White Paper

Safety Demands Use of a Gas Monitor Before Entering Confined Spaces

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Abstract

No one should ever enter a confined space without proper training and suitable equipment to monitor the air before entry, and during the entire time the space is occupied. A confined space should always be considered dangerous and monitored for oxygen deficiency/enrichment, combustible gases, and toxins. Many airborne contaminants cannot be detected by smell or sight, so a gas monitor is the best defense against harmful, or even fatal, exposure to airborne contaminants. Used properly a gas monitor can be a life saving tool, and the manufacturer should always be consulted to optimize your selection and use of such an important piece of equipment. This white paper describes the design of portable electronic gas monitoring systems, how they work, and criteria for their selection.

Confined Space Monitoring

There is a wide range of industrial settings where entry into a confined space is required in the course of a day's work. Some of the more common settings are chemical plants, gas extraction sites, liquid product distribution terminals, oil platforms, paper mills, petrochemical processors, refineries, steel mills, underground mines, utility passageways, and water/waste water facilities. In the confined workspaces of these environments there is often a danger of the air being contaminated with toxic or combustible gases.
A variety of gas monitors are available for detecting airborne combustibles and toxins, but for confined workspaces a portable electronic gas detection system is the most practical (Figure 1). This type of monitor can be fitted with a flexible sampling tube, allowing it to be inserted into a confined space to check the air before entry. Selection decisions are often based on monitor size, price, “bells and whistles”, and other features that have nothing to do with the instrument’s basic monitoring capabilities. While these factors may be valid selection criteria, they should be considered after evaluating the gas monitor’s sensing capabilities. The sensor is the most important component inside a gas monitor.

Gas Monitor Design

Still, understanding the overall design of a typical gas monitor can be a great help in selecting the appropriate device. The seven basic building blocks of a monitor are the:

- Sensors
- Power Supply
- Electronic Circuitry
- User Interface
- Alarms
Monitoring Targeted Substances – Portable gas monitoring systems may be designed for a single substance, or could be fitted with multiple sensors (Figure 2). A multiple sensor design is often driven by OSHA requirements, which specify confined space monitoring by following this detection sequence: oxygen, combustible gases, and any potential toxic contaminants (29 CFR 1910.146, page 4551, Section (ii)(c)). Oxygen readings must be taken prior to testing for combustibles, because a minimum of 12-15 % (by volume) of oxygen is necessary for proper operation of a conventional catalytic oxidation (CAT) sensor. This type of sensor must burn the combustible using a heat of reaction principle. If the oxygen level is too low, the combustible gas will not burn and the combustible gas reading will be too low. Combustible and toxic gas sensors are generally selected based on the probability of the targeted gases being present in the confined space.

More specifically, gas monitoring prior to each entry and continuously while in a confined space should include sensors for:

- $O_2$ – to check the oxygen level for deficiency or enrichment
- Combustible gas – to test for levels of flammable or explosive gases
• Toxic gas levels – typical confined space monitors have hydrogen sulfide (H₂S) and carbon monoxide (CO) sensors; additional toxic sensors may be used based on the application.

Each person entering the confined space should be equipped with a portable gas monitor worn on the person in a position where it can be checked easily and frequently.

**Sensor Types** – The four most common electronic sensor technologies used in gas monitors are electrochemical (EC), catalytic oxidation (CAT), infrared (IR), and photoionization detector (PID). As a general rule, each type of sensor is best suited for certain substance categories. Nevertheless, some sensor types can be calibrated for more than one category. Substances that can be found in confined workspaces are typically classified in one of the following groups:

• Oxygen
• Toxic gases and vapors (organic or inorganic)
• Combustible gases and vapors (organic or inorganic)
• Combustible dusts (coal, grain, etc.)
• Toxic dusts (lead, asbestos, etc.)

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**Gas Sensor Operating Principles**

**Electrochemical sensors**

Electrochemical gas sensors measure the concentration of a target gas by oxidizing or reducing that gas at an electrode and measuring the resulting current. This electrical signal is directly and linearly proportional to the gas concentration.

