**Workshop Technical Notes:**

**Gas Sensors and Monitors**

**Description:**

This workshop can be used as a stand-alone activity or as part of a related lesson. This activity uses a metallic oxide gas sensor to detect levels of carbon dioxide (CO2) gas in the air. Participants will connect the gas sensor to an Arduino Uno microcontroller board to measure the concentration of CO2 gas in the air, and a small OLED display to show the measured CO2 gas concentration in parts per million (ppm). This activity requires approximately 30 minutes to complete.

**Related topics:** indoor air quality, confined spaces, manure pit safety, silo gas safety, biogas safety, STEM activity, DIY electronics.

**Introduction:**

Most gases in the air we breathe do not have properties that allow you to detect, either by sight or smell, their presence. Some of these gases, in varying levels of concentrations, can be found in agricultural confined spaces such as barns or manure pits. These can create hazards for animals as well as humans. It is important to detect the concentration of gases present in an enclosed building or space to limit the risk of injury, illness, or death. Gas concentration is often expressed in parts per million, or ppm, which is a ratio of the volume of gas to the volume of air (1,000,000 ppm = 100%). Examples include manure pit gases such as hydrogen sulfide, which is immediately dangerous to life and health at a concentration of 100 ppm (100 ppm / 1,000,000 = 0.01% by volume), and silo gases such as nitrogen dioxide which can be toxic above 20 ppm. Methane is a flammable gas that is generated when animal manure breaks down in storage pits and may explode at concentrations greater than 50,000 ppm when exposed to sparks or heat. If we can’t see or smell these gases, how can we detect them to know when hazardous situations exist?

Many mechanical methods exist to detect toxic gases and hazardous atmospheres at worksites. Davy lamps were used in the early 1800s to detect flammable gases and low oxygen levels in coal mines (Thomas, 2015). The lamp flame would burn higher in the presence of flammable gases or would be extinguished if the oxygen level became dangerously low. The lamps used a fine mesh screen around an oil lamp wick. This wire mesh served as a flame arrestor by preventing explosions since the flame was not able to propagate into the work area. Another early method of detecting toxic gases included the use of Canaries. Canaries were used in the early 1900s in coal mines to detect toxic gases, because the birds would experience distress or die before gas levels were high enough to hurt human workers (Eschener, 2016). Today, there is a wide range of gas detection technology to measure and monitor gas concentration in real time.

Metallic oxide gas sensors were first developed in the 1950s (Moseley, 2017). They contain a heated metallic oxide sensing element, such as SnO2 (stannic oxide), that changes resistance when exposed to different concentrations of certain gases. We can measure this change in resistance using a voltage divider circuit built into a gas sensor module and calculate the concentration of the target gas in the air. The technology has advanced enough that small sensors can be manufactured for little cost. Since metallic oxide sensors are compact and react to gas concentration changes very quickly, they are well suited for use in gas detector circuits.

Human workers occasionally must enter manure pits or silos for equipment maintenance. Ventilation and gas detection are important to keep human workers safe, but they are also an important aspect of agriculture for animals raised for food that live indoors in environmentally controlled barns. In addition to being hazardous to humans, high levels of ammonia gas can negatively affect the health and welfare of poultry, swine, and other animals raised indoors. And gases such as hydrogen sulfide that are toxic to humans are also toxic to animals.

How do we reduce toxic gas hazards on farms? If you can’t see or smell the hazard, you must treat the situation with caution. Use personal gas monitors to detect toxic gases and concentrations. Avoid areas such as manure pits during pumping and agitation events. Use ventilation to deliver fresh air prior to and during work in or near manure handling areas, monitor gas levels using gas detectors, and immediately leave the area and retreat to safety (away from the hazard to fresh air) if a gas detector alarm goes off.

**Sensor Details:**

Arduino is an open-source electronics platform that allows users to connect a wide variety of inexpensive sensors and other hardware with a microprocessor that can be easily programmed to perform many useful functions. The Arduino boards used for this activity should be pre-programmed, so participants do not need to write or upload code.

The MQ-135 gas sensors we will use for this activity are sensitive to more than one type of gas: carbon dioxide, ammonia, and alcohol. If these sensors are used in the presence of multiple gases at the same time, the measured concentrations may not be meaningful. Selection of sensor type should be based on the make-up of gases in the air you expect to measure. The MQ-135 gas sensors would be appropriate for measuring CO2 concentration if you do not expect any of the other gases listed to be present in the air.

