



GfG Instrumentation

Worldwide manufacturer of gas detection solutions

AP 1001:
Choosing the best detection technologies for measuring combustible gas and VOC vapors

G450 / G460 Battery pack performance and maintenance procedures

TN 2014:
Calibrating GfG Micro IV instruments equipped with hydrogen fluoride (HF) sensors

TN 2015:
Electrochemical (EC) sensors: gases measured, ranges and resolution



Substance-specific electrochemical (EC) sensors are available for an increasing number of toxic gases and vapors. Besides the primary gas the sensor is designed to measure, it may be possible to calibrate and use the same sensor to measure other gases with similar chemistries.

Electrochemical (EC) sensors are one of the most common types of sensors used in portable gas detectors. Multi-sensor confined space monitors generally contain an oxygen sensor, a flammable/combustible sensor and one to three additional electrochemical sensors for specific toxic gases. Single-sensor instruments equipped with EC toxic sensors are also extremely popular for use in situations where a single toxic hazard is present.

Electrochemical sensors are available for monitoring for an increasing number of contaminants including hydrogen sulfide (H₂S), carbon monoxide (CO), sulfur dioxide (SO₂), chlorine (Cl₂), chlorine dioxide (ClO₂), ammonia (NH₃), phosphine (PH₃), cyanide (HCN), hydrogen (H₂), ethylene oxide (C₂H₄O), nitrogen dioxide (NO₂), nitric oxide (NO), ozone (O₃), hydrogen fluoride (HF), hydrogen chloride (HCl), phosgene (COCl₂), and others.

EC sensors are usually designed to minimize the effects of interfering contaminants, making the readings as specific as possible for the gas being measured. However, most substance-specific sensors still show some cross-sensitivity to at least a few other gases. Alternatively, "broad-range" EC sensors are deliberately designed to provide a measurable response to a wide array of contaminants. Most electrochemical sensors fall somewhere between the two extremes in terms of specificity.

The following tables provide a partial list of the gases and vapors detectable by means of EC sensors in GfG products.

Table 1 lists the types of available EC sensors by the gas they are designed to measure, as well as the standard range and resolution for each sensor.

Table 2 shows other substances which are also detectable by using sensors listed in Table 1.

Always consult the manufacturer before using an EC sensor to measure a different gas from the one it is primarily designed to measure!



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Application Notes and Technical Notes

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AP 1001:

Choosing the best detection technologies for measuring combustible gas and VOC vapors



No one single sensor (or type of sensor) is capable of detecting all types of dangerous gases and vapors. This is why workers who may be exposed to multiple hazards use instruments with multiple sensors installed.

The most commonly used sensors are for the measurement of combustible gas, oxygen, carbon monoxide and hydrogen sulfide. The majority of multi-sensor instruments are equipped with at least these four sensors. However, in many cases, these basic sensors are not capable of measuring all of the atmospheric hazards that are potentially present.

The sensors utilized in portable gas detectors are extremely good at detecting what they are designed to measure. The problem is that users are frequently unaware of the limitations, and use the sensors in ways that result in inaccurate readings. It is critically important for instrument users to understand what the sensors in their instrument cannot properly measure as well as what they can.

The good news is that there is an extremely wide range of technologies and types of sensors available for use in portable multi-sensor instruments. Just because one type of sensor does not work for a particular gas does not mean there are no alternatives. The only limitation is that the instrument must be sufficiently flexible to make use of the most appropriate detection technologies (Figures 1 and 2).

Oxygen, carbon monoxide and hydrogen sulfide sensors are designed to measure a single type of gas. There is very little ambiguity in the readings these sensors provide. The only

gas an oxygen sensor responds to is oxygen. Electrochemical sensors designed to measure a particular gas may not be quite so specific. Although sensor manufacturers design their products to minimize responsiveness to gases other than the one they are supposed to measure, no design is perfect. For instance, CO sensors may also respond to hydrogen as well as to the vapors produced by alcohols, solvents and other volatile organic chemicals (VOCs). Since most interfering effects are positive, the possibility that the sensor may occasionally provide higher than actual readings for CO is generally not regarded as a safety concern. It just means that workers leave the affected area a little sooner. Similarly, hydrogen sulfide sensor readings can be affected by exposure to degreasers and solvents such as methanol and citrus oil cleaners.

The sensor with the most important limitations is the traditional "catalytic" or "pellistor" type percent lower explosive limit (% LEL) combustible gas sensor. In spite of the millions of combustible sensor equipped atmospheric monitors in service around the world, there is still a lot of misinformation and misunderstanding when it comes to the performance characteristics and limitations of this very important type of



Figure 1: Flexibility to support the needed sensors is critical! The G460 Multi-sensor Atmospheric Monitor from GfG Instrumentation is capable of measuring up to six different atmospheric hazards at the same time.



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sensor. Understanding how combustible sensors detect gas is critical to correctly interpreting readings, and avoiding misuse of instruments that include this type of sensor.

How combustible sensors detect gas

“Pellistor” type LEL sensors detect gas by catalytically oxidizing or “burning” the gas on an active bead or “pellistor” located within the sensor. The “active” bead is treated with a platinum or palladium-based catalyst that facilitates the oxidation of combustible gas on the bead. Even trace amounts of gas or vapor in the air surrounding the sensor can be catalytically oxidized on the active bead. As oxidation occurs the bead is heated to a higher temperature. A “reference” bead in the circuit that has not been treated with catalyst provides a comparison value. Since heating due to oxidation of the combustible gas only occurs on the active bead, the difference in temperature between the two beads is proportional to the concentration of gas in the area where the sensor is located.

Catalytic-bead sensors respond to a wide range of ignitable gases and vapors, but are unable to differentiate between different combustible gases. They provide one signal based on the total heating effects of all the gases capable of being oxidized that are present in the vicinity of the sensor. The heating effect or “relative response” of the sensor varies from gas to gas. Generally speaking, the larger the molecule, the lower the relative response. For instance, when a pellistor type LEL sensor that has been calibrated for the measurement of methane (CH₄) is exposed to 50% LEL CH₄, the instrument shows a reading of 50% LEL. However, if that same instrument is exposed to 50% LEL pentane, (C₅H₁₂) it will show a reading of only about 25% LEL.

Pellistor type sensors generally include a flame arrestor that can slow, reduce or prevent larger hydrocarbon molecules from entering the sensor. Small combustible gas molecules like hydrogen (H₂), methane and propane (C₃H₈) diffuse through the flame arrestor very rapidly.

The larger the molecule, the slower it diffuses through the flame arrestor into the sensor. Figures 4 and 5 show the difference in the time it takes for the same pellistor LEL sensor to respond to methane (CH₄) compared to hexane (C₆H₁₄). Saturated hydrocarbons larger than nonane (C₉H₂₀) are unable to penetrate the flame arrestor at all in appreciable quantities. Traditional pellistor type LEL sensors should not be used to measure hydrocarbon gases larger than nonane in size. To put this in perspective, less than 4% of the molecules in a bucket of diesel fuel are small enough to pass through the flame arrestor and enter the sensor. This is one of the reasons that

LEL sensors show such a low response when exposed to the vapors of “heavy” fuels such as diesel, kerosene, jet fuel and heating oil.

Although most VOC vapors are combustible, the toxic exposure limits are much lower than the flammability limits. For example, for diesel fuel 10% LEL is equal to about 600 ppm vapor. However, the TLV® (Threshold Limit Value®) for diesel vapor is only 15 ppm (as an 8 hour TWA). If you wait for the combustible gas alarm to go off at 10% LEL you could potentially exceed the toxic exposure limit by 40 times! Clearly, from a toxic exposure limit standpoint a different detection technique is required.

Another limitation of pellistor type sensors is that they require the presence of oxygen in order to oxidize the gas being measured. Most manufacturers stipulate that the atmosphere must contain at least 10% O₂ in order for the LEL sensor to detect gas accurately. Readings are increasingly affected as the concentration drops below this level. In zero percent O₂



Figure 2: Multi-sensor instruments are able to use a wide range of sensors and detection technologies including O₂, standard pellistor LEL, NDIR combustible gas and CO₂, PID and over 20 different substance-specific electrochemical sensors for toxic gas measurement.



pellistor type combustible sensors cannot detect gas at all. For this reason confined space instruments that contain catalytic pellistor type LEL sensors should also include a sensor for measuring oxygen.

Another concern is loss of sensitivity due to the age and usage of the sensor. Catalytic bead sensors are easily damaged or destroyed by exposure to sensor "poisons" such as silicones, phosphine (PH₃) and high concentrations of H₂S.

Fortunately, there are alternative detection techniques that are not affected by these constraints. It is important to note that these alternative types of sensors should not be seen as replacements for the pellistor sensor. Pellistor sensors are still the best and most cost effective solution for many applications. It is also true, however, that in many cases the best approach is to include one or more additional types of sensor in the instrument.

What other types of sensors are available for combustible gas and VOC measurement?

The major alternatives for combustible gas and VOC measurement are thermal conductivity detectors (TCDs), photoionization detectors (PIDs) and non-dispersive infrared (NDIR) sensors.

- **Thermal conductivity (TCD) sensors**

Thermal conductivity sensors are a specialized type of sensor most frequently used to detect high range concentrations of combustible gas.

Thermal conductivity sensors are capable of measuring combustible gas in concentrations up to 100% by volume. The sensor contains two coils of fine wire that are coated with a



Figure 3: Pellistor type LEL sensor with flame arrestor (sinter) removed from stainless steel housing

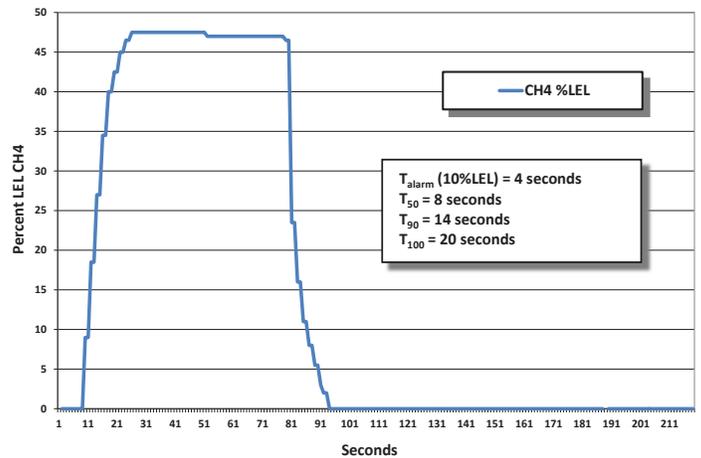


Figure 4: Pellistor type LEL sensor response to 50% LEL methane (2.5% Volume). Note that the "time to alarm" (10% LEL) is about 4 seconds.

ceramic material to form beads. The beads are strung onto the opposite arms of a balanced Wheatstone bridge circuit. Neither bead receives a catalyst coating. Instead, the reference bead is isolated from the air being monitored in a sealed or semi-sealed chamber. The active bead is exposed to the atmosphere being monitored for gas. Power is provided to the sensor to heat the beads to operating temperature. Detection depends on the "air-conditioning" effect of high concentrations of gas on the active bead.

If a lighter than air combustible gas is present (such as hydrogen or methane), the active bead will dissipate heat in the attenuated atmosphere more efficiently than the reference bead. If a heavier than air gas is present (such as propane) the bead is insulated by the denser atmosphere. Once again, the difference in temperature between the two beads is proportional to the amount of combustible gas present in the atmosphere being monitored.

Some pellistor type sensors are capable of operation in both catalytic oxidation and thermal conductivity modes. In this type of combustible sensor the catalyst coated active bead is constructed and positioned in the normal way within the sensor, but the compensating reference bead is housed in a semi-sealed chamber which is penetrated by a capillary pore to limit diffusion. During percent LEL range detection readings are obtained in the usual way by catalytic oxidation on the active bead. When operated in thermal conductivity mode, power to the active bead is cut to guard against damage to the bead, while the compensating bead continues to be maintained under power. Once again it is the "air-conditioning" effect of the combustible gas on the compensating bead that is used to provide a reading.

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TCD type sensors are often paired with a pellistor type sensor in the same instrument. The pellistor sensor (or mode) is used for 0 – 100% LEL range measurement, while the TCD is used for high range 0 – 100% volume measurement. In fact, a common approach is to put both types of sensor into a single housing that shares the same flame arrestor and certification as a flame proof device.

The chief limitations of TCD sensors are the accuracy of the sensor at lower concentrations of gas, and the effects that changes in the makeup of the air being tested can have on readings. TCD sensors are not recommended for use in confined spaces where there is the potential for oxygen deficiency. The “air conditioning” effect of combustible gas on the active bead in the sensor is significantly different when the gas is present in fresh air than when the gas is present in oxygen deficient air, or air that contains elevated concentrations of nitrogen or carbon dioxide.

Another issue is the damaging effect sensor poisons and / or high concentrations of gas can have on the pellistor sensor, or on the TCD sensor if it includes a catalytic pellistor bead or is operable in a catalytic LEL detection mode.

• Intrinsically safe versus flame proof sensor designs

Pellistor type LEL and TCD sensors are “flame proof” devices. Flame proof sensor designs depend on physical barriers such as robust stainless steel housings and flame arrestors to limit the amount of energy that can ever be released by the sensor (Figure 3). Even under catastrophic failure conditions (i.e. a “flame” on the inside of the sensor) the sensor is incapable of releasing enough energy to be the source of ignition when located in a fully combustible atmosphere. Flame proof sensors can be certified as safe for use in different categories or “gas groups” of combustible gases. Most flame proof sensors installed in instruments sold in North America are Certified for use in Class I, Division 1, Gas Groups A, B, C and D Hazardous Locations. The indicator gas for the most highly explosive “Group A” category is acetylene.

The NDIR and PID sensors used in most portable instruments are designed as “intrinsically safe” devices. That means they are incapable of producing or releasing enough energy to be the source of ignition for a flammable concentration of gas. Because they are intrinsically safe it is not necessary to include a flame arrestor in their designs. As long as the combustible gas molecules are present in the form of a vapor, they are capable of entering the sensor and (depending on the type of molecule) being measured by the sensor.

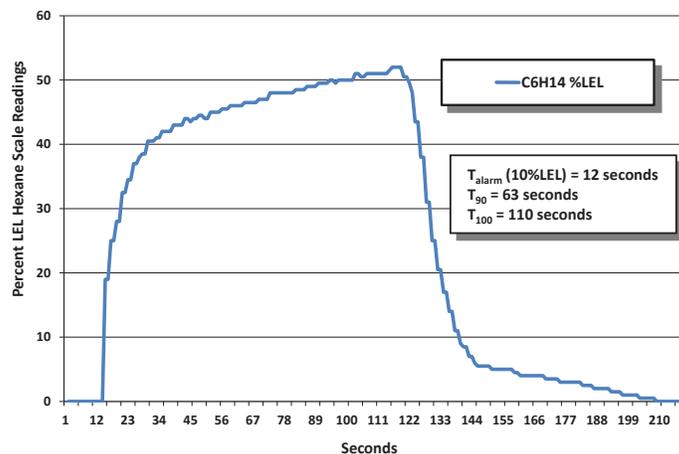


Figure 5: Pellistor type LEL sensor response to 50% LEL hexane (0.6 % Volume). Note that the “time to alarm” (10% LEL) is about 12 seconds.

• Photoionization Detectors (PIDs) for VOC measurement

Solvent, fuel and other VOC vapors are pervasively common in many workplace environments. Most have surprisingly low toxic exposure limits. For most VOCs the toxic exposure limit is exceeded long before you reach a concentration sufficient to trigger an LEL alarm. PID equipped instruments are generally the best choice for measurement of VOCs at exposure limit concentrations.

Photoionization detectors use high-energy ultraviolet light from a lamp housed within the detector as a source of energy used to remove an electron from neutrally charged VOC molecules, producing a flow of electrical current proportional to the concentration of contaminant. The amount of energy needed to remove an electron from the target molecule is called the ionization energy (IE). In general, larger and / or more reactive molecules have lower ionization energies than smaller less reactive molecules. Thus, as a general rule, the larger the VOC or hydrocarbon molecule, the easier it is to detect! This is exactly the opposite of the performance characteristics of catalytic pellistor type combustible sensor.

Pellistor type combustible sensors and photoionization detectors represent complementary, rather than competing detection techniques. Pellistor sensors are excellent for the measurement of methane, propane, and other common combustible gases that are not detectable by means of a PID.



On the other hand, PIDs can detect large VOC and hydrocarbon molecules that are effectively undetectable by pellistor sensors, even when the catalytic sensor is operable in ppm measurement ranges. The best approach for VOC measurement in many cases is to use a multi-sensor instrument equipped with both a pellistor LEL sensor and a PID sensor.

- **Non-dispersive infrared (NDIR) sensors for combustible gas measurement**

Non-dispersive infrared (NDIR) sensors measure gas as a function of the absorbance of infrared light at a specific wavelength or range of wavelengths.

Different molecules absorb infrared radiation at different wavelengths. When infrared radiation passes through a sensing chamber containing a specific contaminant, only those wavelengths that match the absorbance spectrum of the molecule are absorbed. The rest of the light is transmitted through the chamber without hindrance. For some types of molecules (like combustible gases) it is possible to find an absorbance peak that is not shared by other types of molecules likely to be present. In the case of combustible gas, the wavelength most frequently used is 3.3 μm (Micrometers). The active detector in an NDIR combustible gas sensor measures the amount of infrared light absorbed at this wavelength. A reference detector measures the amount of light at another wavelength where there is no absorbance (Figures 6 and 7).

The greater the concentration of combustible gas, the greater the reduction in the amount of light that reaches the active detector when compared to the reference signal.

While pellistor type LEL sensors are more sensitive to small molecules like methane than to larger molecules like pentane or nonane; the opposite is true for NDIR sensors (Figures 8 and 9). It is the chemical bonds in the molecules being measured that actually absorb the infrared light. Since larger molecules have more chemical bonds holding the atoms in the molecule together, they provide more opportunities for infrared radiation to be absorbed. In many cases, the larger the molecule, the stronger the signal (Figures 10 and 11). Of course, this assumes that the chemical bonds present within the molecule absorb IR at the wavelengths being measured. The molecule is not measurable unless the bonds absorb IR at the measurement wavelength.

For instance, although acetylene (C_2H_2), has two C-H bonds, the presence of a triple bond between the two carbon atoms reduces absorbance at 3.3 μm , and renders the molecule unmeasurable at this wavelength. However, the $\text{C}\equiv\text{C}$ triple bond shows strong absorbance at a wavelength of 2.3 μm .



Figure 6: Instrument with NDIR sensor. Since the amount of IR light absorbed is proportional to the amount of target gas present, the longer the optical path-length through the IR sensor, the better the resolution.

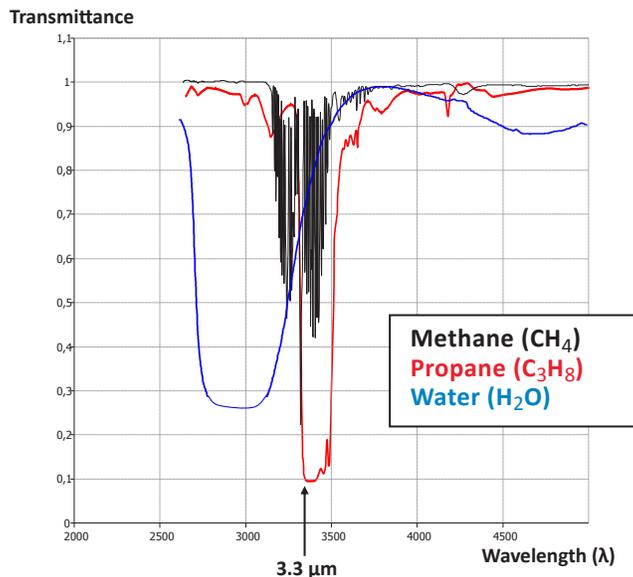


Figure 7: Infrared transmittance spectra for methane, propane and water. IR sensors usually measure combustible gas at a wavelength of 3.3 μm (= 3,300 nm). Since water also absorbs some IR light at this wavelength, the sensor should be zeroed in the ambient atmosphere in which the instrument will be used before each day's use.



