The Occupational Safety and Health Administration (OSHA) released the regulation, 29 CFR 1910.146, Permit-Required Confined Spaces, 2 years ago, but people are still having serious and even fatal accidents in confined space operations. From 1993 through the end of 1994, there have been 37 fatalities, 20 accidents, 3,203 citations, and over $5 million levied in fines. Clearly, understanding the hazards of confined spaces is critical in any industry.

A complete discussion of the regulation and compliance is beyond the scope of this article. The present article instead addresses the primary contributor to accidents in confined spaces—hazardous atmospheres. The article begins with a review of the definition of permit-required confined spaces. It then describes the 3 basic types of hazardous atmospheres in confined space, procedures for testing for hazardous atmospheres, and guidelines for selecting test instruments.
What Is a Permit-Required Confined Space?

In December 1979, the National Institute for Occupational Safety and Health (NIOSH) issued a document, "Working in Confined Spaces," which recommended procedures for protecting employees from the hazards of entering, working in, or exiting confined spaces. OSHA used the document to define a confined space in its 1993 regulation, 29 CFR 1910.146. A confined space, according to the OSHA rule, • is large enough and so configured that an employee can bodily enter and perform assigned work; • has limited or restricted means for entry or exit (for example, tanks, vessels, silos, storage bins, hoppers, vaults, and pits); and • is not designed for continuous employee occupancy.

OSHA continues by defining a permit-required confined space as a confined space with one or more of the following characteristics:

- contains or has the potential to contain a hazardous atmosphere;
- contains a material that has the potential for engulfing an entrant;
- has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross-section; or
- contains any other recognized serious safety or health hazard.

OSHA puts hazardous atmospheres high on the list of potential dangers of confined spaces. The most critical atmospheric hazards are oxygen-enriched or oxygen-deficient atmospheres, flammable atmospheres, and atmospheres containing toxic gases. Each condition must be addressed separately in preparation for confined space entry. OSHA requires testing for these conditions to take place in the following order:

- oxygen,
- combustible gases and vapors, and
- toxic gases and vapors.

Each type of atmosphere is described below.

It is important to note that these hazardous atmospheric conditions may occur in wide open spaces as well as confined spaces. Painting contractors should always be very cautious of the atmosphere when working in new areas. Crews should check with the host employer or general contractor and discuss the hazards on the work site.

Oxygen-Enriched or Deficient Atmospheres

The level of oxygen for safe operations must be between 19.5 percent and 23.5 percent by volume. Oxygen concentrations below 19.5 percent by volume of oxygen are considered deficient; concentrations above 23.5 percent by volume are considered enriched. As Table 1 shows, both oxygen-enriched and oxygen-deficient atmospheres are dangerous. Each can occur naturally, purposely, or accidentally, so oxygen conditions should always be tested.

There are 4 main causes of oxygen deficiencies: burning, oxidation or rust, decomposition of organic material, or displacement by other gases. (Even normal breathing in a confined space can displace oxygen and create an oxygen deficiency.) In addition to the need to assure that the oxygen level is safe for workers in a confined space, combustible gas detectors require air or oxygen to make a correct reading. Most instruments must have at least 10 percent oxygen by volume for proper readings; lower levels of oxygen will result in lower flammability readings.

Oxygen enrichment occurs when the volume of oxygen exceeds 23.5 percent by volume. This condition poses a new dan-
space shall not contain flammable gas, vapor, or mist in excess of 10 percent of the lower explosive limit. These conditions may occur for reasons similar to those for low oxygen: naturally through decomposition; accidentally because of a leak; or purposely because the container or confined space is used to store products like gasoline, kerosene, or other solvents.

A good understanding of the Fire Triangle, shown in Fig. 1, will help prevent fires or explosions in confined spaces. For a fire or explosion to occur, 3 components must be present at the same time: a fuel such as methane, oxygen (air) in the hazardous or dangerous proportion, and a source of ignition (spark or flame). The specific mixture of fuel and oxygen that will ignite or explode varies with each combustible gas.

The critical point at which ignition or explosion occurs is the lower explosive limit (LEL). Once an LEL is reached, the danger of a fire or explosion is continuous all the way to the upper explosive limit (UEL).

If the gas mixture is below the LEL, it is too “lean” to burn or explode. The mixture simply does not have enough fuel. If the gas mixture is in the UEL, a fire or explosion will not occur because the concentration is too rich. The high gas concentration causes the oxygen level to drop and breaks the complete triangle. A UEL condition still should not be considered safe. A high gas concentration can be diluted quickly by outside air and bring a UEL condition into a combustible range.

