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Recent changes in confined space entry requirements

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History of OSHA Confined Space Entry Requirements

- In 1982 OSHA enacted 29 CFR 1910.146 “Permit-Required Confined Spaces”
- Provisions applied only to general industry work
- Original intent was to extend 1910.146 to include construction
- However, it was quickly recognized that 1910.146 did not fully address issues unique to the construction industry, such as higher employee turnover rates, worksites that change frequently, and the multi-employer business model that is common on construction worksites

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OSHA 29 CFR 1910.146

- Permit Required Confined Spaces
  - Requirements for practices and procedures to protect employees in general industry from the hazards of entry into permit-required confined spaces
  - 1910.146 is a “horizontal standard”
    - If an employee is working in an industry where a vertical or industry-specific standard applies, then the entry is subject to the vertical standard
  - If a vertical standard is applicable, the general industry standard is not applicable
- 1910.146 does not apply to industries with their own vertical standards:
  - Agriculture
  - Construction
  - Shipyard employment

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Even though the activity might be taking place in a confined space, 1910.146 does not apply to construction. Until recently, this left a gap in construction-related confined space procedures. As of 2015, Construction finally has its own standard: 29 CFR 1926 Subpart AA “Confined Spaces in Construction.”

The Construction CS rule is similar in content and organization to the general industry confined spaces standard, but incorporates additional provisions that address construction-specific hazards. Includes a permit program designed to protect employees from atmospheric and physical hazards associated with work in construction confined spaces.

Characteristics of Confined Spaces
- Large enough for worker to enter
- Are not designed for continuous worker occupancy
- Limited openings for entry and exit
Meeting basic CS criteria

- Limited means of entry and exit
- Not designed for continuous occupancy

Permit Required Confined Spaces

- One or more of the following:
  - Hazardous atmosphere (known or potential)
  - Material with the potential for engulfment
  - Inwardly sloping walls or dangerously sloping floors
  - Contains any other serious safety hazard

Under 1910.146 after construction, these are normally non-permit confined spaces

- Large enough for worker to enter
- Are not designed for continuous worker occupancy
- Limited openings for entry and exit
- Means: there are no other serious safety hazards
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Under 1926 Subpart AA, during construction, these can easily be permit confined spaces:

- If depends on what is being done at that moment in the construction process
- For example:
  - When a cement is being applied in the crawl space, the oxygen content in the crawl space can be drastically reduced.
  - O₂-catalyzed sealants and freshly poured concrete absorb oxygen while curing, making the atmosphere in the pit dangerous because of O₂ deficiency.

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Types of confined spaces covered by 1926 Subpart AA

- 29 CFR 1910 includes a lengthy list of confined spaces that are covered by the rule.
- The list includes many types of spaces that are not usually deemed to be permit confined spaces under the general industry rule (29 CFR 1910).

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Typical construction confined spaces

- Boilers
- Manholes (sewer, storm drain, electrical, communication, street, utility, etc.)
- Precast concrete manhole units
- Tanks (fuel, chemical, water, other liquid, solid or gas)
- Incinerators
- Concrete piers columns
- Storm and sewer drain
- Transformer vaults
- Heating, ventilation, and air conditioning (HVAC) ducts
- Ducts
- Silos
- Screens
- Elevators
- Bag houses
- Mixers/reactors
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Some confined spaces are open topped

- Bins
- Pits (silo, elevator, pump, valve, etc.)
- Degreasers
- Open-topped water tanks
- Digesters and lift stations

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Confined Spaces in Construction: Crawl Spaces and Attics

- Even if the space is not a PRCS, the employer must ensure that workers are not exposed to hazards during construction.
- Confined space hazards in crawl spaces and attics have led to worker deaths:
  - Two workers died while applying primer to floor joists in a crawl space. They were burned when an incandescent work lamp ignited vapors from the primer.
  - A flash fire killed a worker who was spraying foam insulation in an enclosed attic. The fire was caused by poor ventilation.

