the monitor with gas to make sure the sensors can "see" the gas and the monitor alarms to give you warning. You can use the calibration gas to do this check (without putting the monitor in calibration mode).
4. If oxygen content *decreases* when using an LEL meter, the %LEL reading will be wrong: Respond to a LOW Oxygen reading as an indication of dangerous LEL and evacuate.

lower explosive limit is 5% in air, or 50,000 ppm. Therefore, when the monitor reads "10% LEL", this means that the methane concentration is approximately 5000 ppm
(calculated by: 0.10 x 50,000 ppm).

How do I respond to a reading of %LEL in a manure storage area?

Fire risk is *high* when the monitor indicates 10% LEL or greater. Confined space programs should specify "no entry" when 5% LEL is measured. Why this factor of safety? This is because you are only monitoring one area of the manure storage pit, and concentrations might be higher in other areas. If someone enters the pit and generates a spark in an area of high methane, an explosion can occur. The storage area should be ventilated (see ASABE S607) and the space retested prior to allowing entry.

Note that the meter only reads the concentration in the immediate vicinity of the monitor: if there is little air movement in the room, you may have pockets of air at dangerous concentrations. Hence, it is critical to have turned off electrical sources and prevent sparking (hitting metal on metal, electrical equipment cycling on/off) when testing these spaces.

How does a monitor measure hydrogen sulfide (H_2S)?

Direct reading monitors specific for hydrogen sulfide as a single gas component are available for $100-200, each. These units also require calibration to ensure accurate readings and testing to make sure the sensor is still working. Rental companies can provide calibrated monitors, but plan ahead to make sure you have monitors for manure pit activities, including pumping and entry. These meters provide readouts that will indicate the presence of hydrogen sulfide to let you know if the indoor environment has a problem.

Using Gas Monitors – Hydrogen Sulfide (H_2S)

1. Gas monitors should be calibrated, at least as frequently as is specified by the manufacturer's directions. Follow calibration procedures in a safe area, where concentrations are anticipated to represent clean air.
2. To make sure the sensors are working before needing to rely on them to protect you, bump test the monitor with gas to make sure the sensors can "see" the gas and the monitor alarms to give you warning. You can use the calibration gas to do this check (without putting the monitor in calibration mode).
3. When performing a bump check, evaluate how long it takes for the monitor to display the concentration that matches the one in your calibration gas. If this starts to take longer than it did last time (or longer than the manufacturer's book indicates), it is time to order a new sensor and replace it so you are ready the next time you need it.

Know the limitations of the sensor that you have. Traditional hydrogen sulfide sensors use metal oxide semiconductors or electrochemical sensors. Metal oxide sensors have *slower response times* (up to 120 seconds) and *may have difficulty responding to low concentrations* until a "bump" test (putting high concentration of hydrogen sulfide gas onto the sensor), although new nano-technology sensors may be improving these devices. Alternatively, traditional electrochemical sensors operate by measuring a voltage change from a chemical reaction between the sensor chemicals and hydrogen sulfide in the air: the voltage change is converted to concentration information in the monitor display. Note that these sensors *may take 30 seconds to respond* to hydrogen sulfide, and many *do not respond well in cold (-20^o C) temperatures*.

Hydrogen sulfide monitors have been typically set to alarm at 10 or 15 ppm. These are old concentration limits that were set by the American Conference of Governmental Industrial Hygienists (ACGIH) to protect workers over an 8-hour and 15-minute work duration, respectively. **Current exposure limits are now set at 1 and**

5 ppm, and it is appropriate to set alarms to these new limits. Note that OSHA regulations specify that workers not exceed 20 ppm at any time, with a 50 ppm exposure ceiling for 10 minutes if there is no other exposure occurs. These levels may not be protective of human health.

How do I get the sampler into the area I need to monitor?

To minimize the risk to the worker during monitoring, you need to make sure the sampler measures the air *before* a person has a chance to breathe the air. Stand outside the manure pit and place the monitor inside the air space of a manure pit. Take care not to get liquid onto or into the monitor, as this will foul the sensor and make it unusable.