**Catalytic sensors**

Catalytic sensors are used to detect combustible gases based on a heat of reaction principle. A catalyst facilitates the reaction between oxygen in
the air and the targeted combustible gas. The oxidation reaction creates heat that increases the resistance of the detector element in the catalytic bead, changing the flow of electrical current. The electrical current signal is translated into a reading on a digital (LCD) display.

**Infra Red sensors**

Infrared (IR) sensors use a light source that emits radiation from the infrared region of the light spectrum and a corresponding IR detector that produces an output current. The air sample enters the detection chamber where there is a specific distance (path length) between the emitter and detector. The target chemical compound in the air sample absorbs some of the IR radiation, resulting in less radiation reaching the detector. The reduction in radiation at the detector reduces its output current, which is proportional to the concentration of the chemical compound.

**PID Sensors**

A photoionization detector (PID) utilizes ultraviolet light to ionize gas molecules between a pair of electrode plates placed in close proximity to the light output. The electrodes are biased with a stable DC voltage, and as gas molecules move into the electric field between the plates they are ionized. This creates free electrons that are collected at the electrodes, resulting in a current flow whose magnitude is directly proportional to the gas concentration.

Each sensor, regardless of type, is calibrated using a gas that is either a specific target gas, or a gas that will produce the desired signal for a category of gases.

**Sensor Characteristics**

*EC Oxygen Sensors* can measure the volume of this gas in air over the range of 0-25%. When installed in a gas monitor, this type of sensor can provide a relatively accurate alarm point at a volume of 19.5% (to protect personnel from reduced oxygen levels). An upper alarm level may also be set to warn of an elevated combustion risk with other airborne substances. Another advantage of EC oxygen sensor is the ability to use
fresh air for calibration (at 20.9% volume). On the other hand, it only indicates oxygen levels, and many of these sensors have limited operating lives before they need to be replaced.

*EC Toxic Gas Sensors* can be used to detect and monitor CO, H2S, SO2, Cl2, and many other toxic gases. Gas detectors equipped with these sensors can accurately measure targeted gases at parts per million (ppm) levels, making them suitable for monitoring short-term exposure limits (STELs) and time weighted averages (TWAs) specified by OSHA and other agencies. Typically, gas monitors with these sensors will be set to provide an alarm at the appropriate real-time concentration, STEL, or TWA for the monitored substance. Two considerations in using this type of sensor are the fact they are subject to cross-sensitivities between different gases, and they typically require more frequent calibration than some of the other sensor types.

*CAT Sensors for Combustible Gases* can detect a wide range of substances. They can be calibrated to measure combustible gas concentrations in the range of 0-100% of the lower explosive limit (LEL). In some situations, a possible disadvantage is that they are not specific to any one gas or vapor, but sensitive to several different ones within the same general group of substances. As alluded to earlier, CAT sensors require at least 12-15% oxygen present to operate properly. They also have lower sensitivity to heavier vapors than some sensors, and are sensitive to physical shock, which can impair their operation. In addition, CAT sensors are prone to environmental poisoning from silicon, sulfur, and chlorine, resulting in reduced sensitivity and shortened life of the sensor.

*IR Combustible Gas Sensors* provide the advantages of not being subject to poisoning, do not require oxygen to operate, and like CAT sensors can measure a wide range of combustible gases and vapors over the range of 0-100% LEL. On the other hand, they detect a smaller variety of substances compared to CAT sensors, cannot measure hydrogen, and although more expensive up front, last much longer.

*PID Sensors* are typically used to detect low concentrations of volatile organic compounds in the air, such as fuels like gasoline and diesel. They are also used to measure many solvents, such as acetone, xylene, etc. Because of their ppm sensitivity,
they can be used for STEL and TWA measurement applications. Their detection capabilities are not specific to any one compound, and their relative responses to different compounds can vary widely. Generally, they require more frequent calibration than some of the other sensor types. Another disadvantage is a rather limited operational life of the inert gas-filled lamps that emit ultraviolet (UV) light used as an integral part of the detection technology. These lamp assemblies tend to be fragile and quite expensive.