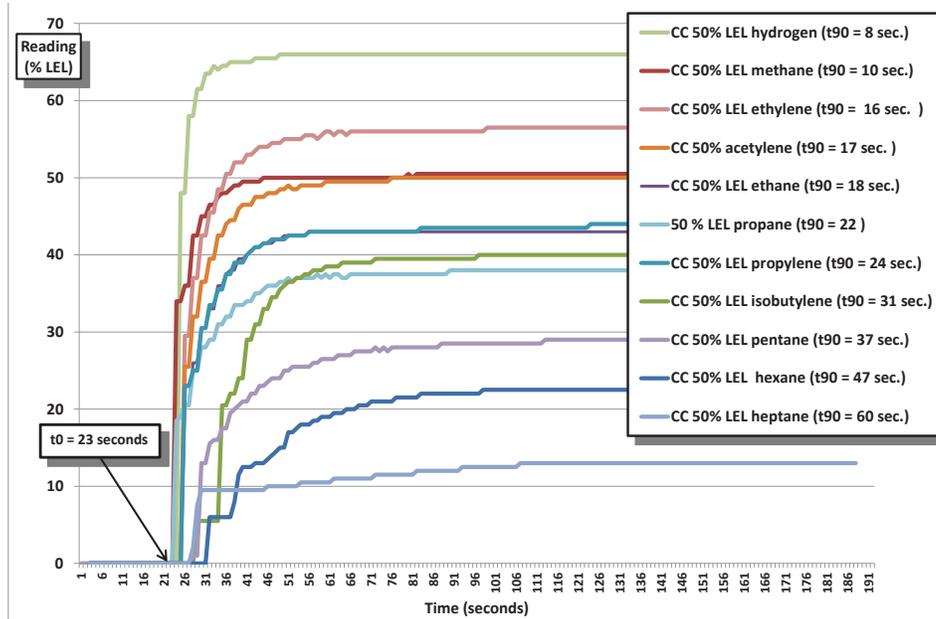


Figure 8: Pellistor type LEL sensors show lower relative responses to larger molecules than to smaller. In the example above the response to methane (CH_4) is about two times higher than the response to pentane (C_5H_{12}), and about four times higher than the response to heptane (C_7H_{16}). The response to larger molecules is also much slower. It takes only 10 seconds for the methane reading to reach t_{90} (90% of its final stable response), while it takes a full minute for heptane.

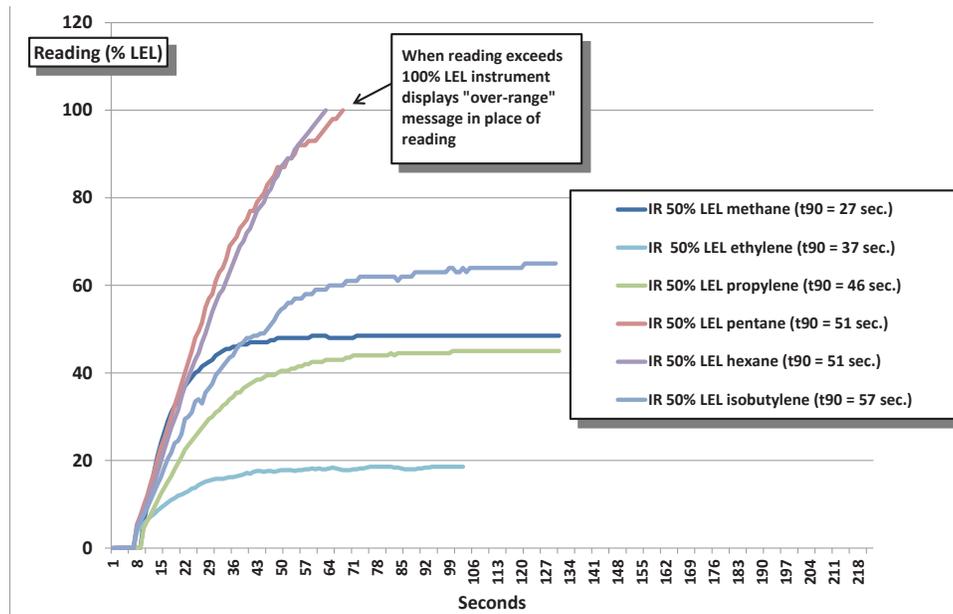


Figure 9: Two-wavelength infrared type LEL sensors usually measure combustible gas at a wavelength of $3.3 \mu\text{m}$. The C-H bond in hydrocarbon molecules absorbs IR radiation at this wavelength. The more C-H bonds in the molecule, the greater the absorbance. In the example above, the response to methane (CH_4), which has only four C-H bonds, is much lower than the response of the sensor to larger hydrocarbon molecules like pentane (C_5H_{12}), which has 10 C-H bonds. In fact, the response of the IR LEL sensor to pentane and hexane is so strong compared to methane that the reading exceeds 100% LEL.

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Unfortunately, because water vapor also strongly absorbs IR at 2.3 μm , it is not possible to use this wavelength for combustible gas measurement in ambient air unless you measure and deduct for the effects of humidity interference on readings. At 3.3 μm the effects of humidity interference are much less severe, which is why most manufacturers use this as the standard wavelength for combustible gas measurement.

NDIR combustible gas sensors have a number of other advantages when compared to pellistor type sensors. NDIR sensors are not equipped with flame arrestors that limit their ability to detect large hydrocarbon molecules. NDIR sensors do not require oxygen. They are also not subject to damage due to exposure to sensor poisons. Finally, unlike pellistor type sensors, they can be used for measurement of high concentration combustible gas above the 100% LEL concentration.

One of the most important limitations of NDIR combustible gas sensors is that they cannot be used for measurement of diatomic gases such as oxygen (O_2), nitrogen (N_2) and hydrogen (H_2). In applications where H_2 may be potentially present, the instrument should be equipped with a type of sensor designed to respond to H_2 , such as a pellistor LEL sensor or an electrochemical sensor capable of measuring H_2 in the desired range.

Examples of sensor configurations optimized for specific applications:

- **Confined space monitoring for shipyards**

Two categories of combustible gas hazards are of special concern during shipyard and maritime confined space entry procedures; the heavy fuel vapors from the diesel, bunker and fuel oil used to power the ship’s engines; and hydrogen gas produced by the electrolysis of metals when exposed to seawater or moisture. Pellistor sensors used in this type of environment are frequently damaged due to exposure to sensor poisons. In addition, in many cases the monitor must be used to obtain samples from compartments and spaces that have been purged with an inert gas such as nitrogen or CO_2 to remove the oxygen.

Pellistor sensors cannot be used for monitoring combustible gas in oxygen deficient atmospheres unless equipped with dilution fittings or a second pump used to introduce enough fresh air into the sample for the pellistor sensor to be able to oxidize and properly detect the gas. Pellistor sensors are also incapable of providing dependable LEL range measurement for diesel, bunker and fuel oil vapors.

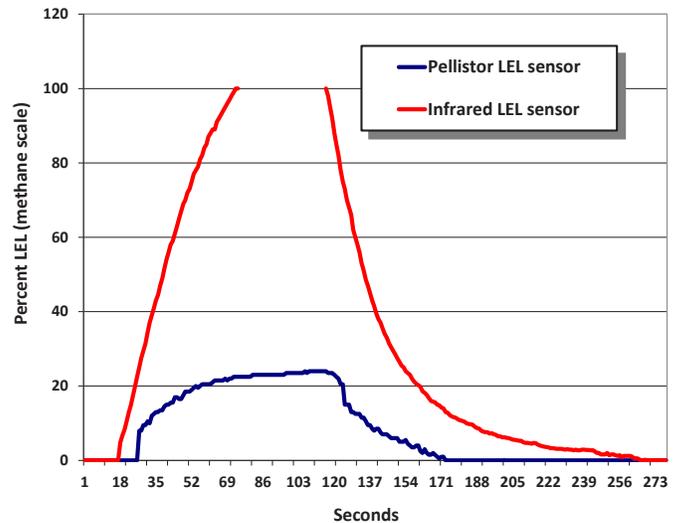


Figure 10: Relative response of pellistor and infrared sensors to n-hexane. Both sensors were calibrated to 50% LEL methane (CH_4), then exposed to 50% LEL n-hexane (C_6H_{14}). The uncorrected readings for the pellistor sensor are much lower than the true concentration (50% LEL); while the uncorrected readings for the IR sensor are more than twice as high as the true concentration, (in fact, the readings exceeded the over-range limit of 100% LEL).

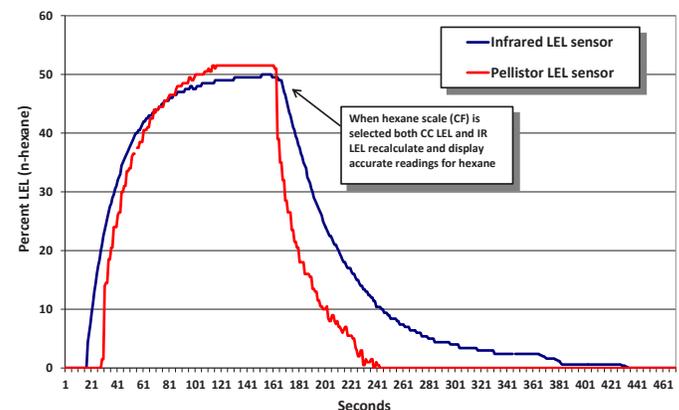


Figure 11: Response of n-hexane calibrated pellistor and IR sensors to 50% LEL n-hexane. The readings for both sensors are now very close to the true 50% LEL concentration applied. The initial response of the IR sensor is slightly quicker than the response of the pellistor sensor. However, the time to the final stable response (T100) is virtually identical for both sensors, (about 150 seconds).

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The optimal configuration for this application would be an instrument equipped with an oxygen sensor, an NDIR sensor for LEL range combustible gas measurement, a PID for ppm range VOC measurement, and an electrochemical hydrogen sensor for LEL range (1 – 4% volume) H₂ measurement.

- **High range measurement of natural gas from “sour” (high H₂S content) natural gas wells**

The natural gas from many of the older fields in North America is often extremely “sour”; with H₂S concentrations up to 30,000 ppm or even higher. It is sometimes necessary for workers wearing appropriate PPE and respiratory protection (pressure demand SCBA) to enter areas where the concentration of combustible gas is above the explosion limit, and where the H₂S concentration routinely exceeds 3,000 ppm. It is often necessary to use multi-sensor instruments as “leak detectors” capable of measuring the natural gas in both the LEL and the percent volume ranges. Although TCD sensors are excellent for the measurement of high range methane in air, they cannot detect large hydrocarbon and VOC molecules, and (if they include a catalytic pellistor sensor or mode of operation) are vulnerable to sensor poisons such as H₂S.

The optimal configuration is an instrument with an oxygen sensor and a dual range NDIR sensor capable of monitoring both in the 1 – 100% LEL as well as in the 1 – 100% volume range. Because infrared sensors are not subject to damage due to sensor poisons (like H₂S), not having to purchase replacement sensors generally saves instrument users more than the cost of purchasing the more expensive NDIR sensor to begin with.

Important note: Carbon monoxide sensors include protective internal or external filters, but once they are saturated, the sensors show a strong response to VOC vapors and hydrocarbon gases such as hexane (Figure 16). While the effects of this cross sensitivity may not be significant in low range concentrations, high concentrations of VOC vapor may make it impossible to use an instrument that has been equipped with a CO sensor.

It is generally best to use a dedicated instrument that does not include a CO sensor when the instrument is routinely used in atmospheres with high background VOC concentrations. An alternative is to use a CO sensor equipped instrument, but to turn the CO sensor off while the instrument is being used in this application.

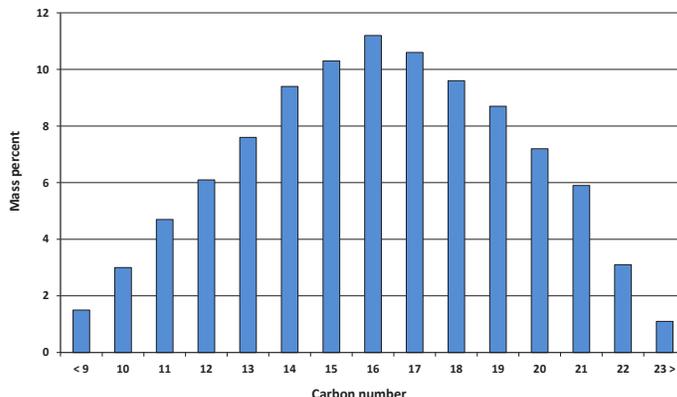


Figure 12: Typical carbon number distribution in No. 2 Diesel Fuel (liquid). Less than 1.5% of diesel molecules are small enough to diffuse through the flame arrestor of a typical pellistor LEL sensor. Less than 4% of molecules present as vapor (STP) are small enough to diffuse through the flame arrestor.

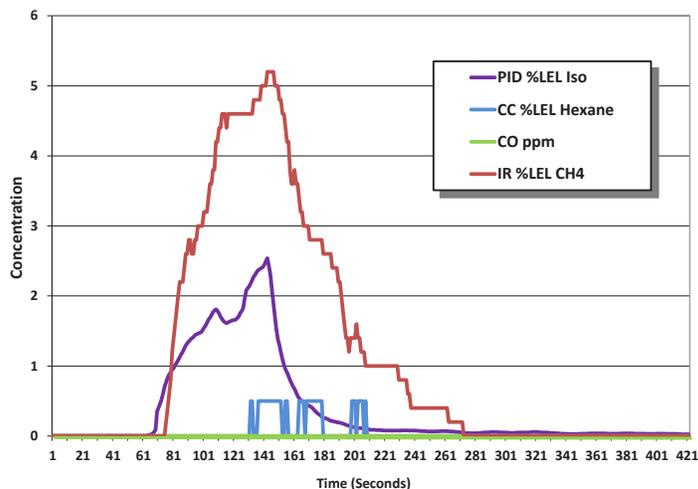


Figure 13: Response of PID, catalytic (pellistor) %LEL, IR %LEL and CO sensors exposed to diesel vapor. The IR LEL sensor shows the most accurate response, while the catalytic LEL sensor barely shows any response at all. PID is the best detection technology for low range ppm detection.



- Instruments at oil refineries used to measure ppm range VOC vapors, LEL hydrogen (H₂), C1-C9 hydrocarbons (methane through nonane), carbon monoxide and hydrogen sulfide

Industrial hygienists at refineries routinely deal with a wide range of toxic VOCs such as hexane, toluene, xylenes and benzene as well as the vapors associated with the products produced for sale (e.g. diesel, gasoline, jet fuel, etc.). It is widely understood by hygienists that it is not enough to depend on readings from the LEL sensor to determine whether or not a hazardous condition exists due to the presence of toxic concentrations of VOC vapors (Figures 12 and 13). The optimal instrument in this case is equipped with a standard % LEL pellistor sensor (which is capable of detecting all of the C1-C9 hydrocarbons as well as hydrogen), an oxygen sensor, a PID and a dual channel electrochemical "COSH" sensor capable of providing independent readings for both CO and H₂S.

- Instrument used to measure O₂ and % LEL combustible gas in procedures that include vessel inertion at an oil refinery

In order to reduce the risk of explosion, it is a common practice at many refineries and chemical plants to replace the oxygen in the atmosphere of tanks and vessels with an inerting gas such as nitrogen or carbon dioxide. Typically, two readings are of equal importance during inertion procedures. The oxygen concentration must remain below a certain threshold (at many facilities the threshold is 2.0% volume oxygen). The second reading is a direct measurement of the amount of combustible gas present in the atmosphere in the vessel. The types of combustible gases encountered often include hydrogen.

As previously discussed, pellistor type LEL sensors can be used for this purpose, but only when the instrument includes provision for introducing enough fresh air into the sample for there to be sufficient oxygen for the LEL sensor to accurately detect gas. Monitoring of inerted vessels has been done in the past at many refineries by means of a specialized instrument equipped with a pellistor LEL sensor and two internally housed pumps. One pump is used to pull the sample through a hose and probe assembly back to the instrument. The second pump is used to dilute the sample with fresh air from a location outside of the vessel. The instrument recalculates the readings shown on the instrument display to make up for the effects of introducing the fresh air into the sample.



Figure 14: Sampling inerted vessels often requires very long sample lines. Use of an attachable motorized sampling pump allows the G460 from GfG Instrumentation pictured above to be located up to 300 feet away from the point where the sample is obtained.

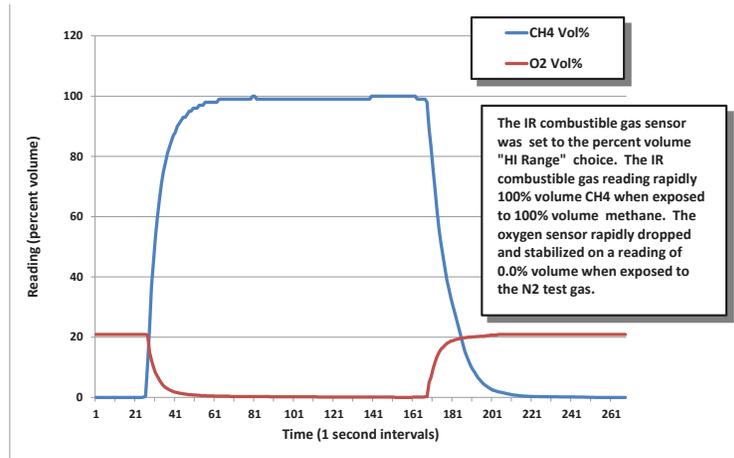


Figure 15: Response of "high range" (percent volume) infrared (IR) LEL and O₂ sensors exposed to 100% volume methane (CH₄). The IR combustible gas sensor was set to the percent volume "HI Range" choice. The IR combustible gas reading rapidly reached 100% volume CH₄ when exposed to pure methane. The oxygen sensor rapidly dropped and stabilized on a reading of 0.0% volume when exposed to the oxygen free CH₄ gas.

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These specialized instruments are “lunch box” type monitors too large to be worn, and are typically left outside of the vessel in an area far enough away that air drawn into the instrument by the second pump is contaminant free and can safely be used for sample dilution. Problems experienced by users of this specialized instrument include difficulty maintaining the proper dilution ratio due to filter loading, and damage to the pellistor sensors due to exposure to sensor poisons such as H₂S. As always, the flame arrestor in the pellistor sensor limits the ability of the sensor to detect hydrocarbon gases larger than nonane (C₉H₂₀).

The optimal solution is an instrument equipped with an oxygen sensor with an “inverted” alarm activated by the concentration climbing above 2.0% volume, an IR %LEL combustible gas sensor (which does not require oxygen to detect gas), and a 1–4.0 % volume range electrochemical hydrogen sensor (the LEL concentration for H₂ is 4.2% volume). The instrument should also be equipped with an attachable (or internal) motorized pump for sampling the atmosphere in the vessel through a hose and probe assembly (Figure 14). Since it is not necessary to dilute the sample with fresh air in order to obtain readings, it is not necessary to position the instrument in a contaminant free area remote from where the readings are being obtained.

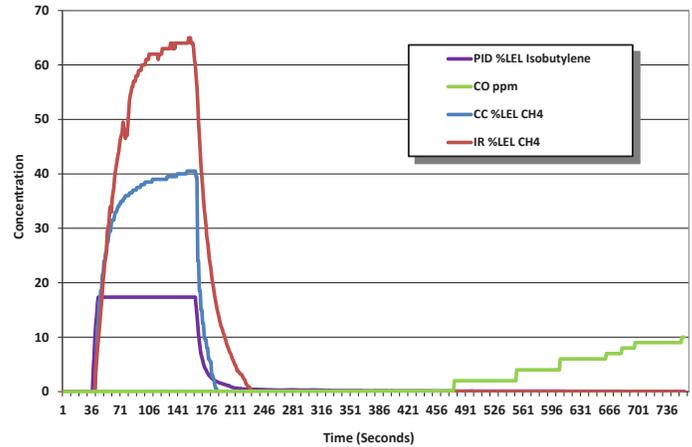


Figure 16: Response of standard pellistor (catalytic) LEL, O₂, PID and CO sensors exposed to 50% LEL (9,000 ppm) isobutylene. The PID was calibrated to isobutylene. The LEL sensor was calibrated to methane (CH₄). The relative response of the LEL sensor to isobutylene is about 0.8. The maximum over-limit concentration of the PID is 1,700 ppm. Readings above this concentration are logged at this maximum value. Note the delayed response of the CO sensor to this very high concentration of VOC vapor.

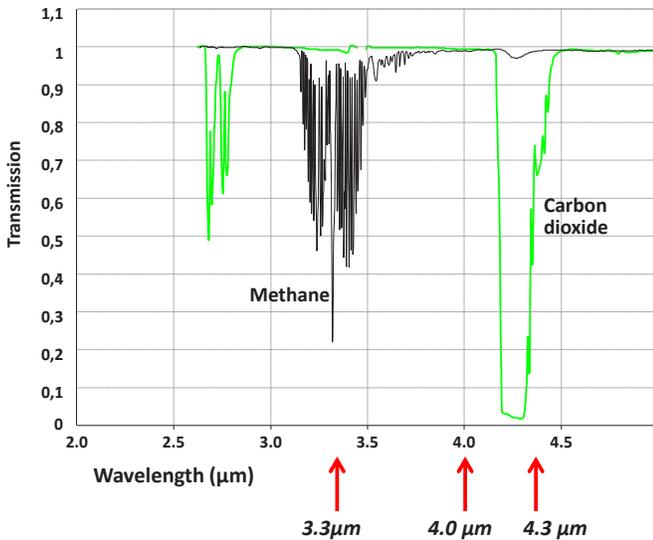


Figure 18: Transmittance spectra of methane and carbon dioxide. Dual-channel IR combustible gas / CO₂ sensors actually measure absorbance at three wavelengths. Combustible gas is measured at 3.3 µm (= 3,300 nm). CO₂ is measured at 4.3 µm (= 4,300 nm). A single reference wavelength (4.0 µm) is used for both measurement channels.