Pentane is a good example of a combustible gas. Its combustible properties are similar to those of gasoline. The combustible range of pentane is between 1.4 percent and 7.8 percent by volume (Fig. 2). A fluctuation of the oxygen level can change both the LEL and UEL for pentane or any other combustible gas.

**Combustible Atmospheres**

OSHA’s regulation is very clear when it comes to combustible atmospheres in confined spaces: “Atmospheres in a confined space shall not contain flammable gas, vapor, or mist in excess of 10 percent of the lower explosive limit.” These conditions may occur for reasons similar to those for low oxygen: naturally through decomposition; accidentally because of a leak; or purposely because the container or confined space is used to store products like gasoline, kerosene, or other solvents.

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Instruments for detecting combustible gases should be designed to warn users when 10 percent of the LEL is reached. This alarm level will prevent workers from entering a combustible atmosphere and provide a 90 percent safety factor against the possibility of a fire or explosion. Conditions in confined spaces can change quickly, so this safety factor should not be treated lightly.

**Toxic Atmospheres**

Toxic atmospheres contain gases, vapors, or fumes known to have poisonous effects. These toxic effects are independent of the oxygen concentration of a confined space. The most commonly encountered toxic gases are carbon monoxide (CO) and hydrogen sulfide (H₂S).

Some toxic gases may have severely harmful effects that may not be manifested until years after exposure, such as the carcinogenic effects of hydrogen chloride. Other toxic gases such as nitric oxide may kill quickly. As outlined in Table 2, some toxic atmospheres can produce both imme-

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**Table 1**

**Effects of Various Oxygen Levels**

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.5%</td>
<td>Maximum safe level according to OSHA regulation</td>
</tr>
<tr>
<td>23% and above</td>
<td>Oxygen-enriched; fire hazard may occur</td>
</tr>
<tr>
<td>21%</td>
<td>Oxygen concentration of “air” (Actual concentration of O₂ in the atmosphere is 20.954%)</td>
</tr>
<tr>
<td>19.5%</td>
<td>Minimum Safe Level, according to OSHA and NIOSH</td>
</tr>
<tr>
<td>17%</td>
<td>Impairment of judgment starts to be detected</td>
</tr>
<tr>
<td>16%</td>
<td>First signs of anoxia (oxygen deficiency to body tissue resulting in permanent damage)</td>
</tr>
<tr>
<td>16-12%</td>
<td>Breathing and pulse rate increase; muscular coordination is slightly impaired</td>
</tr>
<tr>
<td>14-10%</td>
<td>Consciousness continuous; emotional upsets, abnormal fatigue upon exertion, disturbed respiration</td>
</tr>
<tr>
<td>10-6%</td>
<td>Nausea and vomiting, inability to move freely, and loss of consciousness may occur</td>
</tr>
<tr>
<td>&lt;6%</td>
<td>Convulsive movements and gasping respiration occurs; respiration stops, and a few minutes later, heart action ceases</td>
</tr>
</tbody>
</table>

*Although OSHA considers 23.5% oxygen the maximum safe level, precautions against oxygen-enriched atmospheres are advisable at a concentration of 23% and even 22.*
Intermediate and delayed effects. These toxic conditions can also occur because of natural, accidental, or purposeful actions.

**Initial Atmospheric Testing**

OSHA’s rule clearly sets out the requirements for testing confined space atmospheres: “Before an employee enters the space, the internal atmosphere shall be tested, with a calibrated direct-reading instrument, for the following conditions in the order given:

- oxygen content,
- flammable gases and vapors, and
- potential toxic air contaminants.

There may be no hazardous atmosphere within the space whenever any employee is inside the space.”

Because different gases have different weights, hazardous or toxic gases accumulate at the top, middle, or bottom of a confined space, creating what OSHA calls a stratified atmosphere (Fig. 3). The OSHA rule says that when entrance into a confined space requires a descent through a stratified atmosphere, the atmosphere should be tested at a distance of 4 ft (1.3 m) in each direction of travel and side to side. Samples should always be taken, therefore, at least, at the top, middle, and bottom of the space with a properly calibrated instrument.