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General Requirements

- Employers Must:
  - Identify Confined Space hazard areas
  - Inform employees by posting signs where feasible
  - Prevent entry by unauthorized persons
Employers Must:
- Establish procedures and practices to allow safe entry (Permit system)
- Train employees
- Provide required equipment
- Control hazards where possible through engineering or work practices

Employers Must:
- Ensure procedures and equipment necessary for rescue
- Protect entrants from external hazards
- Enforce established procedures

Employers Must:
- Provide required equipment:
  - Testing and monitoring
  - Ventilation
  - Communications
  - Lighting
  - Barriers
  - Other personal protective equipment
  - Any required rescue and emergency equipment
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**General Requirements**

- Options for entry into Permit Required Confined Space (PRCS)
- Reclassification
- Alternate entry procedures
- Permit program

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**Reclassification as non PRCS**

- A PRCS can be reclassified as a non-permit space IF AND ONLY IF the space contains no actual or potential atmospheric hazards, and if all other hazards can be eliminated without entry into the space
- Reclassification requires that no ongoing measures are required to keep the space safe
- The reclassification is valid only as long as the hazard is eliminated
- When hazards are reintroduced into a space, the space becomes a permit space again

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**Reclassification as non PRCS**

- The employer must certify that all hazards from the space have been eliminated and provide that certification to all employees entering that space
- The reclassification is valid only as long as the hazard remains eliminated
Elimination of hazardous conditions

- In order to reclassify the space, all serious hazards must be eliminated prior to entry.
- "Serious" recognized hazard is broadly defined.

If a hazard cannot be eliminated, but can be controlled by continuous forced air ventilation, then alternate entry procedures can be used.

- State EPA criteria for the conditions under which alternate entry procedures can be used.
- Benefits:
  - Substantially lower equipment requirements
  - No attendants required
  - Solo entries permitted

Before employee exits the space, internal atmosphere must be tested with a calibrated, direct-reading instrument for oxygen, flammable gases and vapors, and for potential toxic air contaminants.

- Once testing is completed, the atmosphere within the space must be periodically tested as necessary to ensure that the continuous forced air ventilation is preventing the accumulation of a hazardous atmosphere.
- There may be no hazardous atmosphere within the space, whereas only equipment is inside the space.

1926.1203(e)(2): Alternate Entry Procedures

- The employer must:
  - Demonstrate that the entry space is not an arrest or potentially hazardous atmosphere.
  - Demonstrate that continuous forced air ventilation is sufficient to maintain the space safe.
  - Maintain detailed ventilation records, and
  - Make this information available to employees.
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Alternate Entry Procedures

• Continuous forced air ventilation must be used for the entire duration of the entry.
• Entry under the alternate entry procedures would not be acceptable if hazards in the space quickly increased if the ventilation were to fail.
• Sufficient time must be available for an entrant to safely exit the space if the ventilation fails.

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Alternate Entry Procedures in Practice

• Some industries, such as telecommunications, have had millions of safe entries into their vaults using ventilation, training, and procedures that successfully meet OSHA requirements.
• However, many other employers have also used for using alternate entry procedures inappropriately.

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Alternate Entry Procedures

• The employer must certify that the space is safe for entry.

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Permit Program

- If hazards cannot be eliminated or controlled, only remaining option is implementation of comprehensive permit space program.
- Permit specifies means, procedures, and practices for safe entry.
- Establishes all protective measures have been taken.

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Emergency Procedures

- Must reflect the specific dangers of the confined space.
- Attendant should not enter confined space until help arrives.
- Two out of three workers killed in confined space accidents are rescuers.

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Rescue

- Self rescue: Entry procedures should aim at getting workers out under their own power before conditions become life-threatening.
- Non-entry rescue: Established approach is to use procedures that allow rescue without having to enter the space.
- Rescue entry: Least desirable, highest risk, most equipment and personnel intensive approach.
1926 Subpart AA: Increased emphasis on training

- Dangers associated with construction confined spaces can change from day to day because of the work being performed.
- Even more important that workers are trained to recognize potential dangers.
- Training must result in:
  - Understanding the hazards and the methods used to isolate, control, and protect employees.
  - Understanding the dangers of attempting rescue operations without proper equipment and authorization.