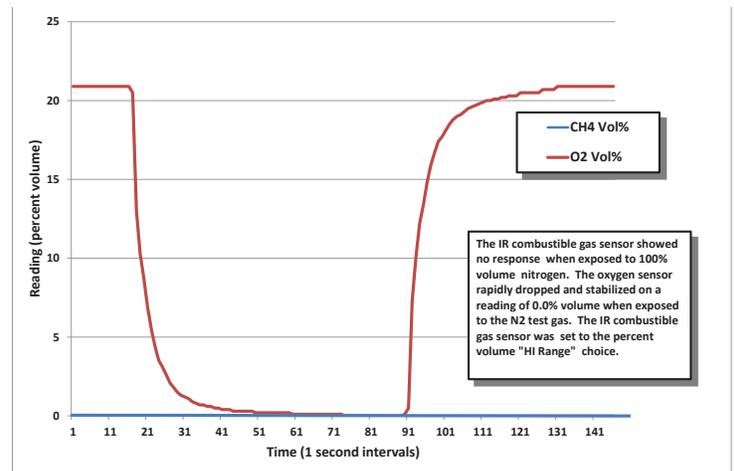


Figure 17: Response of infrared (IR) combustible gas and oxygen sensors exposed to 100% volume nitrogen (N₂). The IR combustible gas sensor showed no response when exposed to 100% volume nitrogen. The oxygen sensor rapidly dropped and stabilized on a reading of 0.0% volume when exposed to the N₂ test gas. The IR combustible gas sensor was set to the percent volume “HI Range” choice.

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- **Instrument used to monitor atmospheres at landfills**

Landfill monitoring applications involve a number of unique requirements. The anaerobic decomposition of the organic material in the buried trash has the potential for generating massive quantities of methane and carbon dioxide, as well as potentially lethal concentrations of hydrogen sulfide.

Carbon dioxide is much heavier than air, and can easily accumulate in excavations, trenches and other localized areas. Besides the danger to workers, these localized areas of oxygen deficiency may not contain enough O₂ for pellistor LEL sensors to accurately detect combustible gas. It should be noted that CO₂ is not a “simple asphyxiant” that harms workers only by displacing oxygen. Carbon dioxide is a recognized toxic gas, with an exposure limit of 5,000 ppm (8 hour TWA) in most jurisdictions.

Another concern is the high concentrations of combustible gas that may be present. Landfill instruments need to be able to measure in the percent volume as well as percent LEL ranges (Figure 15). Yet another consideration is that landfill instruments are often used to obtain readings from “bore holes” drilled into the buried material. This type of usage requires the instrument to be available for use with a motorized pump.

The optimal solution is a G460 equipped with a dual-channel infrared sensor that measures absorbance at two different wavelengths, 3.3 μm for combustible gas, and 4.3 μm for CO₂ (Figure 18). (The same 4.0 μm reference wavelength is used for both channels.) The infrared sensor is “dual-range” as well as dual-channel. Combustible gas can be measured in either of two user-selectable ranges; 1 – 100% LEL or 1 – 100% volume. The instrument should also be equipped with substance-specific sensors for measuring O₂, CO and H₂S. The G460 also needs to be equipped with an attachable motorized pump for sampling the atmosphere in the vessel through a hose and probe assembly (Figure 14).

Summation:

No single type of sensor is perfect for all applications. The four basic sensors (LEL / O₂ / CO / H₂S) used in most multi-sensor instruments are a good start, but may not be capable of properly monitoring for the presence of all potential hazards. Table 1 (following page) summarizes the advantages and limitations of each type of sensor discussed. Table 2 provides specific examples of sensor configuration choices by application.

The key to success is understanding the monitoring environment, and the specific benefits and limitations of the sensors selected. The technologies and sensors are readily available, as long as your instrument is capable of supporting their use.

About the author:

Robert Henderson is President of GfG Instrumentation, Inc. He has been a member of the American Industrial Hygiene Association since 1992. He is a past chair of the AIHA Gas and Vapor Detection Systems Technical Committee, as well as a current member and past chair of the AIHA Confined Spaces Committee. He is also a past chair of the Instrument Products Group of the Industrial Safety Equipment Association.



Table 1: Sensors for measurement of combustible gas and VOCs

	Able to detect LEL range C1 – C5 hydro-carbon gases (methane, ethane, propane, butane, pentane and natural gas)	Able to detect LEL range C6 – C9 hydro-carbon gases (hexane, heptane, octane, nonane)	Able to accurately detect LEL range heavy fuel vapors (e.g. diesel, jet fuel, kerosene, etc.)	Able to detect heavy fuel vapors in low ppm range (e.g. diesel, jet fuel, kerosene, etc.)	Able to use in low oxygen atmospheres	Vulnerable to sensor poisons (e.g. silicones, phosphine, tetraethyl lead, H ₂ S, etc.)	Able to use for high range combustible gas measurement (100% LEL and higher)	Able to measure H ₂
Standard catalytic (pellistor) type LEL sensor	Yes	Yes	No	No	No	Yes	No	Yes
NDIR combustible gas sensor	Yes	Yes	Yes	Yes*	Yes	No	Yes	No
PID (with standard 10.6 eV lamp)	No	Yes**	Yes**	Yes	Yes	No	No	No
Electrochemical H ₂ sensor	No	No	No	No	Yes	No	No	Yes
Thermal Conductivity Sensor	Yes	Yes	No	No	Yes***	No****	Yes	Yes

* Because of their logarithmic output curve, NDIR sensors show the most sensitivity at the lowest concentration of measured gas. An NDIR combustible gas sensor with 0.1% LEL resolution over 0 – 5% LEL provides 50 ppm step-change resolution for methane. Because the LEL concentration is so much lower, the same sensor would provide 11 ppm step change resolution for n-hexane.

** Although PIDs are able to detect a wide variety of VOC vapors, the ability of the PID to measure LEL range concentrations is limited by the full range of the PID. The 10% LEL concentration for most VOC gases ranges between 1,000 and 3,000 ppm. A PID with a full range of 2,000 ppm would only be able to detect maximum concentrations of 6% to 20% LEL, depending on the VOC being measured.

*** Only if the exact composition of the oxygen deficient atmosphere is known and the instrument is properly calibrated for use in this mixture.

**** TCD sensors that include a catalytic bead or operation mode are vulnerable to sensor poisons as long as the catalytic bead is under power.

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Table 2: Examples of possible sensor configurations optimized for specific applications*						
	Confined space monitoring for municipal, water and wastewater	Confined space monitoring for ship-yards	High range CH ₄ from "sour" (high H ₂ S) natural gas wells	Oil refinery confined space instrument	Instrument used to measure O ₂ and %LEL gas in inerted vessels	Landfill monitor
Type of hydrocarbon and / or VOC being measured	%LEL CH ₄ , O ₂ , CO and H ₂ S	Heavy fuel and VOC (diesel, bunker, JP-8, solvents), natural gas and H ₂	%LEL and high-range %Vol. CH ₄	%LEL C1 - C9 gases, ppm range VOC, %LEL H ₂ , CO and H ₂ S	%LEL C1 - C9 gases in low O ₂ atmosphere, ppm range VOC, CO and H ₂ S	%LEL and high-range %Vol. CH ₄ and O ₂
Standard catalytic (pellistor) type LEL sensor	Yes	No	No	Yes	No	No
NDIR combustible gas sensor	No	Yes	Yes	No	Yes	Yes
PID (with standard 10.6eV lamp)	No	Yes	No	Yes	No	No
Electrochemical H ₂ sensor	No	No	No	No	No	No
Electrochemical CO sensor	Yes	Yes	No	Yes	Yes	Yes
Electrochemical H ₂ S sensor	Yes	Yes	Yes	Yes	Yes	Yes
O ₂ sensor	Yes	Yes	Yes	Yes	Yes	Yes

* The listed sensor configurations only represent one possible solution for a specific application. The presence of additional conditions or requirements may completely change the optimal sensor configuration.

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Understanding ammonia sensors and their applications

Different types of ammonia sensors are optimized for use in specific applications. The key to success is understanding the monitoring environment, and the specific benefits and limitations of the sensors selected.

According to the United States Geological Survey (USGS), America produces over 10 million metric tons of ammonia per year, making it one of the most common of all High Production Volume (HPV) industrial chemicals. Ammonia is commonly used in many industries, including petrochemical, pulp and paper, fertilizer and the oil industry to name but a few. Anhydrous ammonia (NH₃) is also very widely used as a coolant in large industrial refrigeration systems. In fact, the use of ammonia as a refrigerant (R717) has increased substantially over the past several years as a replacement for environmentally unfriendly chlorofluorocarbon refrigerants. While ammonia refrigeration has long been a standard in the food/beverage industry, it is also now found in pharmaceuticals production, in air-conditioning equipment for many public buildings and in electric power generation plants.

Ammonia is rightly regarded as a highly hazardous chemical. According to the EEA, the worst industrial accident of the last twenty years occurred on 21 September, 2001, when an ammonia / ammonium nitrate explosion at a fertilizer plant in Toulouse, France killed 30, and injured more than 2,000 workers and nearby residents. According to the government investigation, as horrific as the accident was, it could have been much worse if intervening buildings had not broken the force of the explosion, preventing the potential detonation of 20 more railroad tank cars full of anhydrous ammonia.

Smaller incidents are extremely common. A study published by the State of New York Department of Health¹ illustrates just how commonly these accidents occur. The report documents 107 serious ammonia spills that occurred in New York State between 1993 through 1998. Sixty-one people were seriously injured, and one person killed in the reported accidents. Forty-four percent of the injured persons were employees, 41% were members of the general public, and 15% were emergency responders. Seven of the nine injured emergency responders sustained serious chemical burns. Most of the releases occurred in food/beverage processing (29%) or at chemical/



Figure 1: Compact electrochemical ammonia sensors exhibit excellent linearity, are capable of low ppm range resolution, and are comparatively inexpensive.

metal/equipment manufacturing facilities (27%). Most of the accidents (101) occurred at fixed facilities; the other six releases were during transportation. Equipment failure caused 58% of the releases. More than 1,889 people were evacuated following these 107 ammonia releases.

Liquid anhydrous ammonia expands over 850 times when released to ambient air, and readily forms large vapor clouds. These clouds are normally lighter than air and tend to rise. However, liquid anhydrous ammonia may also form an aerosol consisting in part of small liquid droplets. As an aerosol, the droplets of ammonia are heavier than air and sink toward the ground. The sudden drop in temperature due to release of ammonia may also cause water vapor in the air to condense, forming a visible white cloud. Convective air currents due to the heavier than air cloud may carry the ammonia downwards as well. Therefore, when anhydrous ammonia is released to the air, it may rise and disperse as a gas, or it may travel along the ground as an aerosol or because it has trapped water vapor. In either case, the cloud may remain low instead of rising into the air.

¹A copy of "Ammonia Spills in New York State (1993-1998)" is available at the following link: <http://www.health.state.ny.us/nysdoh/enviro/hsees/ammonia.pdf>



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Figure 2: Compact electrochemical (EC) sensors are available for an increasing number of specific toxic gases. Ammonia sensors show very little response to interfering gases, are capable of low ppm range resolution, require very little power, and are comparatively inexpensive.

Ammonia is a highly toxic gas, and proper safety monitoring procedures and equipment must be in place at all times to avoid serious accidental injury or death. The most widely recognized exposure limits for ammonia are an eight-hour TWA (Time Weighted Average) of 25 ppm, with a 15-minute STEL (Short Term Exposure Limit) of 35 ppm. Ammonia is also corrosive to the skin, eyes, and lungs. Exposure to 300 ppm is immediately dangerous to life and health. Fortunately, ammonia has a low odor threshold (20 ppm) with good warning properties, so most people seek relief at much lower concentrations.

Besides its toxic properties, ammonia is also an explosively flammable gas, with a lower explosive limit (LEL) concentration of approximately 15% volume. Although ammonia vapor is not flammable at concentrations of less than 15%, it can easily explode or catch fire throughout its flammability range of 15% to 28% by volume. Ammonia contaminated with lubricating oil, however, can catch fire or explode at concentrations as low as 8%.

In Europe the installation of gas warning systems for ammonia refrigeration systems is required as part of EN 378, "Refrigerating Systems and Heat Pumps - Safety and Environmental Requirements". EN 378 explicitly requires the installation of fixed leak monitors in refrigeration and air-conditioning machinery rooms, as well as other areas where a sudden leak into an occupied space would cause a hazardous condition.

• **Ammonia sensor capabilities and limitations**

Almost anyone who has used ammonia sensors in refrigerated areas is aware of the limitations of the sensors. The environment is just plain tough on sensors. Temperatures can range from -40° (in some flash freezing operations) to +40° C (during defrost periods). Strong jets of water, steam and detergents used during wash-down procedures can potentially damage sensors and other system components. Interfering contaminants from propane powered forklifts, alcohol based disinfectants,

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or even the products being stored or manufactured can have an adverse affect on the performance of the sensors. Most importantly, different types of ammonia sensors have different limitations. The secret to choosing and installing a trouble free system is understanding the limitations of the sensors, and choosing the correct sensors for the locations and conditions in which they will be operated.

The four most commonly used types of fixed sensors used to detect ammonia vapor are (1) infrared, (2) chemisorption (frequently referred to as "MOS" sensors), (3) electrochemical, and (4) solid-state charge-carrier-injection (CI) sensors.

- **Infrared (IR) Sensors**

Non-dispersive infrared (NDIR) sensors measure gas as a function of the absorbance of infrared light. Molecules consist of atoms that are held together by chemical bonds. The bonds in a particular type of molecule (like ammonia) absorb energy at specific wavelengths. When a chemical bond absorbs infrared light it continues to vibrate at the same frequency, but with greater amplitude after the transfer of energy. In other words, molecules that are able to absorb energy at that wavelength are heated to a higher temperature than molecules that are not able to absorb light at that wavelength.

When infrared radiation passes through a sensing chamber containing a specific contaminant, the only wavelengths that are absorbed are the wavelengths that match the chemical bonds in that contaminant. The rest of the light is transmitted through the chamber without hindrance. Since most chemical compounds absorb at a number of different frequencies, IR absorbance can provide a "fingerprint" for use in identification of unknown contaminants. Alternatively, for some molecules it may be possible to find an absorbance peak at a specific wavelength that is not shared by other molecules likely to be present. In this case absorbance at a particular wavelength can be used to provide substance-specific measurement for a specific molecule. For instance, ammonia has a usable absorbance peak at a wavelength of about 1.53 microns (μm). Absorbance at this wavelength is proportional to the concentration of NH_3 present in the sensing chamber of the sensor. The absorbance is not linear per concentration unit, but is mathematically predictable and easily calculated by microprocessor equipped portable gas detectors.

Optical filters or "choppers" are used to limit the wavelengths of the infrared light passing through the sensing chamber to the specific frequencies at which absorbance by the target molecules occur. Some NDIR detectors use "thermopile" detectors to directly measure the amount of infrared light



Figure 3: Ammonia transmitters can be used as "stand-alone" systems that include local display of readings and alarm information, or linked together into larger multi-point arrays

absorbed at specific wavelengths. Other "photo-acoustic" infrared detectors use a microphone to measure pressure changes in the sensing chamber due to the absorbance of infrared light. In this case, the microphone is used to measure pressure changes in the sensing chamber due to the heating effects of the absorbance of infrared energy by the ammonia molecules.

The chief benefits of infrared sensors are high specificity of the sensor to ammonia, long term stability and reduced need for calibration adjustment. Infrared detectors have a wide dynamic range, and are not degraded or consumed by exposure to high concentrations of ammonia. The chief

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Figure 4: Permanently installed ammonia gas detection systems offer 24-hours a day alarm notification for hazardous atmosphere

limitations are the physical size of the detector assembly, the need to protect the detector against the potential effects of fluctuating temperature and humidity, and the substantially higher cost compared to other detector types.

- **Chemisorption (MOS) sensors**

Chemisorption sensors consist of a metal oxide semiconductor, such as tin dioxide (SnO_2) on a sintered alumina ceramic bead contained within a flame arrestor. In clean air the electrical conductivity is low. Oxidation of the measured gas on the sensing element increases conductivity. An electrical circuit is used to convert the change in conductivity to an output signal which corresponds to the gas concentration. Sensitivity to a particular gas is alterable by changing the temperature of the sensing element.

Chemisorption sensors are generally designed to respond to the widest possible range of toxic and flammable gases and vapors. The idea is to provide a “broad range” response to the presence of contaminants. MOS sensors are able to detect chlorofluorocarbon refrigerants as well as other contaminants

that are difficult to detect by other means, as well as ammonia, carbon monoxide, hydrogen, alcohols and many other gases and vapors. This non-specificity can be advantageous in situations where unknown toxic gases may be present, and a simple go/no go determination is sufficient. However, since the sensors are not specific to ammonia, this can lead to false alarms if the sensors are installed in environments subject to the presence of interfering contaminants. The chief benefits of chemisorption sensors are their long operational life and low cost. MOS sensors are by far the least expensive type of fixed ammonia sensor, and are not damaged or consumed by chronic exposure to ammonia. MOS sensors can be used to detect ammonia from concentrations as low as 30 ppm, all the way up to flammable range concentrations. However, because the output signal is highly non-linear, they need to be calibrated and adjusted for use in the desired range. Adjustment for use in high concentrations is at the expense of reduced accuracy and resolution at lower concentrations.

The chief limitations of chemisorption sensors are the difficulty in interpreting readings, the potential for false alarms and the effects of humidity on the sensor. As humidity increases, sensor output increases. As humidity decreases to very low levels, sensor output may fall to zero even in the presence of the contaminant being measured. The extremely low humidity seen in many refrigerated areas (especially flash freezers) may make it effectively impossible to use this type of sensor. In addition, the user must exercise caution in assumptions about other contaminants that may be present in the area being monitored. The best use for MOS sensors is as a “go / no go” alarm device which is adjusted for maximum accuracy near the hazardous condition or “take action” threshold, or for use in measuring refrigerant gases (such as Freons[®]) that are difficult (or more expensive) to detect by other means.

- **Electrochemical (EC) Sensors**

Substance-specific electrochemical sensors are available for many of the most common toxic gases. EC sensors are compact, require very little power, exhibit excellent linearity and repeatability, and are comparatively inexpensive. The detection technique is very straightforward in concept. Gas that enters the sensor undergoes an electrochemical reaction that causes a change in the electrical output of the sensor.

The difference in the electrical output is proportional to the amount of gas present. EC sensors are designed to minimize the effects of interfering contaminants, making the readings as specific as possible for the gas being measured.

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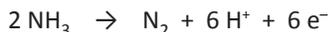
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In the case of ammonia sensors, the electrolyte includes an active ingredient that is consumed in the electrochemical reaction used to detect the ammonia. Thus, the lifespan of the sensor is directly related to its exposure to NH₃. The lifespan is generally listed in parts-per-million exposure hours (ppmh). For instance, a “17,520 ppm hour sensor” has a lifespan of one year when continuously exposed to a constant concentration of 2 ppm of ammonia, (2 ppm x 365 days x 24 hours = 17,520 ppm hours). The same sensor would last only six months if continuously exposed to 4 ppm, three months when exposed to 8 ppm, etc.

There are several variations on the specific electrochemical reaction used to detect ammonia. Some EC sensors depend on a straightforward oxidation reaction where ammonia (NH₃) is converted into nitrogen (N₂) and hydrogen “protons” (H⁺) at the sensing electrode. For every two molecules of ammonia that are oxidized, six electrons (e⁻) of electricity are also produced. This electrical current output is what is used by the instrument to determine the concentration of ammonia present.

The second half of the electrochemical reaction occurs at the “counter” electrode, where the hydrogen protons produced in the first half of the reaction react with oxygen to produce water.

Thus, at the sensing electrode:



At the counter electrode:



The sensor is filled with an organic gel electrolyte mixture in which the reaction occurs. Active ingredients in the electrolyte are incrementally used up as the sensor is exposed to ammonia. Once the “ppm hour” exposure life of the sensor is exceeded, it is no longer capable of detecting gas, and will need to be replaced. The positive benefits for this type of sensor include excellent low ppm range resolution, and excellent cold temperature performance down to -40° C.

In other sensors a patented “pH shift sensitive” set of electrochemical reactions is used to detect ammonia.

