Recent changes in confined space entry requirements

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History of OSHA Confined Space Entry Requirements

• In 1993 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
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 not applicable, the general industry standard prevails

• 1910.146 does not apply to industries with their own vertical standards:
  • Agriculture
  • Construction
  • Shipyard employment

29 CFR 1926 Subpart AA: Confined Spaces in Construction

• 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 construction related CS procedures

• As of 2015, Construction finally has its own standard: 29 CFR 1926 Subpart AA “Confined Spaces in Construction”
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
- However, there are no other serious safety hazards

Under 1926 Subpart AA, during construction, these can easily be permit confined spaces!

- It depends on what is being done at that moment in the construction process
- For example:
  - When a sealant is being applied in the crawl space, the atmosphere may be hazardous due to toxic vapors
  - $O_2$ catalyzed sealants and freshly poured concrete absorb oxygen while curing, making the atmosphere in the pit dangerous because of $O_2$ deficiency
Types of confined spaces covered by 1926 Subpart AA

- 29 CFR 1926 includes a lengthy list of confined spaces that are covered by the new 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 1946)

Typical construction confined spaces

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

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

Confined Spaces in Construction: Crawl Spaces and Attics

- Even if the space is not a PRCS, after construction, it may represent a dangerous permit space at certain stages 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.
General Requirements

- Employers Must:
  - Identify Confined Space hazard areas
  - Inform employees by posting signs where feasible
  - Prevent entry by unauthorized persons

General Requirements

- 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
### General Requirements

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

<table>
<thead>
<tr>
<th>General Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employers must provide required equipment:</td>
</tr>
<tr>
<td>- Testing and monitoring</td>
</tr>
<tr>
<td>- Ventilation</td>
</tr>
<tr>
<td>- Communications</td>
</tr>
<tr>
<td>- Lighting</td>
</tr>
<tr>
<td>- Barriers</td>
</tr>
<tr>
<td>- Other personal protective equipment</td>
</tr>
<tr>
<td>- Any required rescue and emergency equipment</td>
</tr>
</tbody>
</table>
### General Requirements

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

### 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
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.

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.

1926.1203(e)(1) lists the conditions under which alternate entry procedures can be used.

Benefits:

- Substantially lower equipment requirements
- No attendants required
- Solo entries permitted

Before employee enters 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 whenever any employee is inside the space.
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 stop.

Sufficient time must be available for an entrant to safely exit the space if the ventilation stops.

Some industries, such as telecommunications, have had millions of safe entries into their vaults using ventilation, training and written procedures.

However, many other employers have been cited for using alternate entry procedures inappropriately.
**Alternate Entry Procedures**

- The employer must certify that the space is safe for entry

**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
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 would-be rescuers!

Rescue

- Self rescue: Entry procedures should aim at getting workers out under their own power BEFORE conditions become life threatening
- Non-entry rescue: Second best approach is to use procedures that allow rescue without having to enter the space
- Rescuer 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.
- Employer must provide training to ensure employee possess understanding, knowledge, and skills necessary for the safe performance of the duties assigned under this standard.
- Training must result in:
  - Understanding the hazards and the methods used to isolate, control and protect employees.
  - Understanding the dangers of attempting rescues unless trained, equipped and authorized to do so.

Conditions in CS can change!

- Work in confined spaces can produce dangerous atmospheric conditions:
  - Welding
  - Painting
  - De-greasing
  - Scraping
  - Sandblasting
  - Mucking
  - Inerting
1926 Subpart AA: Increased emphasis on communication

- Workers and contractors at construction site can change from day to day
- Whenever responsibility for a PRCS is transferred the Entry Supervisor determines that entry operations remain consistent with terms of the entry permit and that acceptable entry conditions are maintained
- The Entry Employer must ensure that all Entry Supervisors, Authorized Entrants and Attendants are properly trained, and that they properly follow the requirements of the Employer’s confined space entry program

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
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 “safe level”</td>
</tr>
<tr>
<td>16%</td>
<td>First sign of anoxia appears</td>
</tr>
<tr>
<td>16 – 12%</td>
<td>Breathing and pulse rate increase, muscular co-ordination 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 occurs, respiration stops</td>
</tr>
</tbody>
</table>