Some monitors have an internal pump and allow you to put an extension wand on the end of the unit, with an approved tubing to go onto the end. This pump and tubing allows you to measure air far away from where you stand. If you don't have a monitor with a pump to draw air into the sampler, you can secure the monitor to the end of a long stick (for putting the monitor into a space laterally) or rope (if lowering the monitor into a space). When putting the monitor into the space, remain outside the space where the air is "clean". You want to be able to see the readout on the monitor when you are testing the air. If concentrations exceed the alarm levels, the unit will vibrate and the display will probably be flashing: this alarming will let you know *it is not safe to enter* without first ventilating the manure storage pit.

Once the area is tested while standing from the outside, if it is safe to enter, measure air quality in the path that you need to travel in order to do the job that makes you go into the pit. Follow testing methods for "stratified atmospheres", by testing in the direction of needed travel: check at least 4 feet in front of you, in the direction of travel, *and* 4 feet to each side when checking for safe entry.

Remember, however, that it takes TIME for the monitor to react to the chemical in the air and time for the pump to move the air from the pit onto the sensor. Therefore, sampling the air to make sure it is safe to breathe ***will take time***.

The time it takes to test air at each location in the manure storage pit should be a function of the sensor with the longest response time: check the manufacturer's manual for each sensor's response time. If using a pump system, *add to the sensor response time* the time it will take to pull air into the sensing area of the monitor. See the side box for an example of how to calculate the time it will take for the monitor to measure gas at a given location, using sample manufacturer's data in the operation manual.

The order of testing is important if you do not have a multi-gas monitor. Oxygen must be sampled for first, followed by combustible/flammables (methane as %LEL), followed by toxic chemicals (hydrogen sulfide).

Example TIME Calculation for sampling:

1. Identify the maximum response time of sensor in the manual. For this device, the manual provides time to achieve 90% of final reading, when within normal temperature range (0-40°C), in:
    a. O_2: 30 sec
    b. LEL: 30 sec
    c. CO: 60 sec
    d. H_2S: 60 sec
    *Hence, max response time is **60 seconds**.*
2. Look up the sample time for the monitor's pump specs, based on sample line length:

Table 1-1. Device Specifications

TEMPERATURE RANGE	NORMAL	-20 to +50°C (-4 t
SAMPLE LINE TRANSPORT TIMES	25 feet	10 seconds
	50 feet	20 seconds

25 feet: **10 seconds**

3. ***Total Time to Sample at each location*: 70 seconds**.

How do I interpret the monitor readings?

See the table below. The "High Alarm" typically results in louder alarm than the low, or first, alarm. If you don't have two alarm set points, choose the low alarm setting in the table. IDLH is the concentration that is "immediately dangerous to life and health," which is established by NIOSH (the National Institute of Occupational Safety and Health). The IDLH values identify concentrations that are ACUTELY hazardous (Danger!). If the monitor displays concentrations that are at or above the IDLH, *immediately leave the area*. The actions indicated are for the ***acute hazards to the person conducting monitoring***. To safely work in the area, concentrations need ***to be below the alarm set points***, as indicated.

	Set Alarm Levels*			
Contaminant	Low Alarm	High Alarm	IDLH	Notes
Oxygen, % (at sea level)	19.5	19	*No IDLH: Leave if reach 19.5%*	LEL may not read correctly if <19.5%. This presumes no O_2 generation sources.
LEL, %*♦	5	10	Asphyxiant; watch Oxygen% changes	Remove all workers, animals from room if pit > 50% LEL as methane (25,000 ppm)**
CO, ppm	25	50	1000	Headache at 100-400 ppm. If develop flu-like symptoms quickly; get out.
H_2S, ppm	1	5	100	Remove all workers, animals from room if pit gas > 80 ppm.**
NH_3, ppm	25	35	300	Eye irritation may prevent safe action above 140 ppm; lung irritation @ 100 ppm.
CO_2, ppm♦	5000	-	40,000 (4%) will displace oxgen	Remove all workers, animals from room if pit gas > 32,000 ppm.**

*Note: If you don't calibrate the LEL sensor with methane, you need to know the response to the calibration gas and how it relates to methane. For example, calibration with pentane typically gives you %LEL readings higher than the true LEL. Check the operation manual for the sensor and monitor you have.