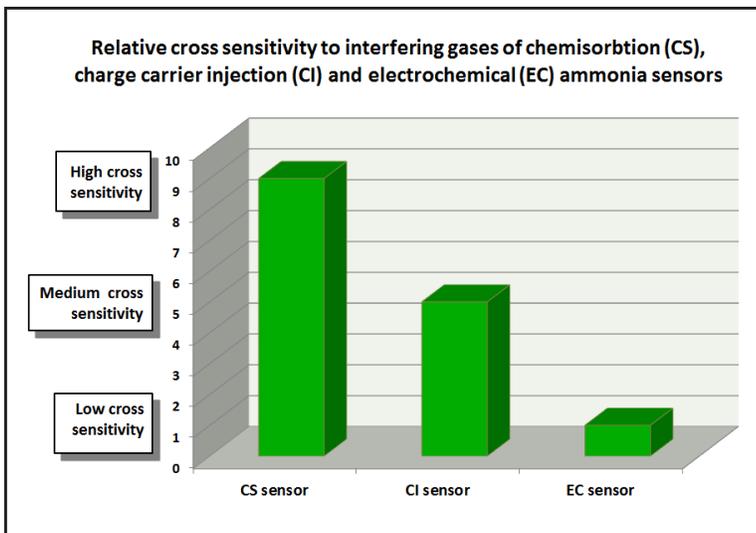


Figure 5: Chemisorption (CS) sensors are very cross sensitivity. Charge carrier injection (CI) are less cross sensitive. Electrochemical (EC) sensors show very low cross sensitivity to other gases.

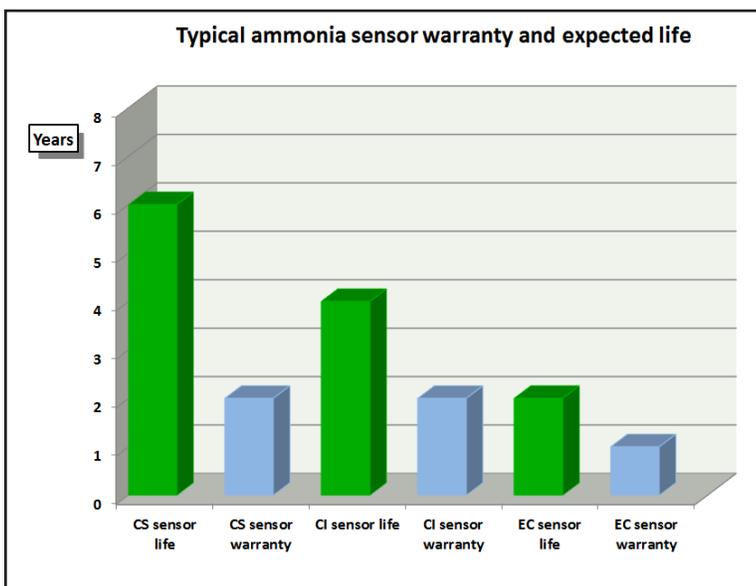


Figure 6: The operational life of ammonia sensors depends on the monitoring environment, but usually exceeds the warranty period. CS sensors can last up to 8 years or longer. CI sensors usually last 3 to 5 years. EC sensors generally last between 1 and 2 years.

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Once again, the electrical output of the sensor is proportional to the amount of ammonia oxidized at the sensing electrode. These sensors are based on a hydrous electrolyte system that, while slightly less able to withstand cold temperatures, provide extended measurement ranges of up to 5,000 ppm, with exposure life of up to 50,000 ppm hours.

Electrochemical ammonia sensors should be used only when the normal ambient background concentration of ammonia is sufficiently low to allow a reasonable operational life. For example, this type of sensor would not be recommended for use at a poultry farm or nitrate fertilizer plant where the routine ambient concentration of ammonia might be as high as 20 to 30 ppm. In this environment the life span of the sensor could be a matter of weeks. On the other hand, the high specificity to ammonia, and low cross sensitivity to other interfering contaminants that may be present (such as the carbon monoxide) makes these sensors the preferred approach in many environments.

- **Charge carrier injection (CI) sensors**

Charge carrier injection (CI) ammonia sensors are based on an entirely different detection principle. CI sensors depend on the adsorption of ammonia by “charge carrier” molecules in a solid state substrate. By absorbing ammonia the charge carriers are “injected” into the sensor element, causing a change in resistance that is proportional to the concentration of ammonia present.

The materials, morphology and layering of the substrate are all carefully selected to maximize the affinity of the sensor to ammonia while minimizing the effects of interfering contaminants. CI sensors are able to be used over an extremely wide detection range, from as low as 20 ppm concentrations to 10,000 ppm or higher. Because the sensing element is operated at an elevated temperature, the sensor functions as its own “heater”, and is an ideal candidate for operation in flash freezers and other environments subject to extreme cold (- 40 °C or colder) temperatures.

Most importantly, the sensor is not “consumed” or permanently altered by exposure to ammonia.

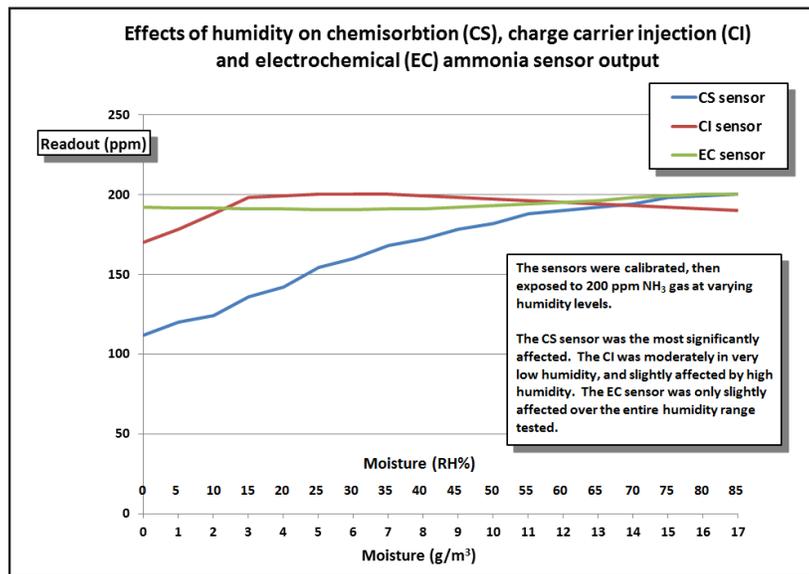


Figure 7: Chemisorption sensors are strongly affected by changes in humidity. CI sensors are modestly affected, but still work well in low humidity. EC ammonia sensors are largely unaffected by even major humidity changes, and work well even in extremely low humidity.

In the presence of ammonia the charge carriers are “injected” into the sensor element, while in fresh air the ammonia is desorbed. CI sensors are extremely stable, with operational life spans of five years or even longer. CI sensors are not affected by shifts in humidity, and offer excellent performance in the extreme low humidity associated with flash freezing operations.

While CI sensors have been designed to minimize the effects of interfering contaminants, they may still respond to volatile organic solvents (such as the limonene in citrus oil cleansers) and high concentrations of carbon monoxide due to engine exhaust. CI sensors are optimized for detection at higher concentration ranges, and should not be used for applications that require taking action at very low concentrations (less than 20 ppm).

No single type of ammonia sensor is perfect for all applications. The key to success is understanding the monitoring environment, and the specific benefits and limitations of the sensors selected.

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Choosing the best confined space gas detector

The “best” confined space gas detector doesn’t come from anyone manufacturer; it’s the instrument that best fulfills the requirements for your confined space program.

The ways in which gas detectors are used can vary widely between different confined space programs. The instrument that provides the best service and value for one program may not be the best choice for another.

Gas detection equipment manufacturers put a lot of emphasis on their confined space products. There are numerous models to pick from, with widely varying features, price points and capabilities. The perfect product for your program is “out there”. The key is understanding which features are the ones that are needed for the way you will be using the product, then choosing the design that best fulfills the requirements for your specific program.

Price should not be the sole determinant

Price is very important, however, the purchase decision should not be driven exclusively by price. The true price you pay for an instrument is not simply the initial purchase price; it is the cost-of-ownership over the life of the instrument. The initial purchase price is only one of a number of factors that should be considered. Remember to evaluate the cost of replacement components, (like batteries and sensors), the standard warranty coverage that comes with the instrument, cost of calibration stations and other calibration materials, cost of factory service, (if required), as well as the willingness of the manufacturer to stand behind the product if you experience a problem.

All of these factors can dramatically increase or reduce the true cost of purchasing and owning an instrument. Most importantly, make sure that the instrument includes the capabilities that are needed per your specific confined space procedures. An instrument with a low purchase price that does not include the capabilities that you need, or an expensive instrument with unneeded features or complexity are equally bad choices.

Which features and capabilities are the most important is a function of many factors including:

- The atmospheric hazards that need to be measured
- The monitoring environment in which the instrument will be used
- The sampling strategy
- The level of sophistication and training of the workers who will be using the instruments
- The requirements for record-keeping
- Other performance criteria specific to your program

The good news for instrument buyers is that whatever you paid the last time you purchased a confined space instrument; expect to pay less this time around.



Figure 1: Multi-sensor confined space instruments almost always include sensors for the measurement of O₂, combustable gas, CO and H₂S. Make sure the design supports any additional sensors that may be required, such as IR combustable gas, PID and other toxic gas sensors.



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Criteria for instrument selection:

1. Sensor selection

Make sure the instrument chosen for a specific application can accommodate the needed types and number of sensors.

The types of sensors selected should reflect the known and potential atmospheric hazards associated with the confined spaces to be monitored.

Most confined space instruments include an oxygen sensor, a catalytic (pellistor) sensor for the measurement of percent LEL combustible gas, and one or two electrochemical sensors for detecting specific toxic gases. An increasing number of detectors additionally include a photoionization detector (PID) for “broad-range” toxic gas measurement. Some specialized instruments include infra-red (NDIR) sensors for direct measurement of carbon dioxide or percent volume methane. The number of possible sensor configurations is very large.



Figure 2: Portable confined space instruments can measure up to seven atmospheric hazards at the same time. Besides standard O₂, LEL, CO and H₂S sensors, the instrument can be equipped with IR combustible gas, PID, IR CO₂, and a wide variety of substance-specific electrochemical toxic gas sensors.

Before deciding on the sensors to include, make sure you know what you need to measure. If the confined space to be monitored is characterized by the known or potential presence of a specific toxic contaminant, the best and safest approach is a substance-specific sensor. Substance-specific sensors are available for a wide range of contaminants including hydrogen sulfide, carbon monoxide, ammonia, chlorine, sulfur dioxide, nitrogen dioxide, phosphine, cyanide, and many others.

Make sure that the sensors and programming used in the instrument permit you to set the alarms at the necessary levels. For instance, if your CS program requires taking action at the 2011 TLV[®] exposure limit for H₂S of 1.0 ppm, the instrument will need to be able to provide readings in sub parts-per-million-increments.

If you need to measure low parts-per-million concentrations of volatile organic compounds (VOCs) such as solvents, gasoline or diesel vapor, you might consider an instrument that includes a PID. If all you need to measure is combustible range concentrations of methane or natural gas, however, a simple catalytic percent LEL (lower explosive limit) sensor may be all that is required.

Some instruments are designed for use exclusively with a limited set of the most commonly specified sensors (typically LEL, O₂, H₂S and CO). Instruments with a limited selection of sensors frequently carry the lowest initial purchase price. They are perfect for many applications where these are the only hazards that will ever need to be measured.

If requirements change, however, you may be left with an unusable product. If you suspect that requirements may change, field configurability is highly desirable. Adding an additional sensor is not difficult, as long as the design gives you the option.

Most importantly, if you are unsure of what hazards are potentially present, it's time to conduct whatever additional hazard assessment is necessary to nail this down before you purchase those new instruments.

2. Sample-draw versus diffusion

In normal operation, most confined space instruments are worn on the belt, used with a shoulder strap or chest harness, or held by hand. Once turned on, the instrument operates continuously until the battery is exhausted.

Diffusion instruments utilize natural air currents to bring the atmosphere being sampled to the instrument. “Pumped” instruments mechanically draw the atmosphere being

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monitored into the instrument. The air may be drawn directly into an inlet port on the instrument, or ducted through a length of sample tubing from a remote location.

Pumped instruments may include a built-in (internally housed) motorized pump or an “attachable” motorized pump that is physically secured to the instrument. “Attachable” pump designs permit users to remove the pump and operate the instrument in diffusion mode when a sample pump is not required. Some pumps operate continuously whenever the instrument is turned on. Other designs include a slide switch or “shutter” that allows the instrument to be operated in either “diffusion” or “sample-draw” mode simply by sliding the switch into the correct position.

Each configuration has both advantages and disadvantages. If you purchase a diffusion instrument, make sure to include a sample-draw kit to use during pre-entry or remote sampling procedures. Availability of such a kit should be an important consideration when purchasing an instrument.

3. Classification for intrinsic safety

Devices classified as “Intrinsically Safe” prevent explosions in hazardous locations by employing electrical designs that eliminate the possibility of ignition. The classification for intrinsic safety carried by the instrument references the severity of the explosive hazard of the flammable atmosphere in which the instrument was tested. For example, many confined space instruments sold in North America are “Classified as Intrinsically Safe for use in Class I, Division 1, Groups A, B, C, and D Hazardous Locations.”

This means that the testing included evaluation for use in “Group A” atmospheres containing an explosive mixture of acetylene. “Group B” atmospheres contain hydrogen or gases or vapors of equivalent hazard. “Group C” includes gases such as ethylene, while “Group D” includes methane and natural gas, or gases of similar explosive hazard. Some confined space instruments also carry a classification for use in Class II, Groups E, F, and G Hazardous Locations. These Class II Groups refer to



Figure 3: In diffusion operation the atmosphere reaches the sensors by diffusing through openings in the instrument housing. The openings are protected by moisture barrier filters. “Attachable” motorized pumps are physically secured to the instrument. A shutter switch permits operation of the in either “diffusion” or “sample-draw” mode.

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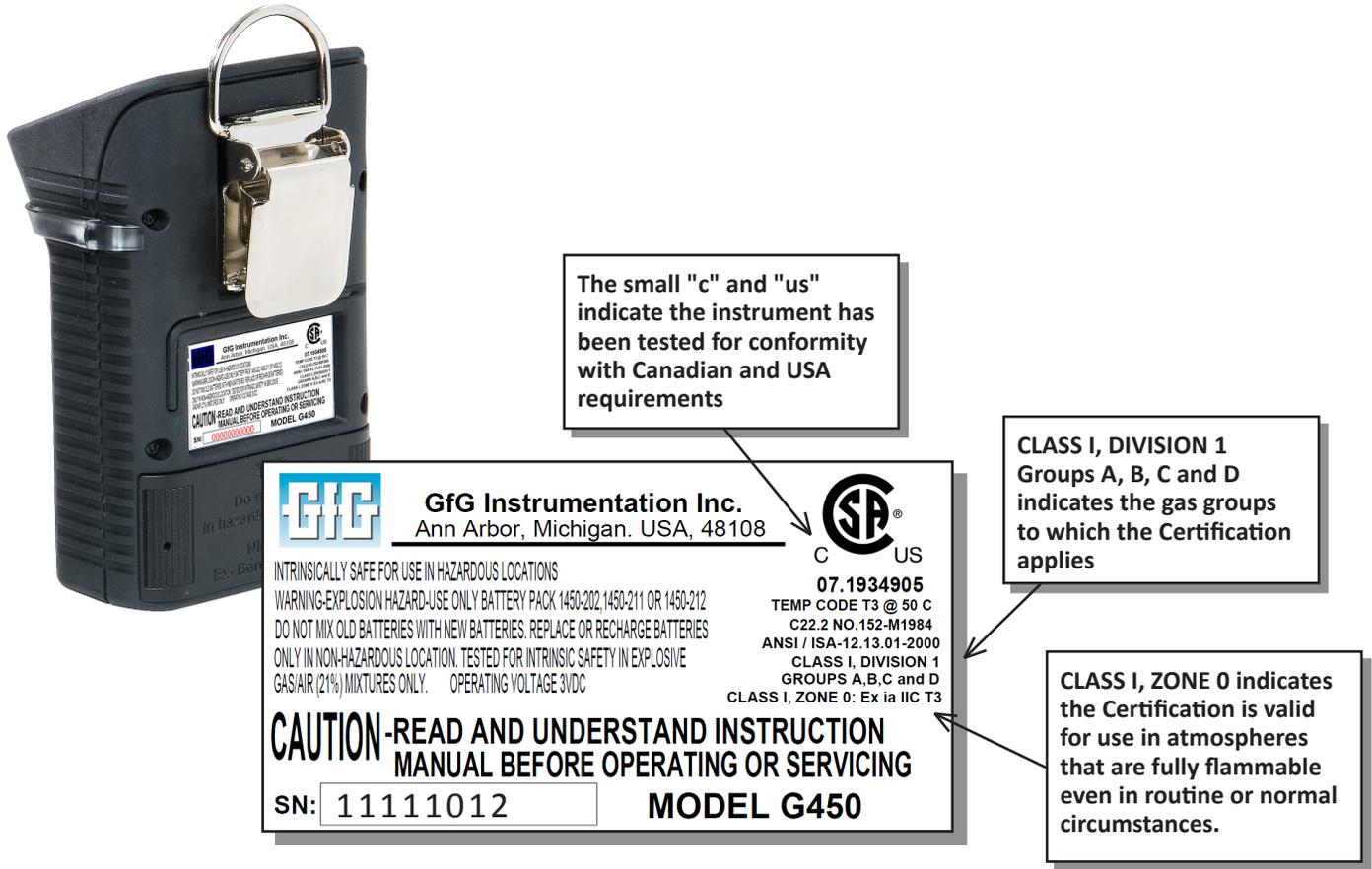


Figure 4: The instrument label includes Certifications and Markings carried by the product. Space on the label is limited! Consult the owners manual for a complete description of all the Certifications, Classifications, Listings and Markings carried by the product.

combustible or “explosible” dusts. Instruments used in some applications (such as grain silos) may be required to carry this additional classification.

Many instruments sold in North America additionally carry IEC Ex or ATEX Certification for Intrinsic Safety. European and harmonized international IEC Ex certifications are based on a slightly different classification scheme for explosively hazardous atmospheres that is based on Zones, Gas Groups and Temperature Codes. The string of letters and numbers that define the scope of the “Ex” Certification provides a great deal of information. It’s worth spending a little time to verify exactly what the certification covers.

The instrument label should carry the logo or “Mark” of the testing laboratory that conducted the evaluation (such as UL®, CSA®, FM®, EXAM®, DEMKO®, KEMA® etc.) as well as the hazardous atmospheres and temperatures for which the Classification or Certification applies.

The evaluation methods used to determine Intrinsic Safety may vary between different test standards. For instance, a small “us” next to the testing laboratory logo indicates that the instrument has been tested for conformity with the United States National Electric Code (NEC) requirements contained in Underwriters Laboratories® UL-913, “Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, III, Division 1, Hazardous (Classified) Locations”. A small “c” next to the logo indicates that the instrument has been tested for conformity with Canadian requirements. Canadian Standards Association C22.2 No. 152-M1984 (R2001), “Combustible Gas Detection” covers the construction, performance and test procedures for portable instruments used to detect or measure combustible gases in hazardous locations characterized by the presence (or potential presence) of combustible gas. CSA 22.2 includes rigorous performance testing of the combustible sensor that may or may not be included in instruments that do not carry the small “c” in their Classification Mark.

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Figure 5: The availability of interchangeable rechargeable and alkaline battery packs is a strong design advantage.

4. Batteries

Confined space instruments may be designed to use only disposable alkaline batteries, rechargeable batteries, or may be able to use both types. The primary advantage of rechargeable batteries is overall cost effectiveness. Frequent (or daily) replacement of disposable batteries can be very expensive, and is increasingly viewed as environmentally objectionable. On the other hand, while alkaline batteries may not be the most cost effective approach, having the ability to use them “in a pinch” is a strong design advantage. Some instrument designs offer interchangeable rechargeable and alkaline battery packs. Other designs allow the optional use of either alkaline or “off the shelf” rechargeable batteries.

Different designs utilize different rechargeable battery technologies. Commonly used types of rechargeable batteries include nickel cadmium (NiCad), nickel metal hydride (NiMH), lithium ion (Li-ion) and lithium polymer batteries. Each type of rechargeable battery has its specific advantages and limitations. The weight of the instrument, run time, time to recharge the battery and the number of charging cycles that the battery can survive without loss of capacity are all affected by the type of battery included in the design. Less obviously, the temperature code and operating ambient temperature range over which the IS classification applies are also affected (or limited) by the type of batteries used in the design.



Figure 6: “Smart” charging cradles include a “trickle charging mode” that prevents damage to the battery pack once charging is complete

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Figure 7: Confined space instruments should be easy to use, ergonomically well designed, and feel as if they can handle rough usage.

Battery manufacturers, as well as manufacturers of battery charging systems have made major improvements in design over the last few years. Today's "smart" battery chargers contain electronics for assessing the condition of the battery pack during charging, and to drop from a "fast" charge rate to a "trickle" the moment charging is complete. The "trickle" charging rate is too low to produce damage or loss of capacity due to heating. As result, instruments containing rechargeable batteries can be recharged in a very short period of time, while still being left on the charger for long periods of time without damage.

While rechargeable Nickel metal hydride batteries may be left on the charger for prolonged periods of time without damage, they still benefit from periodically being deep-discharged, and most instruments that include this type of battery also include an automatic deep discharge cycle.