*Detector Tubes* can also be useful in checking a confined space before entry. Although this paper is concerned primarily with electronic gas monitors, there are situations where detector tubes complement an electronic detector. A detector tube is a hermetically sealed glass tube (Figure 3) containing an inert carrier material mixed with one or more reagents that undergo a colorimetric reaction when specific contaminants are drawn into the tube. Prior to use, both tips are broken away from the ends of the tube using a tube opener or a device on the portable pump used to pull the air sample through the tube. The length of the color change in the tube, or the intensity of color change as compared to a standard, indicates the amount of contaminant present.

*Figure 3.* Detector tubes, shown here with a manual pump, can be valuable tools in determining the type of sensor that should be used in a gas monitor, or when an electronic sensor is not available.
Detector tubes offer the advantage of reacting to a wide range of gases and vapors that could be found in a confined workspace. There are literally hundreds of detector tubes that can identify and quantify the concentration of different substances. Indeed, detector tubes are capable of detecting more gases and vapors than any other on-the-spot field method available, making them applicable to virtually any industry.

Moreover, when there is uncertainty as to the types of gases or vapors that might be found in a confined workspace, there are Screening Tube Kits that can be used as a first step in identifying the substance to be monitored. These tubes are used to answer the question of whether the gas or vapor is basic, acidic, or organic in nature. Getting this information provides a clue on what to check for next, and ultimately helps select the appropriate sensors for electronic gas monitoring.

Electronic gas monitors with four or five different sensors (multi gas monitors) may be sufficient for many confined space applications. However, there are some situations that may require monitoring capabilities for additional substances. Employers are obligated to test confined spaces for possible dangers from known or suspected hazardous gases or vapors in the space to be entered and to ensure a safe working environment while occupying the space.

**Other Sensor Characteristics** to be considered include:

- Sensor positioning that allows gas intake from both the top and front of the monitor
- Contaminant concentration measurement range
- Calibration units (% volume, LEL, ppm, etc.)
- Environmental conditions (range of temperature, pressure, and relative humidity)
- Can the sensor be replaced by the user, or must the monitor be returned to the factory
- Warranty period
An exciting new development in portable gas detection recently became available, making multi-gas confined space detection more reliable than ever. The Draeger X-zone 5000 (Figure 4) breaks through the limits of portable and fixed gas detection systems, providing an innovative design for portable area monitoring, “fence-line” monitoring, and confined space applications. The X-zone can be used as a standalone device to monitor a space, or in a network of up to 25 devices with wireless communication between the devices to quickly announce a hazardous condition. Used in combination with the Draeger X-am 5000 series gas detection monitors it can be used for the measurement of one to six gases.

Figure 4. Draeger X-zone 5000 in a cement kiln monitoring the confined space during refurbishing for combustible gases, oxygen, and carbon monoxide.

Power Supply

Different power supply options are available in portable gas monitors, which can be categorized as either rechargeable or replaceable batteries. Typically, the latter are
single-use alkaline cells, and lithium alkaline batteries are attractive because they can operate a single gas monitor 24/7 for 5–10 months before requiring replacement.

Nickel metal hydride (NiMH) and lithium ion (Li) technologies are the most popular rechargeable types. Compared to the older nickel cadmium technology, these newer types provide longer service life for a given current drain before recharging is needed. The newer types also exhibit less discharge memory effect than the nickel cadmium type. Consult the gas monitor manufacturer before trying to replace nickel cadmium rechargeable batteries with a newer technology. The gas monitor battery charging system may not be suitable for NiMH or Li batteries.