Calibration is necessary because sensors deteriorate with exposure over time. Additionally, other ambient conditions may affect sensor readings such as changes in temperature and humidity. Calibration is typically performed by exposing a gas sensor to a known concentration of target gas and adjusting the output, so the correct reading is displayed. Calibration gas is typically supplied in small gas cylinders with a specific concentration of target gas in a mixture with an inert gas (example: 25 ppm of ammonia gas, balance nitrogen). Bump testing is a periodic calibration check to verify the sensor calibration is still correct.

The CO2 concentration of outdoor atmospheric air is approximately 400 ppm and may exceed 1,000 ppm indoors. For this activity, a background CO2 level of 400 ppm is assumed, and that level will be used to calibrate the MQ-135 sensor after a brief warm-up period.

**Learning Activity Tips and Tricks:**

1. Avoid shorting out the exposed metal pins of the display, sensor, and Arduino board by touching them together or touching them to a metal surface. If you accidentally short something and the display turns off, try pressing the Reset button on the Arduino to restart the board. Do not place the components on a metal surface.
2. Hold the jack on the Arduino board when plugging in the AC adapter to avoid putting too much mechanical stress on the jack.
3. It may help to place a finger on the Arduino USB jack when pressing the Reset button, just to hold things steady.
4. Static electricity can destroy electronic components, so use care when handling parts. If the air is very dry and it is easy to create static, such as during winter, have students’ “ground” themselves periodically by touching something metallic to discharge any static buildup. Suggestions might be a metal desk or chair leg, toolbox, or filing cabinet – anything nearby that is safe to touch (i.e. I would not suggest using the ground from an electric outlet but touching a metal outlet plate cover could be safe).
5. Keep a multimeter on hand for troubleshooting. Jumper wires may break internally after repeated bending and use, and a multimeter can be used to check for continuity. You can also check for continuity across pins of the CO2 sensor or the OLED display to check for shorts. If the onboard Arduino voltage regulator begins to fail, you can use the multimeter to check the 3V3 and 5V pins for correct output voltages. You can also use the multimeter to check the output voltage of the AC adapter or 9V battery.
6. Jumper wires may be difficult to push onto pins when new, and may get loose after repeated use, resulting in loose or intermittent connections. The black plastic insulators at each end of the wire can be removed and the female connectors can be crimped slightly using pliers or wire crimpers to improve contact if needed. The black insulators may also fall off, but these can easily be pushed back into place.

**Gas Sensors and Monitors Workshop Lesson Plan**

**Learning Objectives:**

By the end of today’s workshop, participants will be able to:

* List a few hazardous gases found in agricultural operations.
* Explain why detection of toxic gas levels is important around manure pits or in silos.
* Describe how an electronic gas sensor measures gas concentration in air.
* Explain why gas sensors require calibration and bump testing.

**AFNR Standard Alignment:**

**ESS.01** - Use analytical procedures and instruments to manage environmental service systems.

**ESS.01.02** Properly utilizes scientific instruments in environmental monitoring situations (e.g., laboratory equipment, environmental monitoring instruments, etc.).

2.a: Identify basic environmental monitoring instruments and explain their uses.

2.c: Calibrate and use environmental monitoring instruments according to standard operating procedures.

**ESS.05** – Use tools, equipment, machinery and technology common to tasks in environmental service systems.

**ESS.05.02** Perform assessments of environmental conditions using equipment, machinery and technology.

3.a: Research and summarize methods and tools used to determine air quality and determine if pollution is present (e.g., CO2 probe, particulate matter sampler, etc.)

**Materials, resources and supplies for workshop (each participant needs these):**

* Instruction sheet (color prints preferred)
* One Arduino UNO R3
* One MQ-135 gas sensor
* One 0.96” OLED display
* Eight colored jumper wires (red, orange, yellow, green, blue, white, grey, black)
* One 9V AC/DC adapter
* Optional: One 9V battery + One 9V battery to 5.5mm plug adapter