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
Oxygen displacement in an open topped confined space

Argon

Oxygen enrichment

- Proportionally increases rate of many chemical reactions
- Can cause ordinary combustible materials to become flammable or explosive
- Any area with an $O_2$ level of more than 23.0% is dangerously enriched
**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:  
  \[ 2Pb + O_2 \rightarrow 2PbO \]

**Major components of a “fuel cell” type oxygen sensor**

1. External Moisture Barrier
2. Diffusion Barrier
3. Diffusion Capillary
4. $O_2$ Sensing Electrode
5. Current Collector
6. Separator
7. Current Collector
8. Lead Anode (within electrolyte)
9. Electrolyte
10. Outer casing
11. Connector pins
12. Placement pin
**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
- **Reactions:** Oxidation / Reduction of target gas by catalyst
  
  Sensing: \[ O_2 + 4H^+ + 4e^- \rightarrow 2 H_2O \]
  
  Counter: \[ 2 H_2O \rightarrow O_2 + 4H^+ + 4e^- \]

- Oxygen generated on counter electrode
- Amount electricity required to remove reaction product and return sensor to ground state (by generating \( O_2 \) at counter electrode) proportional to concentration of oxygen present

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**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
- Work being done in the space
- Decomposing materials in the space
- Adjacent areas
Substance-specific electrochemical sensors

- Gas diffusing into sensor reacts at surface of the sensing electrode
- Sensing electrode made to catalyze a specific reaction
- Use of selective external filters further limits cross sensitivity

Typical electrochemical detection mechanism

**H₂S Sensor:**

Hydrogen sulfide is oxidized at the sensing electrode:

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

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

\[ 2\text{O}_2 + 8\text{H}^+ + 8\text{e}^- \rightarrow 4\text{H}_2\text{O} \]

And the overall reaction is: \( \text{H}_2\text{S} + 2\text{O}_2 \rightarrow \text{H}_2\text{SO}_4 \)

City Technology 4HS Signal Output: 0.7 μA / ppm H₂S
**Meaning of parts-per-million (ppm)**

- 100% by volume = 1,000,000 ppm
- 1% by volume = 10,000 ppm
- 1.0 ppm the same as:
  - One centimeter in 10 kilometers
  - One minute in two years
  - One cent in $10,000
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

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!
## Toxic effects of H₂S

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13 ppm</td>
<td>Minimal detectable odor</td>
</tr>
<tr>
<td>4.6 ppm</td>
<td>Easily detectable, moderate odor</td>
</tr>
<tr>
<td>10.0 ppm</td>
<td>Beginning eye irritation.</td>
</tr>
<tr>
<td>27 ppm</td>
<td>Strong unpleasant odor but not intolerable</td>
</tr>
<tr>
<td>100 ppm</td>
<td>Coughing, eye irritation, loss of smell after 2-5 min</td>
</tr>
<tr>
<td>200 – 300 ppm</td>
<td>Marked eye inflammation, rapid loss of smell, respiratory tract irritation, unconsciousness with prolonged exposure</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 – 1,000 ppm</td>
<td>Rapid unconsciousness, stopping or pausing of respiration and death</td>
</tr>
<tr>
<td>1,000 – 2,000 ppm</td>
<td>Immediate unconsciousness, death in a few minutes. Death may occur even if person is moved to fresh air</td>
</tr>
</tbody>
</table>

## H₂S exposure limits

<table>
<thead>
<tr>
<th>Toxic exposure limits for H₂S</th>
<th>8-hour TWA</th>
<th>15-minute STEL</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 (Old)</td>
<td>10</td>
<td>15</td>
<td>NA</td>
</tr>
<tr>
<td>ACGIH TLV (2010)</td>
<td>1</td>
<td>5</td>
<td>NA</td>
</tr>
</tbody>
</table>
Characteristics of carbon monoxide

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

Carbon monoxide

- 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 fatal 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