**Electronic Circuitry**

A key feature of the electronic circuitry in a gas monitor is intrinsic safety. Intrinsically safe designs ensure that the available electrical and thermal energy in the gas monitor is always low enough that ignition of the hazardous atmosphere cannot occur. Among other things, this means that the system does not produce electrical sparks, and that even under fault conditions the temperature of a component cannot reach a level that could cause autoignition of a combustible atmosphere.

To sell a gas monitor as an intrinsically safe device, the manufacturer must have it tested and certified by one or more independent testing labs, such as those operated by UL, CSA, or MSHA (Mine Safety and Health Administration of the U.S. Dept. of Labor). Hazardous areas are separated by classes, divisions, and groups to define the level of safety required for equipment in these locations. The most common intrinsic safety approval ratings on portable gas monitors are Class I, Division 1, Groups A,B,C, and D, and Temperature Rating T4. These conditions are as follows:

**Class I locations** – areas in which flammable gases or vapors may be present in the air in sufficient quantities to be explosive.

**Division 1** – the substance referred to by class is normally present
Typical Class I Area Substances –

**Group A:** Acetylene

**Group B:** Hydrogen, ethylene oxide and other manufactured gases

**Group C:** Acetaldehyde, cyclopropane, ethylene, diethyl ether, and other light organic gases

**Group D:** Acetone, benzene, butane, gasoline, hexane, isoprene, naphtha, natural gas (methane), propane, and many other organic vapors

**Temperature Rating T4** – The surface temperature of any part of the gas monitor will not rise above 135°C.

**User Interface**

An external feature of a gas monitor’s internal electronics is the human (user) interface (see Figure 5). A user interface typically includes multiple elements like a digital display, pushbuttons, control knobs or other adjustment mechanisms, and outputs such as audible alarms and digital or analog data from electronic connectors.

Some considerations in selecting a gas monitor that is user friendly include:

- Is its operation intuitively obvious? (affected by software or firmware design, and some of the following points)

- Controls and adjustments (how many and how easy to understand)?

- Can it be easily operated with one hand by a user fitted with personal protective gloves and equipment?

- Are there adequate security features to prevent tampering?

- Is the display unambiguous and large enough to be easily read

- Besides warning the user of dangerous gas concentrations, are there functions that support documentation and reporting, such as built-in data logging?

Certainly, the visual displays and audible alarms are among the most important functions for protecting the safety of a user. Because of diverse working conditions,
a user shouldn’t have to rely on either a visual or audible warning alone in case of dangerous conditions.

A bright red flashing LED lamp with 360° visibility is an excellent visual alarm, and a loud multi-tone horn sound is a good audible alarm. Still, a personal gas monitor may not always be attached to the user where it can be easily seen, and in workspaces with loud background noises, an audible alarm may not be heard. To handle these situations, it a good idea to have a strong vibrating alarm that the user can feel. In addition, the gas monitor software should allow alarm thresholds to be individually adjusted to comply with company policy or other standards.

Once an alarm is detected, a user typically needs a large, easy-to-read digital display to verify the concentration of a dangerous gas. In case of low light conditions, the display should be adequately backlit.

A signal output interface facilitates the downloading of gas concentrations from a built-in data logger or event recorder. Various interface types are available, including those that use a USB cable to transfer data to a PC, and infrared interfaces that perform a similar function. For example, Draeger gas monitors are available with the ability to store thousands of events and gas concentrations over many hours of sampling. Other significant events can include switching the gas monitor on or off, gas and battery alarms, error codes, configuration changes, fresh air calibrations, and bump tests conducted. In addition, various software packages are available for PCs and Mac computers to store and manipulate data, and generate reports.

Gas Monitor Housing

The main features to consider when evaluating a portable gas monitor housing are:

- Size and weight (affected by electronic design and housing materials)
- Portability accessories (carrying case, shoulder strap, etc.)
- Protection from radio frequency interference (RFI)
• Protection from dust and water ingress (seals)
• Chemical resistance (housing material, protective boot, etc.)
• Resistance to physical shock damage (when dropped)

Typically, a thermoplastic polymer is used for the gas monitor housing. With the appropriate material selection, this creates a housing that is much lighter in weight than metal, and also more resistant to commonly encountered chemicals. The main benefit of a metal housing is RFI protection, but that type of protection can also be had in plastic housings that have electronic shielding. The appropriate plastic will also be resistance to damage due to the bumps and drops that often occur inside the confined workspace of an industrial environment.