### Table 2

**Toxic Gases and Their Effects**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Symbol</th>
<th>PEL/TWA</th>
<th>STEL</th>
<th>IDLH</th>
<th>Physical Properties</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>35</td>
<td>400</td>
<td>1500</td>
<td>Colorless, tasteless, odorless. Explosive at LEL 12.5%. Volume. Formed by incomplete combustion.</td>
<td>Headache, nausea, unconsciousness. Carbon monoxide reacts with the hemoglobin in the blood and prevents the blood from carrying oxygen.</td>
</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>H₂S</td>
<td>10</td>
<td>15</td>
<td>300</td>
<td>Colorless, rotten egg smell. It appears naturally as a by-product of decomposition. Explosive at LEL 4%.</td>
<td>Eye irritation, coughing, respiratory tract irritation, loss of consciousness, and death.</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl₂</td>
<td>0.5</td>
<td>1</td>
<td>30</td>
<td>Greenish-yellow gas, pungent odor. Non-combustible, but will form with other substances and become explosive.</td>
<td>Irritation of the mucous membranes, eyes, and respiratory tract. Pain, tightness in chest, death resulting from long exposure.</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>NO₂</td>
<td>1</td>
<td>5</td>
<td>50</td>
<td>Yellowish-brown gas with pungent odor. Combines with water to form nitric acid. Most toxic substance of diesel emissions.</td>
<td>Irritation of the nose and throat, acute bronchitis, pulmonary edema (water in the lungs), and death.</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>SO₂</td>
<td>2</td>
<td>5</td>
<td>100</td>
<td>Colorless gas, irritating pungent odor. Released from burning fossil fuels.</td>
<td>Irritation of the nose and throat. High concentrations can cause edema of the lungs and death.</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH₃</td>
<td>25</td>
<td>35</td>
<td>500</td>
<td>Colorless gas. Difficult to burn at LEL 15%. Pungent, suffocating odor.</td>
<td>Irritation of the eyes, swelling of the eyelids, vomiting, irritation of the throat, and death.</td>
</tr>
<tr>
<td>Nitric Oxide</td>
<td>NO</td>
<td>25</td>
<td>NA</td>
<td>100</td>
<td>Colorless gas. Reacts with water to form nitric acid. Will accelerate burning. Caused by super-heating of air or welding.</td>
<td>Irritation of the mucous membranes, coughing, burning of the throat. Fatal in high doses for short exposures.</td>
</tr>
<tr>
<td>Hydrogen Chloride</td>
<td>HCl</td>
<td>5</td>
<td>NA</td>
<td>1000 30 min.</td>
<td>Colorless, corrosive gas, commonly known as hydrochloric acid. NIOSH recognizes HCl as a carcinogen.</td>
<td>Irritation of the mucous membranes, eyes, throat, and respiratory tract. Dangerous even for brief exposures around 100-1000 ppm.</td>
</tr>
</tbody>
</table>

1. **PEL/TWA**—Permissible exposure limit: level of gas in ppm workers can be exposed to 8 hours per day/40 hours per week for the rest of their lives, with no long-term health effects, established by OSHA. Time weighted average: average amount of gas workers can be exposed to over 8 hours representing a normal work day, established by American Conference of Governmental Industrial Hygienists (ACGIH).

2. **STEL**—Short term exposure limit: the average amount of gas a worker can be exposed to in a 15 minute period with no long-term health effects. This may occur 4 times a shift with one-hour breaks in between 15 minute exposures, established by the ACGIH.

3. **IDLH**—Immediately dangerous to life and health: the maximum concentration of gas in ppm, from which a worker could escape within 30 minutes without experiencing any escape-impairing or irreversible health effects, as established by NIOSH.
If oxygen deficiency or enrichment, combustible gases or vapors, or toxic gases are detected, the confined space must be ventilated and re-tested before entry is permitted. Re-testing with properly calibrated instruments is essential. Safety personnel should not rely on their senses to test confined spaces. Many toxic and combustible gases cannot be seen or smelled, nor can safe oxygen levels be determined without a reliable measuring instrument.4

Atmospheric Monitoring

Initial testing of the confined space is not enough. OSHA also states the necessity of periodically testing to ensure that the atmosphere of the space stays safe. In this author’s opinion, once pre-testing is complete and the proper equipment is available, the space should be monitored continually, not periodically, for possible changes.

If, however, periodic testing is conducted, safety personnel and workers should be aware of the changes that can occur while working in the confined space and the dangers of the possible changes.

Instrumentation

A variety of portable instruments has been designed for detecting the unseen dangers of unsafe oxygen levels, combustible atmospheres, and toxic atmospheres. Instruments used in conjunction with sampling pumps, a length of flexible tubing, or a probe can draw remote samples from all types of confined spaces prior to entry. These remote sample readings are very important. They must be recorded on the confined space entry permit that the OSHA standard requires.