1926 Subpart AA: Increased emphasis on communication

- Workers and contractors at construction sites can change from day to day.
- Whenever responsibility for a PRCS is transferred, the party responsible determines that all operations and personnel involved in the PRCS are properly trained and that they properly follow the requirements of the employer’s confined space entry plan.
Monitor and ventilate continuously

- Before entry it is mandatory to determine that the CS atmosphere is safe.
- Many accidents result from changes in the CS atmosphere which occur after the entry is initiated.
- Monitoring determines the air is safe, ventilation keeps it that way.
- The only way to pick up changes before they become life threatening is to monitor continuously.

Common atmospheric hazards

- Oxygen deficiency
- Oxygen enrichment
- Presence of toxic gases
- Presence of combustible gases

Oxygen deficiency

- Any area that has an oxygen level of less than 19.5% by volume is considered to be oxygen deficient.
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**Effects of oxygen at various concentrations**

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 23%</td>
<td>Oxygen enrichment</td>
</tr>
<tr>
<td>20.90%</td>
<td>Normal air concentration</td>
</tr>
<tr>
<td>19.50%</td>
<td>Minimum &quot;safe level&quot;</td>
</tr>
<tr>
<td>16 – 12%</td>
<td>Sensation of aches, increase in muscular activity is slightly impaired</td>
</tr>
<tr>
<td>14 – 10%</td>
<td>Consciousness quickly decreases, emotional upset, 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 occurs, respiratory arrest</td>
</tr>
</tbody>
</table>

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**Causes of oxygen deficiency**

- Combustion
- Welding and cutting torches
- Internal combustion engines
- Decomposing of organic matter
- Rotting foods, plant life and fermentation
- Oxidation of metals
- Rusting
- Inerting
- Displacement
- Absorption

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**Oxygen displacement in an open topped confined space**

Argon
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**Oxygen enrichment**

- Proportionally increases rate of many chemical reactions
- Can cause ordinary combustible materials to become flammable or explosive
- Any area with an 
  $$O_2 \text{ level of more than 23.0\% is dangerously enriched}$$

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**Fuel cell oxygen sensors**

- Sensor generates electrical current proportional to the $O_2$ concentration
- Sensor used up over time (one to three years)
- Oxygen reduced to hydroxyl ions at cathode:
  $$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$
- Hydroxyl ions oxidize lead (anode):  
  $$2Pb + 4OH^- \rightarrow 2PbO + 2H_2O + 4e^-$$
- Overall cell reaction:
  $$2Pb + O_2 \rightarrow 2PbO$$

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**Major components of a “fuel cell” type oxygen sensor**
Oxygen pump (lead free) sensor detection principle

- Oxygen passively diffuses into polymer (catalyst) substrate.
- Power from instrument battery used to "pump" the oxygen back out.
- Reaction: Oxidation - Reduction of target gas by catalyst
  Sensing: \( \text{O}_2 + 4\text{H}^+ + 4e^- \rightarrow 2\text{H}_2\text{O} \)
  Counter: \( 2\text{H}_2 + 2\text{O}_2 + 4\text{H}^+ + 4e^- \)
- Oxygen generated on counter electrode.
- Amount electricity required to restore reaction product and reduce sensor to ground state (by generating \( \text{O}_2 \) at counter electrode) proportional to concentration of oxygen present.

Common causes of toxic gases during CS work

- Contents that were stored in the space.
- Compounds absorbed into walls of the space.
- Contents being disturbed upon entry.
- Items being done in the space.
- Decomposing materials in the space.
- Adjacent areas.