All joints and openings should have gaskets or other appropriate seals to prevent the ingress of dust and water. Depending on the application, an IP65 or IP67 rating may be needed for adequate protection from dust, rain, and water spray. In especially harsh environments, a polymer housing may be rubber coated, or a rubber boot may be added, for greater protection from aggressive chemicals and temperature extremes.

For the most part, portable gas monitors are ergonomically designed, light weight, and have dimensions similar to a mobile phone, making them easy to use in daily work activities. Such designs provide a high level of comfort and convenience, which can be enhanced with nylon or leather carrying cases with shoulder straps.
Observe Proper Sampling Procedures

Used properly, a gas monitor can be a life saving tool. Before entry, always test the atmosphere of a confined space with a gas monitor. Follow the manufacturer’s recommendations and all rules and regulations published by the employer, which should be consistent with guidelines published by OSHA, NIOSH, OHSB (Canada) ACGIH (American Conference of Governmental Industrial Hygienists) and other recognized authorities. When the atmosphere in the confined space has reached the IDLH (Immediately Dangerous to Life and Health) level, do not enter without a properly fitted SCBA (Self-Contained Breathing Apparatus) and take other appropriate precautions. The procedures outline below will help in making this determination and point out precautions to be taken.

Figure 5. A polymer housing is resistant to many chemicals and can include shielding that protects the monitor electronics from radio frequency interference (RFI).
Figure 6. A sampling hose and probe assembly allows a monitor user to reach areas where toxic and combustible gases may be present, and could have stratified due to their density.

Be sure to take samples at various levels to detect gases or vapors that have stratified.

<table>
<thead>
<tr>
<th>Lighter than Air: Methane, Hydrogen, Ammonia......</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar to Air: Nitrogen, Carbon Monoxide......</td>
</tr>
<tr>
<td>Heavier than Air: Gasoline, Hydrogen Sulfide, Chlorine......</td>
</tr>
</tbody>
</table>

Normally, a sampling hose and probe are attached to the gas monitor (Figure 6) to allow the air inside a confined space to be sampled. The air sample is brought into the gas monitor by a sample pump. Some gas monitors have a built-in pump. In other cases, an external pump must be used. This could be either a manual pump or one that is battery powered with automatic volume control. In any case, certain precautions and procedures must be followed.

When sampling reactive gases, such as chlorine, nitrogen dioxide, ammonia, styrene, etc., be aware that such gases can be absorbed into the walls of the sampling tube. For those situations, gas monitor manufacturers offer reactive gas hose options. Generally, Teflon tubing is the best option when dealing with reactive gases. Rigid sampling probes should also be made from a material resistant to reactive gases. To protect sensors that could be contaminated by a spurious gas (i.e., not the target gas), an inline filter may need to be added to the sampling assembly. An appropriate filter material can trap the unwanted gas and prevent it from reaching the sensor.
With a properly designed sampling assembly and pump, it is still necessary to check them. This starts with leak testing the entire assembly. The pump and sampling assembly combination should be tested to confirm there is no leakage anywhere in the sampling train; otherwise, less than the required volume will be drawn into the monitor, resulting in a low reading. To do a leak test you can squeeze the end of the sample tube while initiating a sample reading; then check the monitor display to see if there is a low sample volume warning.

If there is a chance that the sample probe may encounter a liquid inside the space, precautions should be taken to prevent it from entering the sample tube. A simple technique to prevent liquid from being drawn into the tube is to make a loop in the end of the hose such that the probe is facing up. Electrical tape can be used on the tube to form and retain the loop.