♦If CO_2 and %LEL reach significant levels, it will displace oxygen. Watch changes in Oxygen % as an indicator of significant concentrations of these two contamiants combined.

** See ASABE S607 Table 7.

Who can I contact for more information?

The faculty and staff of the Great Plains Center for Agricultural Health are able to help you with monitoring questions. Contact CPH-GreatPlainsCenter@uiowa.edu for assistance. We are glad to provide hands-on training and education to groups of interested farmers, emergency responders, and agricultural outreach organizers to develop expertise to protect farmers and those working on the farm.

New Hazard Communication pictogram indicating health hazard.

Recommended sign to post near manure pit entry locations (ASABE EP470.1)

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Links to More Information

General Information on Manure Pit Hazards

NIOSH has been providing information to prevent asphyxiation in manure pits since 1990. See http://www.cdc.gov/niosh/docs/90-103/

The ASABE is a professional and technical organization dedicated to the advancement of engineering applicable to agricultural, food and biological systems. This organization has developed standards to recommend ventilation (S607) and operation (EP470.1) of manure storage pits with safety in mind. Their recommendations include monitoring spaces prior to entry.
ASAE EP470.1: https://elibrary.asabe.org/azdez.asp?JID=2&AID=39802&CID=s2000&T=2
ANSI/ASABE S607: https://elibrary.asabe.org/azdez.asp?JID=2&AID=36208&CID=s2000&T=2

General Confined Space Program Information

Michigan's Department of Licensing and Regulatory Affairs has provided a sample written program for permit-required confined space entry that can be customized for farming operations: *http://www.michigan.gov/documents/dleg/deleg_wsh_cet5330_346240_7.doc*.

OSHA has developed training program to outline the confined space program (although this is for another sector, the images aren't useful for agriculture, but the content is useful): https://www.osha.gov/Publications/2254.html

OSHA also provides assistance materials on confined spaces to all at: https://www.osha.gov/confinedspaces/index.html

Gas-Vapor Monitoring References

NIOSH Technical Report: Components for Evaluating Direct-Reading Monitors for Gases and Vapors http://www.agronext.iastate.edu/immag/manurevideos.html

OSHA Safety and Health Information Bulletin (SHIB 09-30-2013): Calibrating and Testing Direct-Reading Portable Gas Monitors https://www.osha.gov/dts/shib/shib093013.html

PennState Extension – Confined Space Manure Gas Monitoring Fact Sheet: http://extension.psu.edu/business/ag-safety/confined-spaces/manure/manure-pit-safety-fact-sheets/e-52

FACE Reports

These comprehensive investigations provide details of what happened that caused or contributed to worker fatalities associated with manure storage pit entry. As important as the sequence of events are, these contain recommendations to prevent these from happening in your operation.

Iowa farmer and employee died after collapse and attempted rescue in manure storage pit (http://www.public-health.uiowa.edu/face/Reports/PDF-Reports/2005IA024-025.pdf)

Iowa hog farmer dies from asphyxiation after manure pit agitation (http://www.public-health.uiowa.edu/face/Reports/PDF-Reports/Manure%20Pit%20Agitation.pdf)

Minnesota farm owner and son asphyxiated in manure waste pit (http://www.cdc.gov/niosh/face/In-house/full9229.html)

Minnesota hog farm co-owner and employee die of hydrogen sulfide poisoning in manure pit (http://www.cdc.gov/niosh/face/In-house/full9228.html)

Five family members in Michigan die after entering manure waste pit on dairy farm (http://www.cdc.gov/niosh/face/In-house/full8946.html

Equipment Rental Companies

Google search "Gas monitor rental" to identify monitor rental services. Ensure that the company will provide calibrated equipment, written certification of calibration in the shipment, and operation manual. Request they set the alarms to the limits you need prior to shipping.