5. Durability

Confined space instruments have to be durable. Unfortunately, many designs are less robust than they may appear on the surface. Consider asking the following questions:

- Is the instrument designed to minimize the effects of radio frequency interference (RFI) and electromagnetic interference (EMI)?
- What are the effects of high and low temperatures on the design?
- How water resistant is the design? Ask the manufacturer to document the "IP" (ingress protection) rating of the product. The IP rating is composed of two numbers; the first refers to protection against solid or particulate objects, and the second against liquids. The higher the number, the better the protection.
- Does the instrument feel flimsy or provide unstable readings when picked up and turned on? Don't underestimate the amount of information the "feel" of an instrument can sometimes provide.

Confined space instruments should be ergonomically well designed, and feel as if they can handle rough usage.

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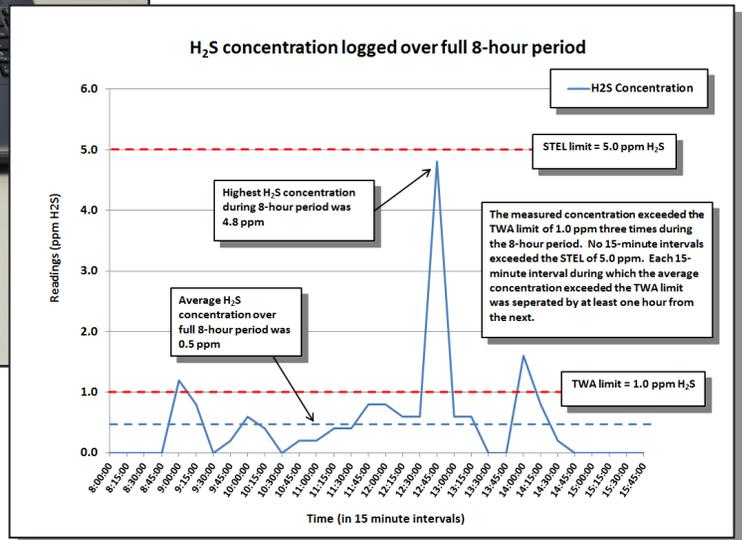
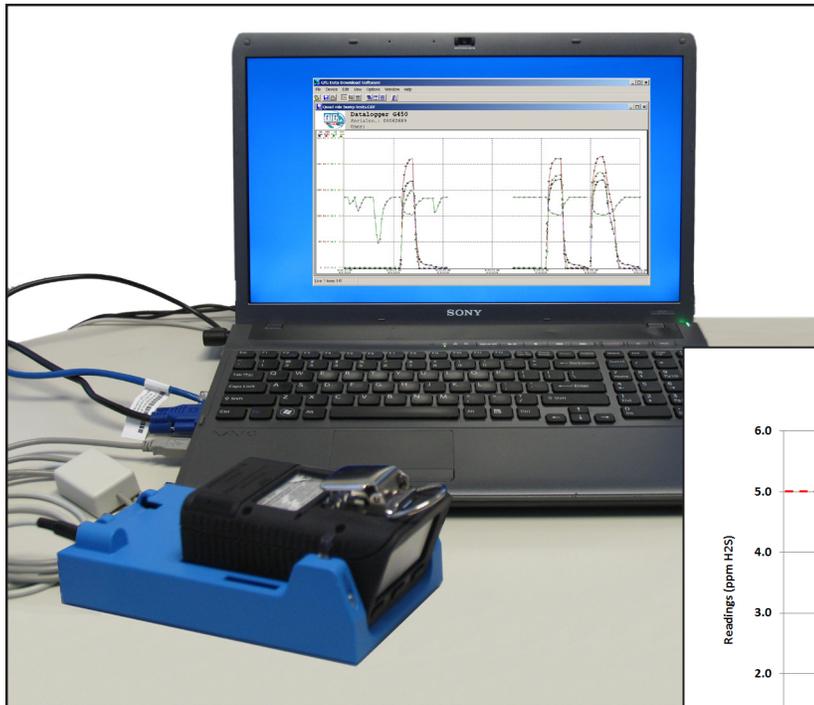


Figure 8: Datalogging instruments automatically record moment by moment measurements, as well as any exposure “events” that trigger the instrument alarms. They also provide a record in the event of an accident.

6. Datalogging versus non-datalogging

Datalogging is an available option or a standard feature with most confined space instruments. Datalogging instruments are usually set up to retain monitoring information whenever turned on. The utility of this information for compliance and record-keeping purposes is obvious. In the event of an accident or unusual occurrence, datalogging instruments are also useful as “black box” recorders of the conditions at the time of the event. The capability to provide documentation of proper use can significantly reduce liability exposure, and in the long run save much more than the cost of including datalogging in the instrument at the time of purchase.

In the past, successfully downloading datalogged information from the instrument to a computer sometimes required a high degree of operational expertise. Today the procedure is nearly automatic.

7. Included accessories

Be sure to verify what accessories are included in the purchase price for the instrument. If the instrument includes a rechargeable battery, does the price include a battery charger? Do the accessories include a sample draw kit or motorized pump? Carrying case? Training video? Calibration materials? Necessary accessories that are not included in the purchase price can considerably add to cost and user frustration.

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Figure 9: Visual LED alarm indicators should be visible from any direction (360°)

8. Warranty

A high quality instrument should carry an excellent warranty. The most expensive replaceable components in the instrument design are usually the sensors, (rechargeable battery packs come in as a close second). You should not have to spend extra money for an “extended” warranty to cover replacement of these components. Most manufacturers now offer a “limited lifetime warranty” on the parts of the instrument that are not consumed or degraded in normal operation, with a two-year or three year-warranty on the most commonly used types of sensors. If you decide to buy an “extended service agreement”, make sure that you factor this in when you calculate the true “cost-of-ownership” over the life of the instrument.

9. Operability

Probably the most important factor of all in the selection of an instrument is ease-of-operation. If the person on the shop floor is unable to use the instrument because of unnecessary complexity, difficulty in calibration or operation – they won’t.

10. Instrument performance specifications

Performance specifications published by manufacturers are a valuable tool for purchasers. Unfortunately, it sometimes takes a practiced eye to interpret specifications when

comparing one instrument design to another. A significant problem is the terminology used by manufacturers to explain the performance of their products. While some terms are straightforward and have a uniform meaning throughout the industry, other terms have specific meanings to a particular manufacturer. Conservative firms often minimize performance capabilities in written specifications, preferring to err on the side of caution. Less conservative manufacturers may use the “best case” or optimal performance to define the capabilities of their products. The best advice is to conduct a field trial prior to purchase! There is no substitute for hands-on experience.

11. Alarms

Alarms should be loud, highly visible, and sufficient to grab the attention of the instrument user. Besides audible buzzers, flashing lights, numerical readings and explanatory messages, many confined space instruments additionally include built-in vibrator alarms for use in high noise areas.



Figure 10: Automatic “docking stations” make calibration and record keeping completely automatic

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12. Calibration

Calibration should be simple and straightforward. Given the requirement for documentation, the capability of instruments to log or automatically retain calibration information is highly desirable. Most datalogging confined space instruments automatically update and store dates and other calibration information. This is one more reason to select a datalogging design.

Most manufacturers now offer automatic calibration or “docking” stations that can automatically calibrate, recharge and store instrument calibration records. The availability – and price point – of automatic calibration stations can have a significant effect on both the usability as well as cost-of-ownership of the instrument over the life of the product. Make sure to find out about the availability – and cost – of calibration and docking stations before rather than after you purchase the equipment.

13. Evaluate before purchase

No matter what performance criteria you decide on beforehand, nothing replaces actually trying out the instrument in the field. Most leading instrument manufacturers, or their distributors, have evaluation instruments available for this purpose. But even if you have to rent an instrument, you will be better off in the long run if you try it out under circumstances similar to the ones in which it will be actually used prior to purchase. The best instrument in the world is the one that’s the best for your own individual conditions of use.

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AP1004:

Using LEL sensors for compliance with the ACGIH® C1-C4 Aliphatic Hydrocarbon (methane, ethane, propane and butane) TLV®



The ACGIH® TLV® for C1-C4 Aliphatic Hydrocarbons (methane, ethane, propane and butane) specifies an exposure limit of 1,000 ppm as an 8-hour TWA.

Customarily, manufacturers and instrument users set the instantaneous low alarm at the TWA limit concentration. This is very easy to do with the GfG G450.

All you need to do is calibrate with methane, set the correction factor to pentane, and set the alarm at 4% LEL.

LEL combustible sensors have a higher relative response to methane than to the other three gases (ethane, propane and butane). That means if you set the hazardous condition threshold alarm at 1,000 ppm methane, the alarm will be activated before you reach the 1,000 ppm limit for the other three gases. Since these gases are frequently encountered as mixtures, with varying concentrations of the constituent gases; setting the alarms conservatively at the methane concentration limit makes good sense.

One thousand ppm methane = 2% LEL methane. While it may be possible to set the LEL alarm in an instrument that has been calibrated to a methane level of sensitivity at 2% LEL, it is not recommended. It is better to set the alarm at a slightly higher concentration. That way the instrument has more “step changes” in readings over which to resolve the measured concentration.

The relative response of the instrument to pentane is 50% (= 0.5) compared to the response to methane. So, when the instrument is calibrated to a pentane level of sensitivity, or when you pick “pentane” from the list of combustible correction factors in the instrument’s on-board library; 1,000

ppm methane (= 2% LEL) produces a reading of 2,000 ppm (= 4% LEL) when the instrument is operated on the pentane scale.

GfG G450 and G460 instruments display LEL readings in 0.5% LEL increments over a full range of 0 – 100% LEL. On the pentane scale, each 0.5% LEL increment = 125 ppm methane. That’s way below 1,000 ppm! Because the instrument has eight 0.5% LEL “step changes” between 0% LEL and 4% LEL, the instrument is able to provide a very solid and dependable reading at this alarm limit concentration.

This approach simplifies or eliminates concerns about which of the four gases, or what mixture of these gases, is causing the alarm. Setting the correction factor to pentane, and the LEL alarm to 4% LEL ensures that whatever gas or mixture of C1 – C4 gases is present, the LEL alarm will be activated at or below the TWA limit concentration. With this setting not only will the alarm go off at 1,000 ppm for methane, the alarm will go off before you reach 1,000 ppm for ethane, propane and butane.



Figure 1: : Calibrating catalytic G450 / G460 LEL sensors to a pentane level of sensitivity and setting the alarm at 4% LEL ensures that the alarm will be activated at the 1,000 ppm TLV® exposure limit for CH₄.



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The following chart helps to explain how this works:

Flammability Ranges and Toxic Exposure Limits for C1 – C5 Alkanes							
Gas	Response of sensor (calibrated to CH ₄) when exposed to 1% LEL of listed gas	Response of sensor (calibrated to C ₅ H ₁₂) when exposed to 1% LEL of listed gas	LEL (%VOL)	TLV® (8 hr. TWA)		LEL reading of pentane calibrated instrument when exposed to TLV® concentration of gas	True ppm concentration of listed gas when alarm activated at 4% LEL (pentane scale)
				in ppm	in % LEL		
Methane	1.0	2.0	5	1000 ppm	2 %	4.0 %	1000 ppm methane
Ethane	0.75	1.5	3	1000 ppm	3.34 %	5.0 %	850 ppm ethane
Propane	0.65	1.3	2.1	1000 ppm	4.76 %	6.2 %	670 ppm propane
Butane	0.6	1.2	1.8	1000 ppm	5.56 %	6.7 %	595 ppm butane
Pentane	0.5	1.0	1.5	600 ppm	4 %	4.0 %	600 ppm pentane

The last two columns in the chart are the most important. What the chart shows is that when the instrument is set to the pentane scale, a concentration of 1,000 ppm methane produces a reading of 4% LEL. A concentration of 1,000 ppm ethane produces a reading of 5% LEL. A concentration of 1,000 ppm propane produces a reading of 6.2% LEL; while a concentration of 1,000 ppm butane produces a reading of 6.7% LEL.

Another way of looking at the same issue is to calculate the ppm concentration necessary to activate the alarm when it is set to 4% LEL pentane. As can be seen from the values in the last column, while it would take 1,000 ppm methane to activate the alarm, it would only take 850 ppm ethane, 670 ppm propane, or 595 ppm butane to activate the alarm.

If you set the instrument to the pentane scale, and set the alarm to 4% LEL, the alarm will always be activated at or below the TLV® limit for these four gases (or any combination of these four gases). As an added bonus, the alarm will also be activated at the TLV® limit for pentane.

Important note: The relative response values listed above are the values the manufacturer has established for the LEL sensors used in GfG instruments. While the relative response values for LEL sensors are usually quite similar between different brands of instruments; they may not match exactly. Alarm settings and take action criteria should always be based on the relative response values supplied by the manufacturer of the instrument used to obtain readings.

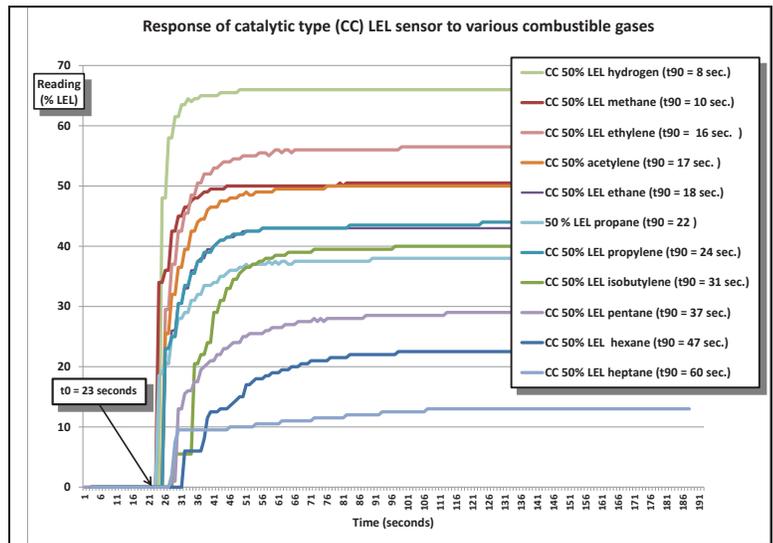


Figure 2: Catalytic pellistor LEL combustible gas sensor response curves. The smallest molecules (CH₄ and H₂) have the highest relative responses. The largest detectable hydrocarbon molecules (octane and nonane) have the lowest relative responses. The larger the molecule, the slower the response as well.

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AP1005:

GfG Instrumentation, Inc. Functional (Bump) Check and Calibration Statement for Canadian instrument users

February 11, 2013

The calibration of the sensors as well as the proper performance of the audible and visual alarms must be tested by performing a functional (bump) test by exposure to known concentration test gas before each day's use.

Readings of the combustible sensor must be within minus zero to plus 20% of the concentration of combustible gas applied. If 50% LEL test gas is used readings must be no lower than 50% LEL and no higher than 60% LEL.

Readings of the CO and H₂S sensors should be within plus or minus 10% of the concentration of gas applied.

The oxygen sensor should be exposed to a concentration of oxygen low enough to activate the oxygen deficiency alarm. Readings should recover to normal fresh air values of 20.9% within 30 seconds.

Any incidents or exposure to contaminants that might adversely affect calibration should trigger a functional (bump) test before further use.

A full calibration should be performed any time the instrument fails a functional (bump) test before further use.

Even if the instrument passes all functional (bump) tests successfully; a full calibration should be performed at least once every six months.

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AP1006:

GfG Instrumentation, Inc. Functional (Bump) Check and Calibration Statement for USA instrument users

February 11, 2013

Calibration of the sensors as well as the proper performance of the audible and visual alarms should be verified by performing a functional (bump) test by exposure to known concentration test gas before each day's use.

Readings of the combustible, carbon monoxide and hydrogen sulfide sensor should be within plus or minus 10% of the concentration of gas applied.

The oxygen sensor should be exposed to a concentration of oxygen low enough to activate the oxygen deficiency alarm. Readings should recover to normal fresh air values of 20.9% within 30 seconds.

OSHA has provided an instructional letter which explains conditions and methods that may be used to lengthen the interval between functional (bump) tests. According to this OSHA guidance the interval should not be lengthened beyond once every 30 days. The letter is available at the following link: <http://www.osha.gov/dts/shib/shib050404.html>

Any incidents or exposure to contaminants that might adversely affect calibration should trigger a functional (bump) test before further use.

A full calibration should be performed any time the instrument fails a functional (bump) test before further use.

Even if the instrument passes all functional (bump) tests successfully; a full calibration should be performed at least once every six months.

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AP 1007:

Calibration Requirements for Direct Reading Confined Space Gas Detectors



Manufacturers and regulatory agencies agree the safest and most conservative approach is to perform a functional test by exposing your gas detector to test gas before each day's use.

Oxygen deficiencies, explosive atmospheres, and exposure to toxic gases and vapors injure hundreds of workers every year. The atmospheric conditions that lead to these accidents and fatalities are usually invisible to the workers who are involved. The only way to ensure atmospheric conditions are safe is to use an atmospheric monitor. The only way to know whether an instrument is capable of proper performance is to expose it to test gas. Exposing the instrument to known concentration test gas verifies that gas is properly able to reach and be detected by the sensors. It verifies the proper performance of the instrument's alarms, and (if the instrument is equipped with a real-time display), that the readings are accurate. Failure to periodically test and document the performance of your atmospheric monitors can leave you open to regulatory citations or fines, as well as increased liability exposure in the event that a worker is injured in an accident.

There has never been a consensus among manufacturers regarding how frequently direct reading portable gas detectors need to be calibrated. However, manufacturers do agree that the safest and most conservative approach is to verify the performance of the instrument by exposing it to known concentration test gas before each day's use. This functional "bump test" is very simple and takes only a few seconds to accomplish. It is not necessary to make a calibration adjustment unless the readings are found to be inaccurate. The regulatory standards that govern confined space entry and other activities that include the use of direct reading instruments are in agreement with this approach.

However, the definition of "bump test" has always been a little slippery. Some manufacturers differentiate between a "bump test" that provides a more qualitative evaluation of the instrument's ability to detect gas and a "calibration check" that verifies that the response of the sensor(s) when exposed to known concentration test gas are within the manufacturer's requirements for accuracy. All manufacturers agree that instruments that fail either a "bump test" or "calibration check" should be put through a "full calibration" before further use.

ISEA Statement on Validation of Operation for Direct Reading Portable Gas Monitors

The International Safety Equipment Association (ISEA) is the leading international organization of manufacturers of safety and health equipment, including environmental monitoring instruments. The ISEA is dedicated to protecting the health and safety of workers through the development of workplace



Figure 1: Performing a functional "bump test" by exposing the instrument to known concentration test gas takes only a few moments perform.



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standards and the education of users on safe work practices and exposure prevention. In 2002 the ISEA (then known as the Industrial Safety Equipment Association) published a protocol to clarify the minimum conditions for lengthening the interval between calibration checks for direct reading portable gas monitors used in confined spaces.

The protocol was designed to reemphasize to OSHA and other standards writing bodies the importance of verifying the calibration of instruments used to monitor the atmosphere in potentially hazardous locations, to clarify the differences between a functional (bump) test and a full calibration, to clarify the circumstances when daily bump tests are needed and when less frequent tests may be appropriate. The protocol applied to all of the sensors installed in the confined space gas detector, not just the combustible sensor. The original ISEA protocol has been widely adopted by the gas detection equipment manufacturing community, even by manufacturers who are not members of the Association. In March 2010 the ISEA released a revised version of the statement to extend it to all direct reading portable atmospheric monitors, and to provide additional guidance concerning the definitions of “bump test”, “calibration check”, and “full calibration”; and to expand the list of conditions and circumstances that should trigger a re-verification of the instrument’s performance before further use.

What causes an instrument to lose accuracy?

Single-sensor instruments are designed to focus on a single toxic contaminant or hazardous condition (such as H₂S or O₂ deficiency), or the presence of a class of atmospheric hazard (such as the presence of combustible gas). “Zero maintenance” single-sensor instruments may or may not include a meter for the display or real time readings, and they may or may not be capable of calibration adjustment while exposed to test gas. Confined space and other types of multi-sensor instruments include several different types of sensors. The type of sensors installed depends on the specific monitoring application.

The atmosphere in which the instrument is used can have profound effect on the sensors. Each type of sensor uses a slightly different detection principle. Sensors may be poisoned or suffer degraded performance if exposed to certain substances. The kinds of conditions that affect the accuracy of sensors vary from one type of sensor to the next.

While the electrochemical sensors used to measure toxic gases like carbon monoxide and hydrogen sulfide are not worn out or consumed by exposure to CO or H₂S, they still eventually need to be replaced when they are no longer able to detect gas. Although CO and H₂S sensors may last for years without



Figure 2: The only way to know whether an instrument is capable of proper performance is to expose it to test gas.

significant loss of sensitivity, the loss of sensitivity at the end of life may be sudden. Incidental exposure to other substances may also reduce sensitivity. For instance, many electrochemical sensors can be permanently affected by exposure to organic solvents and alcohols. Exposure to methanol is well known to affect the performance of CO and H₂S sensors.