Next, flush the sample line with air from the confined space. After initiating the sample, wait long enough for the gas to reach the monitor, which will depend on the flow rate of the pump and inside diameter of the sample tube. For a given pump and sampling assembly, reactive gases can take longer to reach the monitor than inert gases.

When taking a sample, it is important to recognize that gases and vapors inside a confined space can stratify (Figure 6). 29 CFR 1910.146 (page 4557, appendix B, section 4) mandates that employees monitor the gas in four-foot intervals in every direction of travel, vertically and horizontally. It's possible that some of these readings can only be taken after entry into the space. Therefore, it's imperative that a standby person outside the space also takes regular samples in case the worker inside is overcome by toxic gases or a lack of oxygen. This attendant must also have an SCBA immediately available for rescue purposes.

In combustible atmospheres the worker entering the space must take adequate precautions to prevent tools or other metallic objects from creating a spark that could ignite a mixture of air and gas or vapor. This can occur when the atmosphere has reached the lower explosive limit (LEL) or lower flammability limit (LFL).
After each period of gas monitor usage, be sure to flush the system. Flush the pump and tube assembly with clean air to purge them of any residual gas or aerosol that could cause corrosion in the pump, or otherwise shorten the operating life of the system. This is particularly important for acidic samples. If the pump has o-ring seals and check valves, as is the case with piston type pumps, these should be lubricated according to the manufacturer’s specifications.

Understand the Measurement Units

A gas monitor will be calibrated in units appropriate for its sensors and the gases or vapors being monitored. Figure 7 is an example of a typical multisensory gas monitor display. Different monitor measurement scales compare as follows:

- **1 ppm** = 1 part per million
- **1%Vol.** = 1 part per hundred
- **1%Vol.** = 10,000 ppm
- **LEL** = Lower Explosive Limit
- **LFL** = Lower Flammable Limit
- **UEL** = Upper Explosive Limit

![Figure 7](image)

**Figure 7.** Monitors typically display concentrations in units pertinent to the specific gases and vapors being targeted.

In Figure 7 the O₂ indication of 20.9 percent by volume (%VOL) is the normal concentration of oxygen in air at sea level. An oxygen content of 19.5 percent can
support life and is adequate for entry. In the event of an oxygen reading below 19.5 percent, the cause of the oxygen deficiency must be determined.

Things get a bit more complicated when checking air in a confined space for combustible or flammable gases and vapors with a multi-gas sensor. For these gases and vapors, the lower explosive limit reading (%LEL) usually has the greatest significance. Once the gas or vapor reaches 100%LEL, it can be easily ignited with an open flame or spark. Below 100%LEL, the air/gas mixture is called lean and is not ignitable. There is also an upper explosive limit where the mixture is too rich, and also is not ignitable. (See Figure 8.)

![Figure 8. Explosive range for gases and vapors.](image)

The LELs and UELs for some common gases and vapors are given in Table 1. Various factors affect the ignition of a gas or vapor, including its flash point temperature, oxygen concentration in the air/gas mixture, and whether or not there are any combustible dusts in the air.

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1 Various standards are used for defining the terms “combustible” and “flammable”. Typically, volatile liquids with a flash point less than 60.5°C (141°F) or 37.8°C (100°F), depending on the standard used, are defined as flammable; liquids with a flash point above the flammable standard temperature are defined as combustible. The flash point is the lowest temperature at which the vapor from a volatile liquid can form an ignitable mixture in air.
Table 1. Explosive range of various substances in %VOL.

<table>
<thead>
<tr>
<th>Compound</th>
<th>LEL</th>
<th>UEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Propane</td>
<td>2.1</td>
<td>9.5</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.7</td>
<td>5</td>
</tr>
<tr>
<td>Ethanol</td>
<td>3.3</td>
<td>19</td>
</tr>
<tr>
<td>Ethylene Glycol</td>
<td>3.2</td>
<td>15.3</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4</td>
<td>80</td>
</tr>
<tr>
<td>Ammonia</td>
<td>15</td>
<td>28</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>12.5</td>
<td>74</td>
</tr>
</tbody>
</table>

When facing an unknown gas hazard, the Draeger catalytic EX sensor (calibrated to methane) provides dependable detection of combustible atmospheres. It responds quickly to many explosive gases and has a high level of sensitivity to combustible organic vapors. The gas monitor measurement will be in units of %LEL. If methane is in fact the gas detected, then a reading should be well below 100%LEL (i.e. 5%VOL) for the confined space to be safe for entry, i.e., have a low risk of explosion.