Substance-specific electrochemical sensors

- Gas diffusing into sensor reacts at surface of sensing electrode.
- Sensing electrode made to catalyze a specific reaction.
- Use of selective external cross reacting.
Typical electrochemical detection mechanism

\[ \text{H}_2\text{S Sensor:} \]

Hydrogen sulfide is oxidized at the sensing electrode:

\[ \text{H}_2\text{S} + 4\text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 + 8\text{H}^+ + 8e^- \]

The counter electrode acts to balance out the reaction at the sensing electrode by reducing oxygen present in the air to water:

\[ \text{O}_2 + 4\text{H}^+ + 4e^- \rightarrow 2\text{H}_2\text{O} \]

And the overall reaction is:

\[ \text{H}_2\text{S} + \text{O}_2 \rightarrow \text{H}_2\text{SO}_4 \]

City Technology 4HS Signal Output: 0.7 mA / ppm H\textsubscript{2}S

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Response of H2S Sensor When Exposed to 25 PPM Gas

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Meaning of parts-per-million (ppm)

- 1% by volume = 1,000,000 ppm
- 1 ppm the same as:
  - One centimeter in 10 kilometers
  - One minute in two years
  - One cent in $10,000
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**Toxic exposure limits**
- Toxic exposure limits are defined by means of:
  - 8-hour TWA
  - 15-minute STEL
  - Ceiling
- The exposure limit for a particular contaminant may include more than one part.

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**Characteristics of hydrogen sulfide**
- Colorless
- Smells like "rotten eggs" (at low concentrations)
- Heavier than air
- Corrosive
- Flammable (LEL is 4.3%)
- Soluble in water
- High concentrations kill sense of smell
- Extremely toxic!

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**Toxic effects of H2S**

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13 ppm</td>
<td>Animal detectable odor</td>
</tr>
<tr>
<td>4 ppm</td>
<td>Easily detectable, moderate odor</td>
</tr>
<tr>
<td>10 ppm</td>
<td>Beginning eye irritation</td>
</tr>
<tr>
<td>17 ppm</td>
<td>Strong unpleasant odor but not immediately</td>
</tr>
<tr>
<td>100 ppm</td>
<td>Coughing, eye irritation, loss of smell after 30 min</td>
</tr>
<tr>
<td>200 – 1000 ppm</td>
<td>Blurred vision, shortness of breath, respiratory tract irritation</td>
</tr>
<tr>
<td>500 – 700 ppm</td>
<td>Loss of consciousness and possible death in 30 to 60 min</td>
</tr>
<tr>
<td>700 – 800 ppm</td>
<td>Rapid unconsciousness, stopping or pausing of respiration and death</td>
</tr>
<tr>
<td>1,000 – 1,500 ppm</td>
<td>Immediate unconsciousness, death in a few minutes. Death may occur even if person is rescued.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Toxic exposure limits for H2S</th>
<th>TWA (PMV)</th>
<th>STEL (PMV)</th>
<th>Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA NIOSH</td>
<td>10</td>
<td>15</td>
<td>NA</td>
</tr>
<tr>
<td>USA OSHA, Confined Space (1910.146)</td>
<td>10</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>ACGIH TLV (1987)</td>
<td>10</td>
<td>15</td>
<td>NA</td>
</tr>
<tr>
<td>ACGIH TLV (2010)</td>
<td>10</td>
<td>15</td>
<td>NA</td>
</tr>
</tbody>
</table>

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- Colorless
- Odorless
- Slightly lighter than air
- By-product of combustion
- Flammable (LEL is 12.5%)

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- Bonds to hemoglobin in red blood cells
- Contaminated cells can’t transport O₂
- Chronic exposure at even low levels harmful
Toxic effects CO

- Concentration of only 1,600 ppm can kill within hours.
- Even lower level exposures can result in death if there are underlying medical conditions, or when there are additional factors (such as heat stress).