The most commonly used “fuel cell” oxygen sensors consume themselves over the use-life of the sensor, and will eventually need to be replaced. Defective or malfunctioning O₂ sensors may need to be replaced sooner. Oxygen sensors near the end of their use-life may develop other types of performance problems, such as abnormally slow response. For these reasons performing a daily bump test on oxygen sensors is particularly important.

Combustible sensors are prone to damage due to exposure to poisons or substances that inhibit the sensor’s response to combustible gas. Combustible sensors may be affected by exposure to silicone containing substances, chlorinated solvents, sulfides (including H₂S), or even exposure to high concentrations of combustible gas. Sensors may also suffer

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loss of sensitivity due to aging or desiccation, mechanical damage due to dropping or immersion, or loss of sensitivity due to other causes.

Even if a sensor is internally healthy, if gas is not capable of reaching and diffusing into the sensor because of blockage or leakage in the pump or sampling system, or because the external filter has become clogged or contaminated, the sensor cannot properly respond. Thus even "zero maintenance" single-sensor instruments should be periodically exposed to gas to ensure that the instrument is capable of proper response. Even if the sensor response and readings are correct, if the alarms are not properly activated, or if the instrument fails to operate properly in other ways when exposed to gas, the instrument must be serviced to restore proper function before it can be used.

What do the regulations say?

OSHA 1910.146 "permit-required confined spaces" paragraph (c)(5)(ii)(C) explicitly states (in part) that, "Before an employee enters the space, the internal atmosphere shall be tested, with a calibrated direct-reading instrument". OSHA Compliance Directive CPL 2.100, "Application of the Permit-Required Confined Spaces (PRCS) Standards, 29 CFR 1910.146" explains what is meant by "calibrated":

"A testing instrument calibrated in accordance with the manufacturer's recommendations meets this requirement. The best way for an employer to verify calibration is through documentation."

In other words, instrument users are held accountable to calibrating and / or testing the performance of their instruments in accordance with the manufacturer's instruction manual. OSHA expects instrument users to be able to document that their procedures match the requirements listed. The instructions, cautions and warnings listed in the owner's manual are governed not by OSHA, but by the standards to which the instrument is Classified, Listed or Marked by Nationally Recognized Testing Laboratories such as Underwriters Laboratories® or the Canadian Standards Association® (CSA®).

Instruments used in environments characterized by the potential presence of flammable or explosive gases usually carry a classification for intrinsic safety. Devices classified as "Intrinsically Safe" prevent explosions in hazardous locations by employing electrical designs that eliminate the possibility of ignition. Classification for intrinsic safety is based on performance of the instrument when tested in a specific flammable atmosphere. The instrument should carry the logo of the testing laboratory that conducted the evaluation, as

well as the specific hazardous location groups for which the classification applies.

Most manufacturers whose confined space instruments are sold in North America have submitted their designs for testing in accordance with both United States and Canadian performance criteria. A small "c" included in the classification mark indicates compliance with Canadian performance criteria.

Canadian Standards Association C22.2 NO. 152-M1984 (R2001), "Combustible Gas Detection" is the CSA standard that covers the details of construction, performance, and test procedures for portable instruments used to detect or measure combustible gases in hazardous locations characterized by the known or potential presence of combustible gas. Section 5.3, "Instruction Manual" lists the minimum information and warnings that must be included in the owner's manual of gas detectors that are compliant with this standard. Paragraph (k) requires that the manual include the following statement:

CAUTION: BEFORE EACH DAY'S USAGE SENSITIVITY MUST BE TESTED ON A KNOWN CONCENTRATION OF _____ (SPECIFY GAS) EQUIVALENT TO 25-50% OF FULL SCALE CONCENTRATION. ACCURACY MUST BE WITHIN -0+20% OF ACTUAL.



Figure 3: Automatic "Bump Test" stations are compact, automatic, cost effective, and very easy to use.

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In other words, to comply with Canadian requirements, the performance of the combustible sensor must be verified by exposure to known concentration combustible gas before each day's use. The manufacturer is free to specify the type and concentration of combustible gas to be used, and is free to specify a tighter performance tolerance if desired. The standard does not require that the instrument be adjusted before each day's use, only that it is found to be capable of detecting combustible gas according to the tolerances listed in the instruction manual. The standard is mute regarding the verification of performance of other types of sensors that may be included in the instrument. The only requirements are for the verification of performance of the combustible sensor.

Instrument users who operate and maintain their instruments in accordance with USA rather than Canadian requirements have more latitude in determining the interval between calibration checks.

Validation of operability

The complete text of the International Safety Equipment Association (ISEA) Statement on Validation of Operation for Direct Reading Portable Gas Monitors can be downloaded from the ISEA website at the following link: http://www.safetyequipment.org/userfiles/File/calibration_statement-2010-Mar4.pdf

The latest version of the ISEA statement applies to all types of direct reading portable gas detectors, not just confined space instruments. The ISEA protocol has been widely adopted by the gas detection equipment manufacturing community, even by manufacturers who are not members of the Association.

The ISEA protocol begins by clarifying the differences between a "bump test", a "calibration check" and a "full calibration":

- A "bump test" (function check) is defined as a qualitative check in which the sensors are exposed to challenge gas for a time and at a concentration to activate all of the alarms to at least the lower alarm settings. It is important to understand what a qualitative test of this kind does not do. The test confirms that the gas is capable of reaching the sensors, that when they are exposed to gas the sensors respond, the response time (time to alarm) after gas is applied, and that the alarms are activated and function properly. However, a qualitative function test does not verify the accuracy of the readings or output of the sensors when exposed to gas.
- A "calibration check" is a quantitative test using a traceable source of known concentration test gas to verify that the response of the sensors is within the manufacturer's acceptable limits. For instance, a manufacturer might

specify that readings in a properly calibrated instrument should be within $\pm 10\%$ of the value of the gas applied. If this is the pass / fail criterion, when 20 ppm H₂S is applied to the instrument, the readings must stabilize between 18 ppm and 22 ppm in order to pass the test. It should be stressed that these pass / fail criteria are manufacturer guidelines. Different manufacturers are free to publish different requirements.

- A "full calibration" is defined as the adjustment of an instrument's response to match a desired value compared to a known traceable concentration of test gas. Once again, the calibration procedure, including the concentration of gas applied, method used to apply gas, and method used to adjust the readings are determined by the manufacturer.

The statement goes on to recommend the frequency for validation of the instrument's operability:

- A "bump test" (functional test) or "calibration check" of direct reading portable gas monitors should be made before each day's use in accordance with the manufacturer's instructions using an appropriate test gas.



Figure 4: Docking Stations are designed to automatically perform functional bump tests and calibrations, and automatically store test results.

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- Any instrument that fails the test must be adjusted by means of a “full calibration” procedure before further use, or taken out of service. If environmental conditions that could affect instrument performance are suspected to be present, such as sensor poisons, then verification of calibration should be made on a more frequent basis.
- A “full calibration” should be conducted as required by the manufacturer. However, as discussed above, a “full calibration” should be conducted whenever testing indicates that adjustment is required. Even if the instrument is not yet “due” for a “full calibration”, if the instrument fails a “bump test” or “calibration check” it must be calibration adjusted before further use.

Lengthening the interval between bump test or calibration tests

Federal OSHA as well as a number of State Occupational Safety and Health administrations have posted instructional letters to identify circumstances under which it may be appropriate to lengthen the interval between verification checks. Testing the instrument less frequently should only be considered if the following criteria are met:

- During a period of initial use of at least 10 days in the intended atmosphere, calibration is verified daily to be sure there is nothing in the atmosphere which is poisoning the sensor(s). The period of initial use must be of sufficient duration to ensure that the sensors are exposed to all conditions that might have an adverse effect on the sensors.
- If the tests demonstrate that it is not necessary to make adjustments, then the time interval between checks may be lengthened but should not exceed 30 days.
- The history of the instrument since last verification can be determined by assigning one instrument to one worker, or by establishing a user tracking system such as an equipment use log.
- Any conditions, incidents, experiences, or exposure to contaminants that might adversely affect the calibration should trigger immediate verification of calibration before further use. Most importantly, if there is any doubt about the calibration of the sensors, expose them to known concentration test gas before further use.

Docking stations make CS instruments even easier to use and maintain

Given the requirement for documentation, the capability of instruments to log or automatically retain calibration information is highly desirable. Most data logging confined space instruments automatically update and store dates and other calibration information. Even non-data logging instruments usually include the date, or number of days since the last time the instrument was calibrated.

Most leading manufacturers of confined space gas detectors now offer automatic calibration or “docking” stations that can automatically calibrate and store instrument calibration records. Docking stations that include fully automatic calibration are redefining the way that users with large numbers of confined space instruments deal with maintenance and calibration issues. Instead of technicians or instrument specialists laboriously calibrating instruments one at a time, instrument users simply drop the gas detector into the docking station. The docking station automatically bump tests or calibrates the instrument, then updates and stores the test results. Use of automatic calibration stations makes it possible to verify the accuracy of confined space instruments on a much more frequent basis. Docking stations are also able to transparently improve the quality of bump test and calibration checks. Many docking station systems verify not only the final stable reading of the sensor, but the time it takes to reach the desired output level, as well as the shape of the sensor response curve, which can provide important diagnostic information on the health of the sensor.

The prices for automatic calibration stations are beginning to drop in the same way that prices for instruments have been dropping. In the past, it might take forty or more instruments to justify the expense of investing in a docking station. As prices continue to drop, customers with only a few instruments are finding that investing in an automatic calibration station makes very good sense.

Direct reading gas detectors are designed to help keep workers safe in potentially life threatening environments. Verifying the proper performance of your gas detectors is a mandatory part of every program that requires their use. But more importantly, it’s an essential part of keeping your workers safe.



AP 1008:

G450 Confined Space Gas Detector Six-year Extended Sensor Warranty Program



GfG Instrumentation offers the longest sensor warranty in the history of gas detection!

GfG Instrumentation gas detectors offer the best features and performance, at the lowest cost of ownership of **any** atmospheric monitors on the market today. GfG instruments carry a lifetime warranty on the instrument itself. The standard G450 sensor warranty is a full 3-years from the date of purchase. The extended sensor warranty option provides coverage for **all four sensors** (O₂, LEL, CO and H₂S) for a **full 6-years** from the date of purchase.

Other manufacturers charge up to \$670.00 for a set of four sensors. To make it worse, most manufacturers only warrant the sensors for 2-years from purchase. Customers may have to replace all four sensors three or four times over the life of the instrument. A single set of replacement sensors is often more expensive than a brand new instrument. GfG thinks that's wrong!

Standard 3-year warranty on all four sensors

All four sensors in the G450 (oxygen, LEL CO and H₂S) carry a standard 3-year warranty. There is no extra charge for the standard 3-year sensor warranty.

Standard lifetime warranty on the instrument

Most of the components in a GfG instrument never need to be replaced, and carry a lifetime warranty for as long as you own the product. The only exceptions are the battery packs, filters and sensors.

Optional 6-year extended sensor warranty

The optional extended warranty provides sensor warranty coverage for a full 6-years. The option is available for an additional \$250.00 at the time the instrument is purchased.

How does the extended sensor warranty work?

Sensors that fail under warranty will be replaced with a brand new sensor at no charge.

How much can I save?

GfG instruments are designed for durability. How much you save depends on how long you own and keep your GfG instrument in service. The list price of a rechargeable four-gas G450 is \$745.00. With the extended warranty option, the six-year cost of ownership is only \$995.00. This is less than the three year cost of ownership for most other confined space gas detectors.

Can I still buy and replace the sensors one at a time as needed?

Yes. When it's finally time to replace the sensors, you can buy and replace them one at a time, or you can purchase a complete set of all four sensors for \$400.00. Replacement sensors carry the same standard three year warranty as the original sensors.



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GfG Six-year Extended Sensor Warranty Program Distributor Questions and Answers



Standard 3-year warranty on all four sensors

All four sensors in the G450, O₂, LEL CO and H₂S continue to carry a standard 3-year warranty. There is no extra charge for the standard 3-year sensor warranty.

Standard lifetime warranty on the instrument

Most of the components in a GfG instrument never need to be replaced, and carry a lifetime warranty for as long as you own the product. The only exceptions are the battery packs, filters and sensors. Battery packs and filters are warranted for 1-year from the date of purchase.

How does the 6-year extended sensor warranty work?

Sensors that fail under the extended warranty will be replaced with a brand new sensor at no charge.

Is there an extended warranty option for the G460?

Yes. However, the 6-year warranty is only available for LEL, O₂, CO, H₂S and COSH sensors. Other sensors in the G460 such as PID, SO₂, Cl₂, NO₂, etc. will continue to carry the standard warranty coverage indicated in the GfG price list.

What part numbers and prices should I use?

For the G450 use part number: 1450-EXT-6 (\$250.00)

For the G460 use part number: 1460-EXT-6 (\$350.00)

How do I sell the extended warranty plan to the customer?

If you are ordering a new instrument with the extended warranty from the factory, just add the additional part number and price to the PO. If you want to add the extended warranty to an instrument sold from inventory, send a PO to GfG in the normal way indicating the warranty part number AND the instrument serial number with which the extended warranty is associated. GfG will track instruments covered by the extended warranty plan by serial number in our system.

What is my distributor discount?

The standard distributor discount is the same as for spare parts and replacement sensors. The extended warranty option discount is list price less 25%.

What if the customer wants to add the extended warranty later?

Distributors have a two week period from the date of delivery of the instrument to the end-user customer to sell them an extended warranty plan.

How will I know if the instrument has a standard 3-year or the 6-year extended sensor warranty?

The GfG Service Department maintains a database of all purchased extended warranty plans, and the instrument serial numbers with which they are associated. If you aren't sure, just call GfG Service!



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G450 Six-year Cost of Ownership Comparison

Cost of Ownership									
Product	M5A Altair 4X	ISC MX4	BW Quattro	X-am 2000	GfG G450				
List price of rechargeable 4 channel instrument	\$920.00	\$695.00	\$745.00	\$805.00	\$765.00				
Standard sensor warranty & price									
LEL	3-year \$210	2-year \$220	2-year \$185	3-year \$175	3-year \$100*				
Oxygen	3-year \$180	2-year \$165	2-year \$135	5-year \$145	3-year \$100*				
CO	NA	2-year \$275	2-year \$200	5-year \$145	3-year \$100*				
H2S	NA	2-year \$275	2-year \$150	5-year \$145	3-year \$100*				
COSH	3-year \$210	NA	NA	NA	NA				
Instrument price Pricing*	\$915.00		\$745.00	\$805.00					
Three year cost of ownership	Between \$860.00 and \$1,630.00**		Between \$880.00 and \$1,415.00***	\$765.00					
Extended warranty option:	Yes	No	No	Yes					
How long?	1-year additional	NA	NA	3-year additional					
How much?	\$315.00	NA	NA	\$250.00					
Total cost of ownership with extended warranty	\$1,230.00 (4-years)	NA	NA	\$980.00 (5-year)****	\$1,015.00 (6-years)				
Total six year cost of ownership	\$1,515.00 (6-years)	Between \$1,795.00 and \$2,565.00 (6-years)	Between \$1,550.00 and \$2,085.00 (6-years)	Between \$980.00 and \$1,475.00 (6-years)	\$1,015.00 (6-years)				

* When bought as a complete set of 4 sensors, G450 replacement sensors are \$100 each. The replacement sensors carry the same standard 3-year warranty as the original sensors.

** The three-year cost of ownership of the MX4 depends on how many sensors have to be replaced after two years. The O2 sensor must be replaced after two years for \$165. Replacement LEL sensors cost \$220, while CO and H2S sensors cost \$275 each. If all four sensors need to be replaced, the MX4 three-year cost of ownership could be as high as \$1,630. The three-year cost of ownership of a rechargeable G450 is \$765.

*** The three-year cost of ownership of the Quattro depends on how many sensors have to be replaced after two years. The O2 sensor must be replaced after two years for \$135. Replacement LEL sensors cost \$185, CO sensors cost \$200, and H2S sensors cost \$150 each. If all four sensors need to be replaced, the Quattro three-year cost of ownership could be as high as \$1,415. The three-year cost of ownership of a rechargeable G450 is \$765.

**** The five-year and six-year cost of ownership of the Drager X-am 2000 depends on how many sensors have to be replaced after the warranty runs out. The LEL sensor is only warranted for three years. It is extremely likely that it will need to be replaced after three years. The LEL sensor costs \$175. The O2, CO and H2S sensors are warranted for five years. If all three sensors need to be replaced after five years as well, the X-am 2000 six-year cost of ownership could be as high as \$1,415. With the extended warranty option, the six-year cost of ownership of a rechargeable G450 is \$1,015.

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New TLV® exposure limit: **Measuring** hydrogen sulfide



Photo courtesy of GFG Instrumentation

By BOB HENDERSON

In the past, the most widely recognized occupational exposure limits for hydrogen sulfide (H₂S) have referenced an 8-hour TWA of 10 ppm, and a 15-minute STEL of 15 ppm. In February 2010, the American Conference of Governmental Industrial Hygienists (ACGIH®) adopted a new threshold limit value (TLV®) recommendation for

higher, inhalation of H₂S can cause immediate collapse and unconsciousness. A single breath at a concentration of 1,000 ppm results in immediate loss of consciousness, followed by cardiac arrest and death unless the unconscious individual is successfully revived.

H₂S is produced by the action of anaerobic, sulfur fixing bacteria on materials that contain sulfur. It is commonly associated with raw sewage, animal

products, and the pulp and paper industry, but can be encountered occasionally in almost any confined space. It is a constituent of natural gas and petroleum, and is

especially associated with oil production and refining activities. H₂S ranks second behind carbon monoxide (CO) as the leading cause of death from toxic chemicals in the U.S. According to the U.S. Bureau of Labor Statistics, H₂S poisoning was the cause of at least 52 occupational-related deaths in the U.S. from 1993 to 1999. Of these deaths,

“nine involved multiple casualties, some of whom were killed

while attempting to rescue co-workers.” Tragically, hardly a week goes by that does not include a fatal accident somewhere in the world due to H₂S exposure.

What are TLVs® & why do they matter?

OSHA uses the term Permissible Exposure Limit (PEL) to define the maximum concentration of a listed contaminant to which an unprotected worker may be exposed. Depending on the contaminant, the PEL may reference an eight-hour, time-weighted average (TWA), a 15-minute short-term exposure limit (STEL) or an instantaneous ceiling (C) concentration that cannot be exceeded for any period of time. Individual states either follow federal regulations, or follow their own, state-specific permissible exposure limits. States may not publish or follow exposure limits that are more permissive than federal OSHA limits.

The ACGIH TLVs® are guidelines for workplace exposure to toxic substances. TLVs® are developed and designed to function as recommendations for the control of health hazards, and to provide guidance intended for use in the practice of industrial hygiene. But ACGIH

H₂S Exposure Limits

	8-hr. TWA	STEL	Ceiling	Acceptable Max Peak Above Ceiling for an 8-Hour Shift	
				Concentration	Maximum Duration
Federal OSHA PEL	NA	NA	20 ppm	50 ppm	10-minutes once only if no other measurable exposure occurs during shift
NIOSH REL	10 ppm	15 ppm	NA	NA	NA
TLV (2010)	1.0 ppm	5.0 ppm	NA	NA	NA

H₂S, lowering the 8-hour TWA to 1.0 ppm, and the STEL to 5.0 ppm. The new TLV® has forced many companies to reconsider exposure limit guidelines and alarm settings. A major issue is whether a company’s current instruments are capable of operation with alarms set to the new 1.0 ppm limit. Employers may need to verify whether or not this is possible with a particular instrument design.

How dangerous is H₂S?

Hydrogen sulfide is a colorless gas that at low concentrations has an odor similar to rotten eggs. At higher concentrations, H₂S rapidly deadens the sense of smell. For most people, a concentration of 150 ppm is enough to immediately deaden the sense of smell. At a concentration of about 750 ppm or

TLVs® Incorporated by Reference in:

- NFPA 306 – Control of Gas Hazards on Vessels
- US Coast Guard regulations (OSHA PEL or TLV, whichever is lower)
- US Army (OSHA PEL or TLV, whichever is lower, or specific Army OEL)
- Some individual state health and safety plans (e.g. California)
- Many international standards and regulations (e.g. Canada)
- Many consensus standards (e.g. ANSI, NFPA)
- Many corporate health and safety plans
- Mine Safety and Health Administration (MSHA) regulations

TLVs® are frequently incorporated by reference into state, federal and many international regulations governing workplace exposure. They may also be cited or incorporated by reference in consensus standards of associations such as the National Fire Protection Association (NFPA), or American National Standards Institute (ANSI).

Given the potential for lawsuits, many employers have made the strategic decision to base their corporate health and safety programs on conservative applicable recognized standards. Since ACGIH recommendations are frequently more conservative than OSHA PELs, many programs, especially the programs of multinational or prominent corporations, use the ACGIH TLV®.

How do H₂S sensors detect gas?