### Toxic effects of carbon monoxide

<table>
<thead>
<tr>
<th>Concentration (ppm)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 ppm</td>
<td>TLV exposure limit for 8 hours (TWA)</td>
</tr>
<tr>
<td>200 ppm</td>
<td>Possible mild frontal headaches in 2-3 hours</td>
</tr>
<tr>
<td>400 ppm</td>
<td>Frontal headaches and nausea after 1-2 hours.</td>
</tr>
<tr>
<td>800 ppm</td>
<td>Headache, dizziness and nausea in 45 min. Collapse and possibly death in 2 hours</td>
</tr>
<tr>
<td>1,600 ppm</td>
<td>Headache and dizziness in 20 min. Unconsciousness and danger of death in 2 hours</td>
</tr>
<tr>
<td>3,200 ppm</td>
<td>Headache and dizziness in 5-10 min. Unconsciousness and danger of death 30 min.</td>
</tr>
<tr>
<td>6,400 ppm</td>
<td>Headache and dizziness in 1-2 min. Unconsciousness and danger of death 10-15 min</td>
</tr>
<tr>
<td>12,800 ppm</td>
<td>Unconsciousness immediately, danger of death in 1-3 min.</td>
</tr>
</tbody>
</table>
**Exposure limits for carbon monoxide**

- **OSHA PEL:**
  - 50 ppm 8-hr. TWA
- **NIOSH REL:**
  - 35 ppm 8-hr. TWA
  - 200 ppm Ceiling
- **TLV:**
  - 25 ppm 8-Hr. TWA

**Explosive or Flammable Atmospheres**
**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

**Gas Concentration**

<table>
<thead>
<tr>
<th>Gas Concentration</th>
<th>Flammability Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEL</td>
<td>UEL</td>
</tr>
</tbody>
</table>

**Explosive Limits**

- Methane (CH₄)

**Methane**

<table>
<thead>
<tr>
<th>Upper Explosive Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Explosive Limit</td>
</tr>
</tbody>
</table>

**Flammable range**

- 5.0 – 15.0%
Explosive Limits

- Propane ($C_3H_8$)

Flammable range
2.2 – 9.0%

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!
Typical carbon number distribution in No. 2 Diesel Fuel (liquid)

Less than 2% of molecules in diesel vapor are small enough to be measured by means of 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

![Diagram showing lighter and heavier than air gases]

Stratification

- Atmospheric hazards in confined spaces form layers
- Check all levels!
**Effects of \( \text{O}_2 \) concentration on combustible gas readings**

- **Look at \( \text{O}_2 \) readings first!**
- **LEL readings may be affected if levels of \( \text{O}_2 \) are higher or lower than fresh air**
- **Catalytic LEL sensors require a minimum level of 10% oxygen to read LEL**
- **If the \( \text{O}_2 \) concentration is too low the LEL reading should be replaced with question marks**

**Combustible sensor poisons**

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

  **Note:** The LEL sensor includes an internal filter that is more than sufficient to remove the \( \text{H}_2\text{S} \) in calibration gas. It takes very high levels of \( \text{H}_2\text{S} \) to overcome the filter and harm the LEL sensor

- **Other sulfur containing compounds**
- **Phosphates and phosphorus containing substances**
- **Lead containing compounds (especially tetraethyl lead)**
- **High concentrations of flammable gas!**

- **Combustible sensor inhibitors:**
  - Halogenated hydrocarbons (Freons®, trichloroethylene, methylene chloride, etc.)
### Combustible sensor limitations