Toxic effects of CO

- 25 ppm: TLV exposure limit for 8 hours (TWA)
- 200 ppm: Possible mild frontal headaches in 2-3 hours
- 400 ppm: Frontal headaches and nausea after 1-2 hours
- 800 ppm: Headache, dizziness and nausea in 45 min. Collapse and possibly death in 2 hours
- 1,600 ppm: Headache and dizziness in 20 min. Unconsciousness and danger of death in 2 hours
- 3,200 ppm: Headache and dizziness in 5-10 min. Unconsciousness and danger of death in 10 min
- 6,400 ppm: Headache and dizziness in 2-3 min. Unconsciousness and danger of death in 10-15 min
- 12,800 ppm: Unconsciousness immediately, danger of death in 1-2 min

Exposure limits for carbon monoxide

- OSHA PEL:
  - 10 ppm 8 hr. TWA
- NIOSH REL:
  - 15 ppm 8 hr. TWA
- 200 ppm: Ceiling
- TLV:
  - 15 ppm 8 hr. TWA
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**Explosive or Flammable Atmospheres**

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**Flammability Range**

- The range between the LEL and the UEL of a combustible gas or vapor
- Concentrations within the flammable range will burn or explode if a source of ignition is present

<table>
<thead>
<tr>
<th>Gas Concentration</th>
<th>Flammable Range</th>
<th>LEL</th>
<th>UEL</th>
</tr>
</thead>
</table>

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**Explosive Limits**

- Methane (CH$_4$)
- Lower Explosive Limit: 5.0 – 15.0%
- Upper Explosive Limit: 15.0 – 20.5%

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Explosive Limits

- Propane (C\textsubscript{3}H\textsubscript{8})

Explosive L\textsubscript{L}

Lower Explosive Limit

2.2 - 9.0%

Explosive L\textsubscript{U}

Upper Explosive Limit

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Catalytic "Hot Bead" Combustible Sensor

- Detects combustible gas by catalytic oxidation
- When exposed to gas, oxidation reaction causes the active (detector) bead to heat
- Requires oxygen to detect gas

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Catalytic Sensor Structure
Typical carbon number distribution in No. 2 Diesel Fuel (liquid)

- More than 60% of molecules in diesel vapor are small enough to be measured by standard LEL sensor.

Vapor density
- Measure of a vapor's weight compared to air.
- Gases lighter than air tend to rise; gases heavier than air tend to sink.

- Carbon monoxide
- Hydrogen
- Ammonia
- Methane

- Propane
- Hydrogen sulfide
- Carbon disulfide
- Gasoline

Stratification
- Atmospheric hazards in confined spaces form layers.
- Check all levels!
Effects of O₂ concentration on combustible gas readings

- Look at O₂ readings first!
- LEL readings may be affected if levels of O₂ are higher or lower than fresh air.
- Some LEL sensors require a minimum level of 10% oxygen to read LEL.
- If the O₂ concentration is too low, the LEL reading should be replaced with question marks.

Readings in fresh air

Readings when O₂ too low for LEL sensor

Readings in O₂ deficient air

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Combustible sensor poisons

- Combustible sensor poisons:
  - Silcones (by far the most virulent poison)
  - Hydrogen sulfide

Note: The LEL sensor includes an internal filter that is more than sufficient to remove the H₂S in calibration gas. It takes very high levels of H₂S to overcome the filter and harm the LEL sensor.

- Other sulfur containing compounds
- Phosphates and phosphorus containing substances
- Lead containing compounds (especially tetraethyl lead)
- Combustible sensor inhibitors:
  - Halogenated hydrocarbons (Freons, trichloroethylene, methylene chloride, etc.)

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Combustible sensor limitations