For other gases and vapor, the gas monitor user needs to know the relative response (sensitivity) of the EX sensor to these compounds. A few relative response values are given in Table 2. The relative responses of catalytic sensors vary between different manufacturers. Even two identical sensors may have slightly different relative responses. In addition, the relative responses of any given sensor can change over time. Moreover, exposure to poisoning compounds (Si, S, Cl2, etc) will change response characteristics.
Table 2. Some relative responses of an EX LEL sensor when calibrated on methane.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>100%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>100%</td>
</tr>
<tr>
<td>Ethane</td>
<td>95%</td>
</tr>
<tr>
<td>Methanol</td>
<td>75%</td>
</tr>
<tr>
<td>Propane</td>
<td>70%</td>
</tr>
<tr>
<td>Acetone</td>
<td>63%</td>
</tr>
<tr>
<td>Pentane</td>
<td>50%</td>
</tr>
<tr>
<td>Xylene</td>
<td>40%</td>
</tr>
<tr>
<td>Octane</td>
<td>38%</td>
</tr>
<tr>
<td>Benzene</td>
<td>33%</td>
</tr>
</tbody>
</table>

Even displacement of air in a confined space by a non-toxic gas can pose a problem, and requires an understanding of the gas monitor reading from a selective gas sensor. For example, suppose carbon dioxide (CO₂) has leaked into a confined space, and the gas monitor measures its concentration at 5%VOL. In this case, what is the expected concentration of oxygen (O₂) in the confined space air. Recognize that 5% of the entire air volume has been displaced by CO₂. Since normal air at sea level is a mixture of about 78% nitrogen and 20.9% oxygen by volume, plus small amounts of other gases, all those gases will be displaced proportionately. Therefore the oxygen concentration will be \((1.00 - .05) \times 20.9\% = 19.9\%\text{VOL}\). Fortunately, if the gas monitor were also equipped with an oxygen sensor, it would read 19.9%VOL of oxygen, eliminating the need to do a separate calculation.

**Maintaining the Gas Monitor**

Checking the air in a confined space for oxygen, combustibles, and toxics before entry is essential in protecting a worker’s health and safety. Making sure the gas monitor is working properly is equally important. As part of good operating practices, this means the monitor should be bump tested every day before using it. It’s recommended by OSHA (for calibration verification), the International Safety Equipment Association
(ISEA), and most gas monitor manufacturers. Therefore, a bump test station is a crucial piece of equipment.

According to the ISEA, a bump test is defined as:

A qualitative function check where a challenge gas is passed over the sensor(s) at a concentration and exposure time sufficient to activate all alarm indicators to present at least their lower alarm setting. The purpose of this check is to confirm that gas can get to the sensor(s) and that all the alarms present are functional. This is typically dependent on the response time of the sensor(s) or a minimum level of response achieved, such as 80% of gas concentration applied.

Note that a bump test is not intended to provide a measure of calibration accuracy. Additional considerations in bump testing include checking the manufacturer’s expiration date on the bump station gas cylinder, and documenting proper instrument calibration and other functions. Generally, bump test stations are designed for specific instruments, or series of instruments, made by a manufacturer. The manufacturer may also offer a portable, battery-operated printer to produce a hard-copy readout of results stored in an instrument’s internal data logger via USB or similar connection.

In matters of worker safety, such as those associated with confined space entry, a final consideration is having a reputable gas monitor supplier that supports their products with training, reference materials, and maintenance services.