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>LEL (Vol %)</th>
<th>Flashpoint Temp (°F)</th>
<th>OSHA PEL</th>
<th>NIOSH REL</th>
<th>TLV</th>
<th>5% LEL in PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>2.5%</td>
<td>-49°F (-20 °C)</td>
<td>1,000 PPM TWA</td>
<td>250 PPM TWA</td>
<td>500 PPM TWA; 750 PPM STEL</td>
<td>1,250 PPM</td>
</tr>
<tr>
<td>Diesel (No.2) vapor</td>
<td>0.6%</td>
<td>125°F (51.7°C)</td>
<td>None Listed</td>
<td>None Listed</td>
<td>15 PPM</td>
<td>300 PPM</td>
</tr>
<tr>
<td>Ethanol</td>
<td>3.3%</td>
<td>55°F (12.8 °C)</td>
<td>1,000 PPM TWA</td>
<td>1000 PPM TWA</td>
<td>1000 PPM TWA</td>
<td>1,650 PPM</td>
</tr>
<tr>
<td>Gasoline</td>
<td>1.3%</td>
<td>-50°F (-45.6°C)</td>
<td>None Listed</td>
<td>None Listed</td>
<td>300 PPM TWA; 500 PPM STEL</td>
<td>650 PPM</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>1.1%</td>
<td>-7°F (-21.7°C)</td>
<td>500 PPM TWA</td>
<td>50 PPM TWA</td>
<td>50 PPM TWA</td>
<td>550 PPM</td>
</tr>
<tr>
<td>Isopropyl alcohol</td>
<td>2.0%</td>
<td>53°F (11.7°C)</td>
<td>400 PPM TWA</td>
<td>400 PPM TWA; 500 PPM STEL</td>
<td>200 PPM TWA; 400 PPM STEL</td>
<td>1000 PPM</td>
</tr>
<tr>
<td>Kerosene/ Jet Fuels</td>
<td>0.7%</td>
<td>100 – 162°F (37.8 – 72.3°C)</td>
<td>None Listed</td>
<td>100 mg/M³ TWA (approx. 14.4 PPM)</td>
<td>200 mg/M³ TWA (approx. 29 PPM)</td>
<td>350 PPM</td>
</tr>
<tr>
<td>MEK</td>
<td>1.4%</td>
<td>16°F (-8.9°C)</td>
<td>200 PPM TWA</td>
<td>200 PPM TWA; 300 PPM STEL</td>
<td>200 PPM TWA; 300 PPM STEL</td>
<td>700 PPM</td>
</tr>
<tr>
<td>Turpentine</td>
<td>0.8%</td>
<td>95°F (35°C)</td>
<td>100 PPM TWA</td>
<td>100 PPM TWA</td>
<td>20 PPM TWA</td>
<td>400 PPM</td>
</tr>
<tr>
<td>Xylenes (o, m &amp; p isomers)</td>
<td>0.9 – 1.1%</td>
<td>81 – 90°F (27.3 – 32.3°C)</td>
<td>100 PPM TWA</td>
<td>100 PPM TWA; 150 PPM STEL</td>
<td>100 PPM TWA; 150 PPM STEL</td>
<td>450 – 550 PPM</td>
</tr>
</tbody>
</table>

### 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**
• VOCs are organic chemicals or mixtures characterized by 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
Catalytic (CC) LEL vs. PID Sensors

- Catalytic LEL and photoionization detectors are complementary detection techniques
- Catalytic LEL sensors excellent for measurement of methane, propane, and other common combustible gases NOT detectable by PID
- PIDs detect large VOC and hydrocarbon molecules that are undetectable by catalytic sensors
- Best approach to VOC measurement is to use multi-sensor instrument 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 AGCIH, 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>BW</th>
<th>Ion</th>
<th>GfG</th>
<th>IE (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 (JP-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>Methyl-ethyl-ketone (MEK)</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>
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<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 hand-held CO₂ detectors)
**Energy Absorbed by “Bond Stretching” and “Bending” Vibration**

- **Must have a COVALENT CHEMICAL BOND**

  ![Molecule Diagram](Image)

  - **H<sub>3}C**
  - **H**
  - **H**
  - **O**
  - **S**

  **Nonlinear Molecules**

  **Linear molecules: SO**

---

**Wavelengths typically used for IR LEL measurement**

![Wavelength Graph](Image)

- 3.33 µm
- 3.4 µm
- 4.0 µm (reference)

- **Ethanol**
- **Propane**
- **Methane**
- **Acetylene**
- **Water vapor**
- **Benzene**

**Transmittance**

**Wavelength (µm)**
Combustible gas NDIR sensor advantages and limitations

- Limitations:
  - Molecule must include chemical bonds that absorb at the wavelength(s) used for measurement
  - Not all combustible gases can be detected!
    - “Diatomic” molecules like hydrogen ($H_2$) cannot be detected at all
    - Gases with double and triple bonds (like acetylene) detect poorly or not at all at some 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 well to large hydrocarbon molecules that cannot be measured by means of standard LEL sensor
Linearized 3.33 μm NDIR combustible gas response curves

![Linearized 3.33 μm NDIR combustible gas response curves](image)

Comprehensive product information

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

Technical support and downloads

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