<table>
<thead>
<tr>
<th>Compound</th>
<th>LEL (Vol %)</th>
<th>Flashpoint (ºF)</th>
<th>OSHA PEL</th>
<th>NIOSH REL</th>
<th>TLV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>2.5%</td>
<td>-</td>
<td>1,000 PPM</td>
<td>1000 PPM</td>
<td>1250 PPM</td>
</tr>
<tr>
<td>Diesel (No. 2)</td>
<td>0.6%</td>
<td>125ºF</td>
<td>None</td>
<td>None</td>
<td>15 PPM</td>
</tr>
<tr>
<td>Ethanol</td>
<td>3.3%</td>
<td>55ºF</td>
<td>1,000 PPM</td>
<td>1000 PPM</td>
<td>1000 PPM</td>
</tr>
<tr>
<td>Gasoline</td>
<td>1.3%</td>
<td>-</td>
<td>None</td>
<td>None</td>
<td>300 PPM; 500 STEL</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>1.1%</td>
<td>-</td>
<td>500 PPM</td>
<td>50 PPM</td>
<td>50 PPM</td>
</tr>
<tr>
<td>Isopropyl alcohol</td>
<td>2.0%</td>
<td>53ºF</td>
<td>400 PPM</td>
<td>400 PPM</td>
<td>400 PPM; 500 STEL</td>
</tr>
<tr>
<td>Kerosene/Jet Fuel</td>
<td>0.7%</td>
<td>100–162ºF</td>
<td>None</td>
<td>100 mg/M3</td>
<td>200 mg/M3 (approx. 14.4 PPM)</td>
</tr>
<tr>
<td>MEK</td>
<td>1.4%</td>
<td>16ºF</td>
<td>200 PPM</td>
<td>200 PPM</td>
<td>200 PPM; 300 STEL</td>
</tr>
<tr>
<td>Turpentine</td>
<td>0.8%</td>
<td>95ºF</td>
<td>100 PPM</td>
<td>100 PPM</td>
<td>100 PPM</td>
</tr>
<tr>
<td>Xylenes (o, m &amp; p)</td>
<td>0.9–1.1%</td>
<td>81–90ºF</td>
<td>100 PPM</td>
<td>100 PPM</td>
<td>150 STEL</td>
</tr>
</tbody>
</table>

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Why use photoionization detector equipped instruments?

- For most VOCs, long before you reach a concentration sufficient to register on a combustible gas indicator, you will have easily exceeded the toxic exposure limits for the contaminant.
- PID-equipped instruments are generally the best choice for measurement of VOCs at exposure limit concentrations.

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Photoionization Detectors

- VOCs are organic chemicals in which a characteristic tendency to evaporate easily at room temperature.
- Familiar VOCs include:
  - Solvents
  - Paint thinner
  - Nail polish remover
  - Gasoline
  - Diesel
  - Heating oil
  - Kerosene
  - Jet fuel
  - Benzene
  - Butadiene
  - Hexane
  - Toluene
  - Xylene
  - Many others

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How does a PID work?

...
Catalytic (CC) LEL vs. PID Sensors

- Catalytic LEL and photoionization detectors are complementary detection techniques.
- Catalytic LEL sensors excel for measurement of methane, propane, and other common combustible gases. NOT detectable by PID.
- PIDs detect large VOCs and hydrocarbon molecules that are undetectable by catalytic sensors.
- Best approach to VOC measurement is to use multi-sensor instruments capable of measuring all atmospheric hazards that may be potentially present.

Decision making with a PID

- Two sensitivities must be understood to make a decision with a PID:
  - Human Sensitivity: as defined by AGMA, NIOSH, OSHA, or corporate exposure limits.
  - PID Sensitivity: as defined through testing by the manufacturer of your PID.
- ONLY USE A CORRECTION FACTOR FROM THE MANUFACTURER OF YOUR PID!

Correction Factors (10.6 eV Lamp)