Substance-specific H₂S sensors are compact, require very little power, exhibit excellent linearity and repeatability, and generally have a long life span. The detection technique is very straightforward. Gas that enters the sensor undergoes an electrochemical reaction that causes a change in the electrical output of the sensor. The difference in the electrical output is proportional to the amount of gas present. The detection reaction is a two-step process.

H₂S that enters the sensor is oxidized at the sensing electrode:



The counter electrode balances out the reaction at the sensing electrode by reducing oxygen from the air to water:



Each molecule of H₂S that is oxidized at the sensing electrode produces a current flow of eight electrons. The amount of current produced is a function of the number of H₂S molecules that enter the sensor. For every 1.0 ppm of H₂S in the atmosphere being monitored, a typical hydrogen sulfide sensor shows a raw electrical output of 0.7 µA (micro amps). This relationship is linear over a very wide range such that 10 ppm

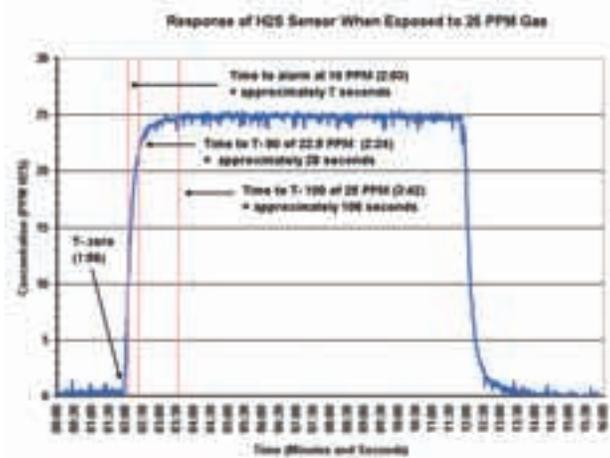
produces 7.0 µA, 100 ppm produces 70.0 µA and so on.

H₂S sensors are usually designed to minimize the effects of interfering contaminants, making the readings as specific as possible for the gas being measured. H₂S sensors are stable, long-lasting, require very little power and are capable of resolution (depending on the sensor and contaminant) to ± 0.1 PPM or even lower. H₂S sensors are normally usable over a wide range of temperatures, depending on the brand of sensor, from as low as - 40°C to 50°C (- 40 to 120 °F).

The sulfuric acid produced in the reaction simply accumulates in the sulfuric acid electrolyte. Water from the electrolyte is used, but is regenerated during the course of the reaction. The only materials consumed during the detection reaction are the molecules of H₂S, power from the battery of the instrument and oxygen. As long as the sensor is located in an atmosphere containing even small amounts of oxygen, the sensor will be able to replenish itself directly from the atmosphere. This is the reason that H₂S sensors have such long life spans. The lifespan of the sensor is not affected by exposure to the contaminant that it measures. No part of the sensor is consumed during the detection reaction. You can expose the sensor to H₂S calibration gas every single day without shortening or affecting the lifespan of the sensor.

Setting H₂S alarms

Most H₂S instruments have four user settable alarms: Low, High, TWA and STEL. The Low and High alarms are instantaneous “Ceiling” type alarms that sound immediately whenever the concentration exceeds the alarm setting. The STEL alarm is a time-history alarm based on the average concentration over the most recent 15-minute period. The TWA alarm is calculated for an 8-hour exposure period. When the exposure is less than 8 hours, the TWA calculation is projected over a full 8-hour period.



Compact electrochemical H₂S sensors can last three years or longer in day-to-day operation.

Until recently, most instrument users (and manufacturers) have set the Low and TWA alarms at 10 ppm, and the High and STEL alarms at 15 ppm. Instrument users who are required to conform to the new TLV will need to use much lower settings. It is possible to set the H₂S alarms (at least on some brands of instruments) as low as 0.5 ppm (one-half the TLV® exposure limit value). How low to set the alarms is a function of legal requirements and company policy. Many instrument users now set the Low and TWA alarms at 1.0 ppm, and the High and STEL alarms at 5.0 ppm. In cases where the ambient concentration of H₂S makes it impractical to set the instantaneous alarms at these very low concentrations, it may make sense to set the TWA at 1.0, and the STEL alarm at 5.0 ppm; but to leave the instantaneous Low and High alarms at the old values of 10.0 ppm and 15.0 ppm.

It's useless unless you use it

Electrochemical H₂S sensors are among the most dependable, stable and reliable type of gas detecting sensors available. However, no sensor can detect gas unless it is used. The only way of being sure that toxic contaminants are not present in dangerous concentrations is to look for them with an atmospheric monitor designed for their detection, and take action at the appropriate concentration.

Bob Henderson is president of GfG Instrumentation.

Hydrogen Sulfide: Real-time Detection Techniques

New TLV® Heightens Industrial Hygiene Monitoring Concerns

BY PHILIP A. SMITH AND ROBERT E. HENDERSON

In 2003, an uncontrolled release from a natural gas well in Chongqing, China, led to the deaths of approximately 240 people.¹ Most deaths occurred in the area 200 to 500 m away from the well-head, but exposed individuals as far as 1,200 m away also died. Over 1,000 people were hospitalized, thousands were evacuated, and according to one published report, “dogs, ducks, rabbits and other domestic animals were killed. Even fish did not escape.”¹

The devastation was caused by hydrogen sulfide (H₂S), a colorless gas with a distinctive “rotten egg” odor that often occurs naturally within oil and gas deposits^{2,3} and in downstream transport² and refining operations.³ In occupational settings, H₂S is a serious threat to worker health. It is soluble in water, explosive (with a lower explosive limit concentration of 4.3 percent by volume), corrosive, heavier than air, and highly toxic. Under certain conditions, decaying organic material yields H₂S,³ so it is potentially present in many situations where workers must enter poorly ventilated confined spaces.

In cases where exposure to H₂S is possible, accurate and reliable detection methods are critical. The poor warning properties of H₂S and the extreme hazard posed by even brief exposures to high concentrations literally make recognition of the potential presence of this extremely dangerous gas a matter of life or death.

Health Effects

Hydrogen sulfide interacts with hemoglobin in red blood cells and myoglobin in muscle tissue,³ interfering with oxygen transport and storage. The most discon-

certing health effects from H₂S arise from impairing the body’s ability to use oxygen in the mitochondrial electron transport chain,⁴ disrupting function of the nervous system, and causing olfactory desensitization as the airborne concentration of H₂S increases above ~100 ppm.^{3,5} With exposure to H₂S concentrations greater than ~1,000 ppm, the phrenic nerve, which controls the diaphragm, ceases functioning almost immediately, causing breathing to stop.^{2,3} This effect combined with a sudden loss of consciousness is known as “knock-down.” If the airborne H₂S concentration is not lowered and breathing is not restored, death will ensue quickly. Irritation and damage to pulmonary, skin, and eye tissues is also possible.¹

Because of the effects of H₂S on the nervous system, as well as damage to lung tissues, even aggressive cardiopulmonary resuscitation may not be sufficient to restore breathing or avoid permanent injury. The knockdown effect of H₂S can give rise to multiple deaths when improperly protected co-workers attempt to retrieve a victim from atmospheres with high H₂S levels.⁶

According to the U.S. Bureau of Labor Statistics, H₂S poisoning was the cause of at least 52 occupational-related deaths in the U.S. from 1993 to 1999. Nine of these deaths involved multiple casualties, including those killed while attempting to rescue co-workers.⁶ Deaths from H₂S exposure were noted in waste management, petroleum and natural gas, food processing, asphalt, fishing, and dye industries. In 1998, occupational-related deaths from H₂S were found to be the second leading cause of death from toxic chemicals, behind carbon monoxide (CO).⁷

Real-time H₂S Detection

Portable instruments used to measure H₂S usually include one or two instanta-

neous alarms (peak or ceiling alarms), as well as short-term exposure limit (STEL) and time-weighted average (TWA) alarms based on time-history exposure. In the past, widely recognized occupational exposure limits for H₂S have referenced an 8-hour TWA of 10 ppm and a 15-minute STEL of 15 ppm. Most manufacturers routinely set instrument alarms at these values.

In February 2010, ACGIH® recognized the potential for adverse health effects from H₂S exposure at lower airborne concentrations and adopted new TLV® recommendations, lowering the 8-hour TWA to 1.0 ppm and the STEL to 5.0 ppm.⁸ The new recommendations forced many practitioners to reconsider exposure limit guidelines and alarm set points. A primary concern has been whether detection instruments are capable of operation with alarms set to the new limits. Industrial hygienists may need to verify with manufacturers whether this is feasible with a particular instrument design.

Methods used to detect H₂S include instruments that measure conductivity changes in a gold film upon absorption of H₂S as well as colorimetric tubes and indicators. This article focuses on electrochemical sensors, which are the most widely used means of real-time H₂S measurement.

How Electrochemical Sensors Work

In many situations, a multigas meter is used to simultaneously detect oxygen (O₂) deficiency and the presence of combustible gases and vapors and will also employ one or more compound-specific electrochemical sensors. When it is known that a single gas or vapor is predominantly present without O₂ deficiency or a combustible gas hazard, a single-gas monitor may be used. The ideal compound-specific sensor would

respond only to the specific compound, while the ideal “broad range” sensor would respond to all air contaminants present. In practice, the selectivity of electrochemical sensors designed for detection of a specific airborne compound such as H_2S falls somewhere between these two extremes.

Each electrode in an electrochemical sensor (Figure 1) has a specific purpose. The sensing electrode (Figure 2), often referred to as the “working” electrode, is where the reaction of interest occurs. Depending on the gas being measured, the target gas is either oxidized or reduced on the working electrode, creating a flow of current proportional to the airborne gas or vapor concentration. The counter electrode completes the circuit with the working electrode. If the measured gas is oxidized at the sensing electrode, some other chemical species (often O_2) is reduced at the counter electrode in a balancing half-cell reaction. Conversely, if the target gas is reduced at the sensing electrode, another chemical species is oxidized at the counter electrode. Zero-biased (often referred to as “unbiased”) sensors are normally installed in a circuit that holds the electric potential of the working electrode at a constant value. The potential of the counter electrode is allowed to “float” as a function of the changing concentration of the gas being measured. Three-electrode sensor designs include a reference electrode that provides a stable output signal unaffected by analyte concentration changes. This stable output is a reference point for comparison with the active signal from the sensing electrode as it dynamically changes with analyte concentration fluctuations.

For electrochemical detection of H_2S the only materials consumed are H_2S and O_2 , and only a small amount of power from the instrument’s power supply is needed. As long as the sensor is located in an atmosphere with a minimal amount of O_2 , the O_2 consumed in these reactions can be replenished.

Figure 3 shows that the instrument readout does not equilibrate instantaneously when an electrochemical H_2S sensor is first exposed to the target compound at 25 ppm, although the “time to alarm” in this case was about 4 seconds. Importantly, the sensor output signal is extremely linear over the full range of the sensor. The ratio of surface area of the sensing electrode is physically quite large compared with the number of H_2S molecules that actually enter the sensor. Even if a substantial frac-

Figure 1. An electrochemical H_2S sensor module.

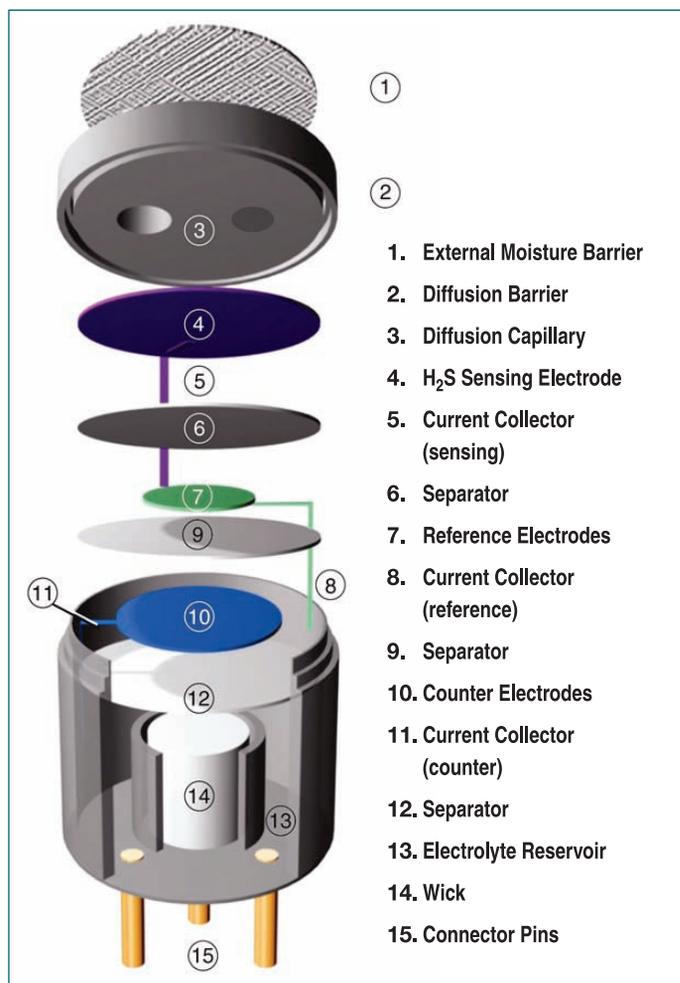


tion of the sensing electrode becomes unusable (for example, from physical damage or poisoning of the catalyst system), the sensor usually has more than enough reserve efficiency to operate normally.

An alternative to the “nonconsuming” type of electrochemical sensor is a detector where a chemical component within the sensor is consumed. In these detectors, the sensor will eventually run out of required reagent. No reagent is consumed within electrochemical H_2S sensors; the oxidation/reduction reactions can theoretically occur indefinitely as long as O_2 is present and even for short periods in oxygen-deficient atmospheres as residual O_2 remains in an electrolyte reservoir present within the detector. Even when exposed to H_2S on a regular basis, electrochemical H_2S sensors routinely last three years or longer. Although these sensors do not lose sensitivity from exposure to H_2S , regularly testing the sensor by exposing it to a known concentration of calibration gas is highly recommended.

All electrochemical sensors employ aqueous chemistry and thus should not be stored at high temperatures, even for brief periods of time. If an electrochemical sensor (see Figure 2) is stored in a hot environment or is left in a car on a warm day, the water within the electrolyte reservoir located within the sensor can evaporate. If the electrolyte dries out beyond a cer-

Figure 2: Schematic diagram showing the components present in an electrochemical sensor module.



tain point, the detector will fail. Also, since the electrochemical H₂S detector requires a small amount of O₂ to function, it will not work correctly for applications where O₂ is absent for extended periods (for example, for H₂S detection within a natural gas pipeline).

Cross-sensitivity

Some cross-sensitivity may occur with electrochemical sensors. Depending on the interfering chemical, either a positive or negative detector response bias is possible. However, in the case of an electrochemical H₂S sensor, because the relative signal strength is much greater for H₂S, a very high concentration of oxidizing gas (for example, Cl₂) would be required to materially affect sensor readings.

A greater concern is the positive interfering effect on electrochemical H₂S sensor readings from certain volatile organic compound (VOC) vapors, such as limonene, methanol or other alcohols, including those present in some hand sanitizers and insect repellents. Always remember to allow these liquids to dry completely before handling gas detectors, and never use methanol to clean or decontaminate gas-detecting instruments. Electrochemical sensors of all types are designed with specific use conditions and requirements in mind, so always follow factory recommendations

regarding cleaning, routine maintenance and calibration.

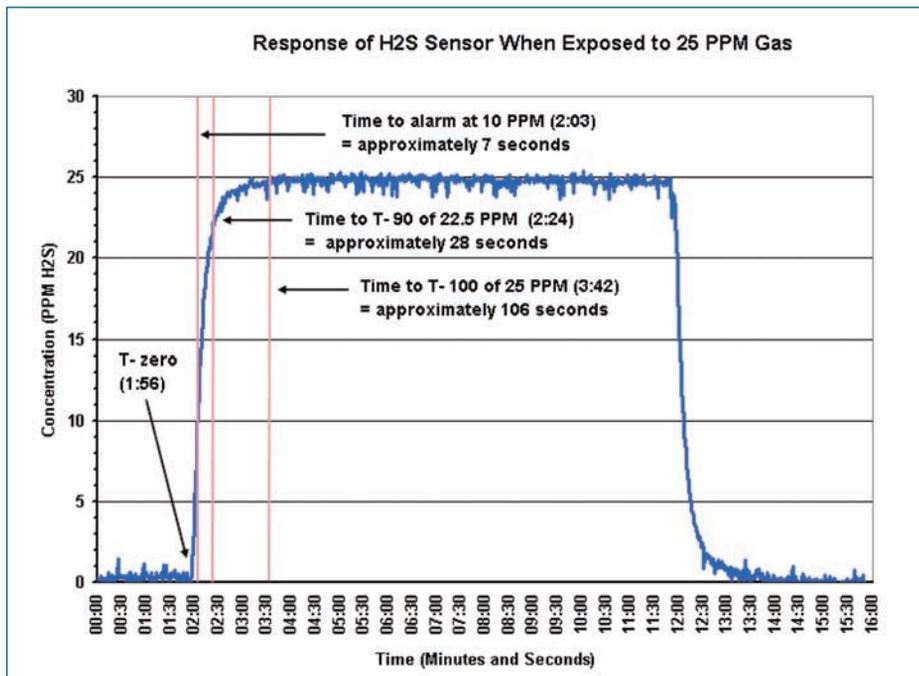
Combined H₂S/CO Sensor Designs

A commonly used variant of the electrochemical H₂S sensor includes a second working electrode for the detection of CO. The sensor includes a single counter electrode, a single reference electrode, and one electrode each for H₂S and CO, thereby providing a separate signal for each detected gas. Typically, once the gas diffuses into the sensor, it first reaches the H₂S working electrode where most of this compound reacts, and the H₂S working electrode is designed not to respond to CO. The sampled air continues to diffuse into the sensor, where it reaches the CO sensing electrode and the CO concentration is then measured.

Four-electrode CO/H₂S sensors usually include an internal filter that limits the amount of VOC interferences and H₂S that reach the CO electrode. However, a certain amount of H₂S is still expected to remain in the gas that reaches the CO electrode. While optimized for the detection of CO, the CO sensing electrode responds to both CO and H₂S. Instruments deduct the effects of H₂S on the CO electrode based on the expected breakthrough ratio. Such a system requires calibration with both gases before use.

[Continued: 32]

Figure 3. Response of a typical electrochemical H₂S sensor to a stable concentration of 25 ppm H₂S.



H₂S Monitoring Concerns

The lowering of the ACGIH TLV for hydrogen sulfide in 2010 caused concern among industrial hygienists about their detection instruments. Below, manufacturers share their responses to the following question from *The Synergist*: “What is the number one complaint you hear from industrial hygienists about H₂S monitoring?”

Bryan Bates, President and CEO, Gas Clip Technologies, Inc.:

It would have to be a tie between two. The first complaint concerns the problems associated with having to switch out existing “disposable”-type instruments in order to comply with the changing TLV for H₂S, and the second is the hassle and cost associated with enforcing facility SOPs for required bump testing of H₂S monitors/detectors for contractors. To solve these issues, we recommend our customers use disposable H₂S detectors with alarm set points that can be changed and an electronic “bump test” frequency alarm LED-flashing indicator. Both functions require a supervisory action and cannot be changed accidentally by the instrument user.

Bob Henderson, President, GfG Instrumentation:

The most common question is about the new 2010 TLV for H₂S, and whether or not an instrument can be successfully used with take-action alarm settings of 1.0 ppm. The answer is a qualified “yes.” It all depends on the specific instrument. Some gas detectors already have the necessary range and resolution to permit users to set the instantaneous or TWA alarm as low as 1.0 ppm (or lower). In other cases it may be necessary to update the operating software. In some cases, however, it may not be possible to upgrade older instruments to be capable of resetting the alarms to the new limits. The only way to determine whether this is the case for a particular design is to ask the manufacturer.

- REACH's influence in establishing de facto limits (derived no-effect levels, or DNELs)
- a lack of understanding of the difference between acceptable risk and a true threshold of toxic risk

Although these challenges are substantial, the speakers and audience agreed that countries motivated by the common goal of protecting human health can set up a process for sharing scientific information, develop exposure limits, and align on the documentation for those limits. Leadership of this collaborative effort would reside with a neutral third party, preferably an international body. The group also suggested that volunteerism, the hallmark of OEL-setting thus far, could not carry the process forward. And finally, funding must be made available to support this effort for the global community. Presentations are posted at www.ioha.net/internationaloelissues.html.

Future Collaboration

The October 2010 Professional Conference on Industrial Hygiene in Ft. Worth, Texas, continued the dialogue with a half-day session on OELs that included presentations on ACGIH's processes for setting TLVs, OSHA's preliminary deliberations on updating PELs, DNELs as de facto OELs, and the pharmaceutical industry's reliance on control banding and its use of risk modeling when data are limited. These presentations are accessible at www.pcih2011.org.

Efforts to define an "acceptable exposure level" continue at the national and international levels. Although approaches to this task vary, the discussions at IOHA and PCIH revealed that we have a better understanding of the challenges. While no unitary solution is expected immediately, the conversation on OELs enables a more robust future collaboration. 