**Some things useful for instructor to have on hand:**

1. Digital multimeter (DMM) – test wire jumpers for continuity, test battery/AC adapter voltage

2. Small hand tools (screwdriver, wire cutters/strippers, pliers)

3. AC power strips – for plugging in 9V AC/DC adapters, need one outlet for each kit

**Instruction Plan:** Use the notes below to guide your instruction.

| **Instructor Directions / Materials****HOW you will teach** | **Content Outline, Instructional Procedures, and/or Key Questions****WHAT you will teach** |
| --- | --- |
| **Review the outline of the presentation** | * **Introduction to gas sensors**
* **Learning Activities**
* **Safety Topics**
* **Resources**
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| **Review learning objectives** | **Present slides and lead discussion with participants** |
| **Conduct learning activity: Arduino Gas Meter Circuit Building** | 1. Provide instruction handouts (color prints preferred).
2. Review safety notes with participants:
* Static electricity can destroy electronic components, so use care when handling parts. If the air is very dry and it is easy to create static, such as during winter, have students’ “ground” themselves periodically by touching something metallic to discharge any static buildup. Suggestions might be a metal desk or chair leg, toolbox, or filing cabinet – anything nearby that is safe to touch.
* When powered on, the voltage regulator on the Arduino board may get hot (the area circled in red in Figure 2 of instructions on both the top and bottom of the circuit board). This is normal and is due to the voltage regulator dissipating power as heat while reducing the 9VDC input to 5VDC used by the Arduino and the MQ-135 sensor. It should not get hot enough to cause injury (i.e. a person should be able to hold their finger to the area without causing burns, but it will feel very warm to the touch).
1. Discuss instructions.
2. Allow participants to complete the circuit.
3. Lead participants through the discussion: What happens when the circuit is powered on?
	* The Arduino microcontroller has been pre-programmed with a set of instructions written in the C++ programming language and loaded into onboard flash memory from a PC. When plugged in, the Arduino will automatically start executing the instructions.
	* First, a set of setup instructions are executed. The display is initialized and cleared, and the text “PSU SAFETY, Calibrating CO2 Sensor, please wait” is displayed.
4. Have students plug the power supply into the Arduino board.
	* Next, a set of instructions is executed to calibrate the MQ-135 gas sensor to a value of 400 ppm, which is the typical level of carbon dioxide (CO2) gas found in ambient air.
	* Once calibration has finished, the display is cleared, and the measured CO2 level is displayed in parts per million (ppm). A new reading is measured and displayed every 4 seconds.
	* Note the displayed CO2 level has dropped since you first turned on the Arduino. This is because the sensor has a metallic oxide element that gets heated using voltage supplied by the Arduino board (5V), and the output voltage (analog output, AO) of the sensor varies with CO2 concentration in the air near the sensor.
5. Have students report what their sensor display is showing in PPM.
	* It takes a few minutes for the element to reach a stable operating temperature, and as this happens, the output readings may change. You can press the Reset button on the Arduino to restart the program and recalibrate the MQ-135 sensor.
6. Have students press the reset button on the Arduino board (shown in Figure 3 of instructions).
7. Discuss limitations and options for various types of sensors:

**Electrochemical Sensors*** + Electrochemical gas sensors are commonly used in hand-held (portable) gas monitors. They contain electrodes that are surrounded by a liquid electrolyte. When gas encounters the sensing electrode, an electrochemical reaction produces an electric current that is proportional to the gas concentration. Electrochemical gas sensors are available for monitoring several toxic gases as well as oxygen content.
	+ Advantages – Low power requirements, high accuracy and repeatability. Can be used to measure oxygen content (% by volume).
	+ Disadvantages – Cross-sensitivity with other gases. Response times may be longer than for other sensor types. Operation in high temperatures with low humidity may dry out the electrolyte. Exposure to prolonged or high levels of target gas reduces sensor life span, even when not in use. Requires routine calibration against a known concentration of target gas to compensate for changes in zero reading and sensitivity due to sensor exposure and aging.

**Infrared (IR) Sensors*** + Infrared gas sensors are based on the principle that gases with more than one type of atom (e.g. CO2, made up of carbon and oxygen molecules) absorb infrared light at certain wavelengths. Infrared gas sensors have a sensing chamber with an infrared emitter located at one end, and an infrared detector at the opposite end where an optical filter only allows the wavelength of infrared light specific to the target gas to reach the detector. When a gas sample passes through the chamber, infrared light gets absorbed by the target gas molecules, which reduces the amount of infrared light received by the detector. The gas concentration is proportional to the amount of emitted infrared light received by the detector.
	+ Advantages – IR sensors have quick response and recovery times and can detect gases in inert atmospheres (little or no oxygen present). They require less frequent calibration and maintenance than other types of sensors. They are not susceptible to poisoning and can be made very specific to a target gas.
	+ Disadvantages – Higher initial cost, and optics may be susceptible to dust, dirt, and humidity. Cannot be used to detect gases made up of only one type of molecule, such as oxygen (O2) or hydrogen (H2).