Several factors should be considered when choosing gas detection instruments. Instruments must be able to detect oxygen and combustible gases and vapors at the levels set by OSHA. Instruments selected should also be able to provide pre-testing and continuous monitoring if required. The oxygen range of detection is usually between 0 and 30 percent by volume, and the combustibles are measured in terms of the percentage of the LEL.

The instrument should be capable of monitoring toxic gases found during the confined space assessment. The toxic gases are detected by most instruments in parts per million (ppm). These detection instruments can also be divided into those that read in increments of 1 ppm and those that read in increments of 0.1 ppm. The precision required in the measurement depends on the toxicity of the gas encountered.

The feature of intrinsic safety should be of the highest concern when selecting instruments. The National Electrical Code defines intrinsically safe equipment as fol-

![Image of stratified atmosphere]

**NOTE:** CI₂, SO₂ and NO₂ are also heavier than air. Methane (lighter than air)

Carbon monoxide (may mix)

Hydrogen sulfide (heavier than air)

**Fig. 3 -** Stratified atmosphere. As noted, chlorine, sulfur dioxide, and nitrogen dioxide are also heavier than air.
bustible atmosphere mixture in its most easily ignitable concentration.” That is, an instrument may be dropped or damaged during use in a hazardous atmosphere where combustible gases are present. An instrument that has been approved as “intrinsically safe” will not cause a fire or explosion when dropped or damaged. The safest approach is to select an instrument that carries an approval for intrinsic safety in Class I, Division I, Groups A, B, C, and D.

“Class I” covers all atmospheres containing flammable gases or vapors. “Division I” means these gases may exist under normal conditions such as repairs, leaks, or breakdown of equipment. The letter designation indicates what combustible gases are present.

• Group A–acetylene;
• Group B–hydrogen, butadiene, and ethylene oxide;
• Group C–ethylene or its equivalent;
• Group D–acetone, ammonia, butane, methane, or similar gases.

The approval groups are arranged in descending order of combustibility. Group A status is the most inclusive; Class B, the next most inclusive; Group C, the third most inclusive; and Group D, the least inclusive. For example, if an instrument has Class A approval, it can be used in any combustible atmosphere. Group B approval means the instrument can be used in any atmosphere except one where acetylene is present. Group A approval is the safest. Instruments with Class I, Division I, Group A approval are the safest and should always be selected. Users may not always know what gases are present; instruments with Group A approval are safe in the worst case scenario, where acetylene is present.

Other factors that should be considered are as follows.

• Radio Frequency Interference (RFI) protection will prevent false indications when radio communication is made.
• Durable construction will ensure that the instruments can withstand the daily wear and tear of maintenance and construction operations.
• Flexibility will indicate how easy it is to reconfigure or change the sensor as well as the number of gases the instrument can detect. Some instruments can now detect and measure 1, 2, 3, or 4 gases continuously and simultaneously.
• Ease of use will encourage employees to use the equipment. If employees are confused about how to operate and read the instruments, they may not use them. Their confusion is a disaster waiting to happen.

Calibration

All gas detection instruments require calibration. This is the only way to ensure proper readings of the detected gases. The operator should do a functions test on the instrument every day. Simply put, the functions test is used to determine if the instrument will detect the gas it was designed for. This test is usually accomplished by applying a known concentration of gas to the instrument and waiting for the alarm to sound. When the alarm sounds, the instrument has detected the gas. If the instrument fails, it should be given to a trained person to determine the reason for the failure.

On a regular basis, usually monthly, full calibration and alarm point verification must be performed. This process is again accomplished by applying a known concentration of gas to a particular sensor and adjusting the reading of the instrument to match that of the applied gas. This one process alone will ensure that the instruments are functioning properly.

Older style instruments require manual adjustment of potentialometers or “pots” to set the instruments at the proper levels. Instruments manufactured now make calibration very simple. Controlled by micro-

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processors, today’s instruments calibrate and diagnose themselves. The most important thing to do is follow the manufacturer’s recommended procedures of calibration and maintenance for any style instrument.

Summary

The information in the present article is an introduction to gas detection and hazardous atmospheres in confined spaces. Additional assistance is available from local or regional OSHA offices. Training, awareness, and preparation are the keys to confined space safety. Once the hazards are understood, of course, compliance with the standard is expensive but necessary for worker protection. *JPCL*

References


Additional Sources