<table>
<thead>
<tr>
<th>Gas/vapor</th>
<th>RAE</th>
<th>W</th>
<th>Lon</th>
<th>GfG</th>
<th>LEL (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>5.50</td>
<td>4.60</td>
<td>4.90</td>
<td>5.40</td>
<td>10.21</td>
</tr>
<tr>
<td>Acetone</td>
<td>1.10</td>
<td>0.90</td>
<td>0.70</td>
<td>1.20</td>
<td>9.69</td>
</tr>
<tr>
<td>Ammonia</td>
<td>9.70</td>
<td>10.60</td>
<td>8.50</td>
<td>9.40</td>
<td>10.20</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.50</td>
<td>0.55</td>
<td>0.50</td>
<td>0.53</td>
<td>9.25</td>
</tr>
<tr>
<td>Butadiene</td>
<td>1.00</td>
<td>0.90</td>
<td>0.85</td>
<td>0.69</td>
<td>9.07</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>0.80</td>
<td>0.93</td>
<td>0.75</td>
<td>0.90</td>
<td>n/a</td>
</tr>
<tr>
<td>Ethanol</td>
<td>12.00</td>
<td>13.20</td>
<td>8.70</td>
<td>10.00</td>
<td>10.48</td>
</tr>
<tr>
<td>Ethylene</td>
<td>10.00</td>
<td>11.00</td>
<td>8.00</td>
<td>10.10</td>
<td>10.52</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0.90</td>
<td>0.73</td>
<td>1.10</td>
<td>1.10</td>
<td>n/a</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>4.30</td>
<td>4.00</td>
<td>3.30</td>
<td>4.50</td>
<td>10.18</td>
</tr>
<tr>
<td>Jet fuel (Jet-8)</td>
<td>0.60</td>
<td>0.51</td>
<td>0.70</td>
<td>0.48</td>
<td>n/a</td>
</tr>
<tr>
<td>Kerosene</td>
<td>n/a</td>
<td>1.11</td>
<td>0.80</td>
<td>n/a</td>
<td>9.53</td>
</tr>
<tr>
<td>aEK</td>
<td>0.90</td>
<td>0.78</td>
<td>0.77</td>
<td>0.90</td>
<td>9.53</td>
</tr>
<tr>
<td>Naptha (iso-octane)</td>
<td>1.20</td>
<td>1.20</td>
<td>1.10</td>
<td>1.30</td>
<td>9.82</td>
</tr>
<tr>
<td>Styrene</td>
<td>0.40</td>
<td>0.45</td>
<td>0.45</td>
<td>0.40</td>
<td>8.47</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.50</td>
<td>0.53</td>
<td>0.51</td>
<td>0.53</td>
<td>8.82</td>
</tr>
<tr>
<td>Turpentine</td>
<td>0.40</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>n/a</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>2.00</td>
<td>2.19</td>
<td>2.20</td>
<td>1.80</td>
<td>10.00</td>
</tr>
<tr>
<td>Xylene (mixed isomers)</td>
<td>0.40</td>
<td>0.50</td>
<td>0.43</td>
<td>0.50</td>
<td>8.50</td>
</tr>
</tbody>
</table>
Non-dispersive infrared (NDIR) sensors

- Many gases absorb infrared light at a unique wavelength
- In NDIR sensors, the amount of IR light absorbed is proportional to the amount of target gas present
- IR absorption has advantages of high sensitivity, low cross-sensitivity, long life, and resistance to contamination
- IR absorption employed in both very high performance laboratory analyzers and in very low performance systems (e.g., inexpensive, non-intrinsically safe handheld CO detectors)

Energy Absorbed by "Bond Stretching" and "Bending" Vibration

- Must have a COVALENT CHEMICAL BOND

Wavelengths typically used for IR LEL measurement
Combustible gas NDIR sensor advantages and limitations

- Limitations:
  - Molecule must include chemical bonds that absorb at wavelengths used for measurement
  - Not all combustible gases can be detected
  - "Diatomic" molecules like hydrogen (H₂) cannot be detected at all
  - Gases with double and triple bonds (like acetylene) often absorb in more measurement wavelengths
  - NDIR sensors with short optical path lengths may have limited ability to measure gases with lower relative responses

- Advantages:
  - Sensor cannot be poisoned
  - Does not require oxygen to detect gas
  - Can be used for high-range combustible gas measurement
  - Responds to large hydrocarbon molecules that cannot be measured by means of standard LEL sensor
Slide 82


Slide 83

Comprehensive product information

- Data sheets
- Manuals
- Specifications
- Software
- Training videos
- PowerPoint training presentations
- Images

Slide 84

Technical support and downloads

- www.goodforgas.com
- Manuals
- Software and software updates
- Data sheets
- Training materials and presentations
  - Application Notes and Technical Notes:
Questions?