**Metal Oxide Sensors (MOS)*** + Metallic oxide gas sensors contain a metal oxide semiconductor, typically tin dioxide (SnO2, also called stannic oxide), which undergoes a chemical reaction that changes its resistance when exposed to a target gas. The reaction works best at high temperatures in air, so a heater is used in the circuit to raise the temperature of the semiconductor. A fine metal screen is often used to prevent ignition, like the Davy miner’s lamp. The concentration of target gas is proportional to the change in resistance of the sensor. Due to power requirements to heat the semiconductor, MOS gas sensors are most used in fixed (non-portable) gas detection systems.
	+ Advantages – MOS sensors have high sensitivity, quick response and short recovery times. Cost is relatively low compared to other types of gas sensors.
	+ Disadvantages – Cross-sensitivity with other gases, and changes in ambient temperature and humidity may affect sensitivity. Will not operate properly in inert atmospheres (little or no oxygen present). Exposure to very high gas levels may result in permanent changes in zero readings and sensitivity.
1. Have students press the reset button.
	* After calibration has finished, the displayed CO2 concentration should be closer to 400 ppm. When you breathe on the sensor, the concentration should increase.
	* Have students try cupping their hands around the sensor and breathing onto them, the value should increase a lot more. They could place the sensor under a paper cup and breathe into that or put the sensor into a hose or fitting to concentrate exhaled CO2 for a more dramatic effect.
2. Potential extras: Use dry ice in water or a carbonated drink bottle as a CO2 gas source, or use a paper towel or cotton ball dipped in rubbing alcohol or glass cleaner such as Windex (which contains ammonia) to hold near the gas sensor and show how the sensors react to other gases in the presence of ambient CO2.
	* Discussion questions: Which gas source results in the highest reading? What happens to the reading as the sensor gets further from the source? How close to the source does the sensor need to be to detect each gas?
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| **Clean-up and Lead Discussion using questions with students/participants** | * Who had the highest recorded CO2 sensor reading? Who had the lowest? Why were there differences? (differences in CO2 levels, temperature, and moisture in exhaled breath from person to person; age and condition of sensors; technique used)
* How could you improve the circuit? (add a warning light or buzzer to alert the user to dangerous gas levels; connect more sensors to detect additional gases; use smaller components to make the circuit more portable)
* What should you do if a personal gas monitor alarm goes off?
* What are some ways we can reduce toxic gas hazards on farms?
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| **Conduct Learning Evaluation** | Utilize a quiz or informal questioning to gauge student learning.Potential Quiz Questions:* Where are hazardous gases commonly found on farms?
* What are two hazardous gases commonly found in manure pits?
* How do electronic gas sensors work?
* T or F: If you can’t see or smell toxic gases, then there is no hazard.
* T or F: You should stop to read the measured gas concentration on a personal gas meter as soon as an alarm goes off.
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**References:**

Chou, J. (2000). Hazardous gas monitors: a practical guide to selection, operation and applications. McGraw-Hill Professional Publishing.

Eschener, K. (2016). "The Story of the Real Canary in the Coal Mine." Smithsonian. Retrieved 11 June 2018. <https://www.smithsonianmag.com/smart-news/story-real-canary-coal-mine-180961570/>

Moseley, P. T. (2017). Progress in the development of semiconducting metal oxide gas sensors: a review. Measurement Science and Technology, 28(8), 082001. <https://doi.org/10.1088/1361-6501/aa7443>

Thomas, J. M. (2015). Sir Humphry Davy and the coal miners of the world: a commentary on Davy (1816) ‘An account of an invention for giving light in explosive mixtures of fire-damp in coal mines’. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 373(2039), 20140288. <https://dx.doi.org/10.1098/rsta.2014.0288>

**Additional Resources:**

Hofstetter, D., and Fabian, E. (2018). Use Personal Gas Monitors to Avoid Exposure to Toxic Hydrogen Sulfide. Penn State Extension. <https://extension.psu.edu/use-personal-gas-monitors-to-avoid-exposure-to-toxic-hydrogen-sulfide>

Murphy, D. (2013). Silo Gases – The Hidden Danger. Penn State Extension. <https://extension.psu.edu/silo-gases-the-hidden-danger>

Penn State Extension. (2016). Biogas Safety. <https://extension.psu.edu/biogas-safety>