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[From: 30]

Another approach is to take advantage of the cross-sensitivity of the CO working electrode in an unfiltered carbon monoxide sensor. Substance-specific CO sensors normally include a robust internal filter designed to remove H₂S and other contaminants before they reach the sensing electrode. When the filter is left out of the design, H₂S readily diffuses into the sensor and is detected by the CO electrode. The signal output of this type of sensor is generally much stronger for H₂S than for CO. Some manufacturers use the single signal to calculate two readings. Each reading assumes that the entire signal is due to the presence of one or the other gas. Some manufacturers use the ratiometric difference between the signal strength for the two gases and simply set the CO sensor alarm at a concentration equivalent to the desired "take action" concentration limit for H₂S. The obvious drawback with this approach is that the user will not know which gas is present, or the relative concentrations of each. Manufacturers do not usually require calibration of this type of sensor using both gases, but calibration is usually with CO only, which is generally much less expensive and stable for a much longer period than calibration gas that includes H₂S.

Conclusion

Electrochemical H₂S sensors based on oxidation of the target analyte at a working electrode are among the most dependable, stable, and reliable type of gas-detecting sensors available. However, no sensor can detect gas unless it is used. The only way of being sure that toxic contaminants are not present in dangerous concentrations is to look for them with an atmospheric monitor designed for their detection. To protect life and health, it is important for industrial hygienists to understand their detection instrument. Using the instrument when needed to detect a dangerous airborne contaminant such as H₂S is critical. 

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Understanding Carbon Dioxide Sensors and their Applications

Safety professionals sometimes forget that carbon dioxide is a toxic gas with a strictly defined Occupational Exposure Limit. The safest approach is to measure CO₂ directly when the gas is present in potentially dangerous concentrations.



Compact multi-sensor instruments are capable of providing direct CO₂ measurement during confined space and other atmospheric monitoring procedure

Liquid and solid carbon dioxide (dry ice) are widely used as refrigerants, especially in the food industry. Carbon dioxide (CO₂) is also used in many industrial and chemical industry processes. CO₂ is particularly associated with the beer and wine making industries, where it is produced by yeast during the fermentation process. CO₂ in the headspace of fermentation vessels can easily reach 50% by volume or even higher concentrations. CO₂ is also widely used in the oil industry, where it is commonly injected into oil wells to decrease viscosity. It is also one of the most common atmospheric hazards encountered in confined spaces.

Carbon dioxide (CO₂) is a byproduct of living organisms, and is naturally present in the earth's atmosphere with an average concentration of about 350 ppm in fresh air. CO₂ is a primary byproduct of bacterial decomposition, and in many confined spaces there is a direct relationship between low concentrations of oxygen and elevated concentrations of CO₂. If the low oxygen is due to bacterial action, a concentration of 19.5% oxygen would be associated with an equivalent concentration of at least 1.4%, or 14,000 ppm CO₂, which is almost three times higher than the occupational exposure limit.

The true concentration of CO₂ can be substantially higher if the oxygen deficiency is due to displacement. Fresh air contains only 20.9% oxygen by volume. The balance consists mostly of nitrogen, with minor or trace concentrations of a wide variety of other gases including CO₂. Because oxygen represents only about one-fifth of the total volume of fresh air, every 5% of a displacing gas that is introduced into a confined space reduces the oxygen concentration by only 1%. In the case of an oxygen deficiency due to the introduction of dry ice into an enclosed space, a reading of 19.5% O₂ would not be indicative of 1.4% CO₂, it would be indicative of 7% CO₂, a concentration fourteen times higher than the toxic exposure limit!

CO₂ is also heavier than air, with a density of 1.5 times that of fresh air. When carbon dioxide is released into an enclosed or confined space it tends to settle to the bottom of the space, reaching the highest concentration in the lowest parts of the space. Because of this tendency to settle, as CO₂ is produced it can reach higher and higher concentrations in localised regions of the space (such as the head space immediately above the liquid in fermentation vats).

In spite of these considerations, in the past it was seen as adequate to simply measure the oxygen concentration. This attitude is changing as it becomes more feasible (and affordable) to directly measure CO₂ by means of compact, portable multi-sensor gas detectors.

Carbon dioxide is a toxic contaminant with strictly defined workplace exposure limits

CO₂ is listed as a toxic contaminant with strictly defined occupational exposure limits in almost every country. The most widely recognised exposure limits for CO₂ reference an 8-hour Time Weighted Average (TWA) of 5,000 ppm, with a 15-minute Short Term Exposure Limit (STEL) of either 15,000 ppm or 30,000 ppm.

While present as a natural component in fresh air, at higher concentrations exposure symptoms include headaches, dizziness, shortness of breath, nausea, rapid or irregular pulse and depression of the central nervous system. Besides displacing the oxygen in fresh air, high concentrations of CO₂ can worsen the symptoms related to oxygen deficiency, and interfere with successful resuscitation. Even moderately elevated concentrations associated with poorly ventilated indoor spaces can produce physiological symptoms. Concentrations of 40,000



Multi-sensor instruments are able to use wide range of sensors and detection technologies including O₂, standard pellistor LEL, NDIR combustible gas and CO₂, PID and over 20 different substance-specific electrochemical sensors for toxic gas measurement

ppm or higher should be regarded as immediately dangerous to life and health. Exposure to very high concentrations has been linked to permanent heart damage, as evidenced by altered electrocardiograms. Concentrations greater than 10% are capable of causing loss of consciousness within 15 minutes or less.

How NDIR (non-dispersive infrared) CO₂ sensors detect gas

The most widely used technique for real-time CO₂ measurement is by means of non-dispersive infrared (NDIR) sensors that measure gas as a function of the absorbance of infrared light.

Specific molecules absorb infrared radiation at precise wavelengths. When infrared radiation passes through a sensing chamber containing a specific contaminant, only the light that matches these wavelengths is absorbed. The rest of the light is transmitted through the chamber without hindrance.

Carbon dioxide has an absorbance peak at a wavelength of 4.3 microns (μm). Absorbance of infrared light at this wavelength is proportional to the concentration of CO₂ present in the sensing chamber of the sensor.

Miniaturised NDIR CO₂ sensors include an infrared lamp that emits light in the desired wavelengths. Most NDIR CO₂ sensors are dual detector systems that provide both a reference and an active signal. The active detector measures the amount of light in the 4.3 μm range that reaches the detector after passing through the sensing chamber. The reference detector measures the amount of light at another wavelength where there is no absorbance for the gas of interest. The greater the concentration of CO₂, the greater the difference between the two signals.

In the past, infrared based instruments have tended to be bulky, expensive, and required a high level of operator expertise to obtain accurate readings. A new generation of miniaturised NDIR sensors has permitted the development of infrared based instruments for an ever widening variety of atmospheric hazards including combustible gas as well as CO₂ detection.

The regulations are already changing. Recent accidents have heightened concerns, and increased the obligation for direct CO₂ measurement during workplace procedures that may expose workers to this contaminant. In Germany and Austria regulations already require direct measurement of CO₂ during most confined space entry procedures. It is clear that with the increased availability, and increasingly affordable cost of miniaturised NDIR CO₂ sensors, more and more atmospheric monitoring programs will include the direct measurement of this dangerous atmospheric contaminant.

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What does it mean when a gas detector displays negative readings?



Although it is physically impossible for the atmosphere to contain a negative quantity of a substance, it is not uncommon for a gas detector to display a negative reading on the LEL, PID or toxic measurement channels.

While each type of sensor uses a different method to detect gas, all gas detecting sensors produce an electrical output that is proportional to the amount of gas detected. In general, the greater the output, the higher the reading. However, the electrical output is not as simple as "gas in = signal out". The changes in current flow produced by the sensor must be interpreted by the instrument before the readings can be displayed. A very important point is that even if the sensor is not detecting gas there is still a current flowing through the sensor. In other words, even when the sensor is located in an atmosphere with "zero contaminants" the sensor is still producing a signal.

Whenever you "Auto Zero" or fresh air adjust a sensor you are telling the instrument that the electrical signal at the time the sensor is adjusted is what the instrument should expect the sensor to produce while it is located in fresh air. The output signal in fresh air is used as the point of comparison for subsequent readings. A higher output signal is interpreted by the instrument as indicating a higher concentration of gas. However, if the signal drops below the output at the time the sensor was last fresh air adjusted, the comparison point is now negative with respect to the actual readings.

- **Do all instruments display negative readings?**

Most instruments eventually display negative readings or sound a "downscale" or "negative alarm" if the negative difference with the fresh air output value becomes significantly large.

However, different manufacturers have different ideas about what constitutes a "significant" negative reading. For instance, to avoid raising concerns with their users because of "minor" fluctuations in readings near zero, manufacturers often include a "dead band" in the instrument's programming. Until the signal exceeds the limits of the dead band, readings remain locked on zero.

In some designs the dead-band can be quite substantial. For instance, some brands of instruments equipped with miniaturized pellistor type LEL sensors have a dead-band that stretches all the way from -3% to +3% LEL. In other words, in the presence of a rising concentration of gas, the first reading displayed is 4% LEL. At 3% LEL the instrument reading is still "locked" on zero. Similarly, until the output signal reaches a value of -4% LEL, the display shows a reading of zero.



Figure 1: Always allow all of the sensors installed in your instrument to stabilize completely in fresh air BEFORE making a fresh air zero adjustment.



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Figure 2: Changes in humidity as well as exposure to certain contaminants can affect the output of gas detecting sensors in fresh air.

Sometimes the manufacturer may simply make the readings a little more "sticky" close to zero, to proportionally reduce fluctuation as the signal gets closer and closer to zero. Whether or not to include a dead-band is a manufacturer decision based on the instrument design and the stability and resolution of the sensor.

Dead-bands may reduce user concerns because of trivial fluctuations in the instrument readings, but they may also leave the user unaware of changes as the instrument initially begins to respond to increasing concentrations of gas. Even worse, when the instrument starts out from a negative output level, it takes that much more gas before the instrument reaches the alarm concentration. For instance, if the LEL alarm is set at 10% LEL, when instrument starts out at -3% LEL it will take 13% LEL gas to cause the instrument to go into alarm. When the display is digitally locked on zero the user is unaware of the need to fresh air zero adjust the instrument.

• **How can I avoid negative readings?**

The best way to reduce or avoid negative readings is simply wait a little longer BEFORE making an Auto Zero adjustment after initially turning the instrument on (Figure 1). Many types of sensors, especially PID and pellistor type LEL sensors, start out with an initially higher output signal, then "count down" as the sensors finish warming up in fresh air. To avoid problems make sure the instrument is located in fresh air that does not contain measurable contaminants, and give the sensors time to stabilize completely before using the instrument or making a fresh air adjustment.

Remember that stabilization can sometimes take quite a bit of time. While pellistor type LEL sensors usually stabilize completely within 6 - 8 minutes, electrochemical sensors that have been exposed to certain interfering contaminants can sometimes take an hour or longer to clear completely. For instance, CO sensors are equipped with an internal filter to prevent or limit the sensor's response to VOC contaminants. However, once the filter is saturated, the sensor responds very strongly to solvents and VOCs such as methanol, MTBE (methyl tert-butyl ether) and toluene. CO sensors are also very responsive to acetylene. Figure 3 shows the clearing time for a CO sensor that was exposed to a 500 ppm (2% LEL) concentration of acetylene (C₂H₂). Even after 30 minutes

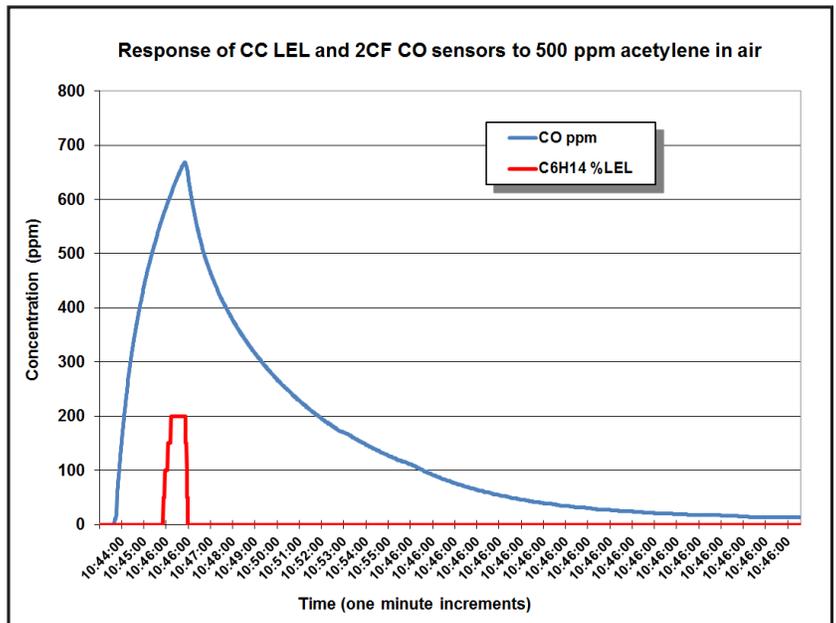


Figure 3: Electrochemical CO sensors can take a long time to clear after exposure to certain interfering contaminants such as acetylene.



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in fresh air the reading is still a few ppm above zero. If the instrument is fresh air adjusted before clearing is complete, readings will drop below zero as the sensor continues to stabilize.

• **Why do sensor readings go negative?**

The potential causes of negative readings are different for each type of sensor.

Standard (pellistor type) LEL sensors detect combustible gas by catalytically oxidizing (burning) the gas on an active bead in the sensor. Along with warm-up issues; mechanical damage due to banging or dropping, exposure to sensor poisons and exposure to high concentrations of combustible gas can all affect the zero offset and lead to negative readings.

Electrochemical sensors used to measure CO, H2S and many other many other substance-specific toxic gases detect gas by means of a chemical reaction between the gas and materials in sensor. The chemical reaction causes a change in the electrical output of the sensor that is proportional to the concentration. The most common causes of negative readings are fresh air adjusting the sensor while it is in the presence of measurable contaminants (especially common with CO sensors that are zeroed in areas contaminated with engine exhaust or where people have been smoking), or fresh air adjusting the sensor before it has finished stabilizing after exposure to an interfering contaminant.

Photo-ionization detector (PID) sensors use photons of highly energetic ultraviolet light to ionize VOC molecules present in the atmosphere being sampled. The detection reaction produces a current flow of electrons "stripped" from the ionized molecules that is proportional to concentration. Like LEL sensors, PID readings often start high, then count downwards while the sensor is warming up. PID sensors can sometimes take up to 15 or 20 minutes to fully warm up. Once again, it is very important to wait until the readings have stabilized completely before fresh air adjusting and using the PID to measure gas.

The output of PID sensors in fresh air can also be influenced by the ambient temperature and humidity. Water vapor molecules can absorb photons of ultraviolet light without being ionized. The more humid the atmosphere the more the signal of the PID in fresh air can be "quenched" by the presence of the water vapor molecules. Fresh air adjusting the PID zeroes out this quenching effect. Changes in humidity from one day to the next, or from one area to another can be the cause of negative readings. The best approach is to fresh air zero PID equipped instruments in the same humidity as the air in which the instrument is used to obtain readings.

Non-dispersive infrared (NDIR) sensors detect gas by measuring the absorbance of infrared light by chemical bonds in the molecules of interest. Just like PID sensors, the output of NDIR sensors can be influenced by changes in humidity. While NDIR sensors warm-up and stabilize completely within a few minutes, differences in the humidity between one day and the next can cause negative readings.

• **What should I do to correct negative readings?**

Correcting negative readings is extremely easy. Almost all instrument designs include a simple procedure to make an automatic fresh air zero adjustment (Figure 4).

Make sure the instrument is located in fresh air, that the sensors are fully warmed up, and that the readings are stable. Continue to pay attention to the fresh air readings. If readings continue to count downwards it may be necessary to repeat the fresh air zero procedure.

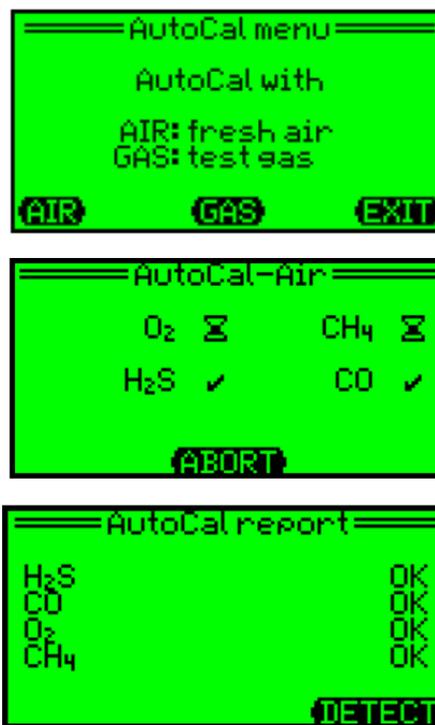


Figure 4: GfG instruments can be automatically fresh air zeroed or calibrated by means of a simple "AutoCal" procedure, (press "Air" to make an automatic fresh air zero adjustment, "Gas" to make a span calibration adjustment, or "Exit" to return to normal operation).



Monitoring for Toxic VOCs in Oil Industry Applications



Increased awareness of the toxicity of VOC chemicals has led to lowered exposure limits, and increased requirements for direct measurement. Photoionization detector (PID) equipped instruments are increasingly viewed as the best choice for measurement of VOCs at exposure limit concentrations.

Organic chemicals consist of molecules that contain carbon. Volatile organic compounds (VOCs) are organic compounds characterized by their tendency to evaporate easily at room temperature.

Crude oil is a complex mixture that includes many different specific hydrocarbons and other chemicals. The hydrocarbons in crude oil are primarily alkanes, (molecules that consist entirely of carbon and hydrogen atoms), cycloalkanes (alkanes that include one or more rings in their structure), and various aromatic hydrocarbons (molecules that include a benzene ring in their structure). The molecules in crude oil present multiple potential hazards. Most of the gases and vapors associated with crude oil are highly flammable. Many hydrocarbon gases and vapors are heavier than air and can displace oxygen containing atmosphere in enclosed environments and confined spaces. In addition, many of the organic molecules associated with crude oil are highly toxic, with exposure limits (in some cases) of less than 1.0 ppm (8 hour TWA).

Toxic VOC exposure is a significant concern at many refineries, chemical plants and oil production facilities. Familiar substances containing VOCs include solvents, paint thinner and nail polish remover, as well as the vapors associated with fuels such as gasoline, diesel, heating oil, kerosene and jet fuel.

The category also includes specific toxic substances such as benzene, butadiene, hexane, toluene, xylenes, and many others. Most VOC vapors are flammable at surprisingly low concentrations. For most VOCs however, the toxic exposure limit is exceeded long before readings reach a concentration high enough to trigger a combustible range alarm.

Solvent, fuel and other VOC vapors are routinely encountered in many types of procedures undertaken at refineries, chemical plants and oil production facilities. VOC vapors are particularly associated with confined spaces and confined space entry procedures at these same facilities. In some cases the presence of VOCs is due to materials being used or stored in the confined space. In other cases, especially sewers and other large interconnected confined space networks, fuels, combustible liquids or other VOCs accidentally introduced in one location can easily spread to other locations within the system. Increased awareness of the toxicity of these common contaminants has led to lowered exposure limits, and increased requirements for direct measurement of these substances at their toxic exposure limit concentrations. Photoionization



Figure 1: Photoionization detector (PID) equipped instruments are increasingly viewed as the best choice for measurement of VOCs at exposure limit concentrations.



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detector (PID) equipped instruments are increasingly viewed as the best choice for measurement of VOCs at exposure limit concentrations. Understanding the capabilities as well as the limitations of photoionization detectors is critical to interpreting test results and making decisions based on the use of this important atmospheric monitoring technology.

Multi-sensor portable gas detectors

Portable gas detectors can be equipped with a number of different types of sensors. The type of sensor used is a function of the specific substance or class of contaminant being measured. Many toxic contaminants can be measured by means of substance-specific electrochemical sensors. Direct reading sensors are available for hydrogen sulfide, carbon monoxide, chlorine, sulfur dioxide, ammonia, phosphine, hydrogen, hydrogen cyanide, nitrogen dioxide, nitric oxide, chlorine dioxide, ethylene dioxide, ozone and others. Although some of these sensors are cross sensitive to other substances, there is very little ambiguity when it comes to interpreting readings. When you are interested in hydrogen sulfide, you use a hydrogen sulfide sensor. When you are interested in phosphine, you use a phosphine sensor. In many cases, however, a substance-specific sensor may not be available.

Volatile organic contaminants (VOCs) are quite detectable, but usually only by means of broad-range sensors. Broad-range sensors provide an overall reading for a general class or group of chemically related contaminants. They cannot distinguish between the different contaminants they are able to detect. They provide a single aggregate reading for all of the detectable substances present at any moment.

The most widely used technique for the measurement of combustible gases and volatile organic contaminants continues to be use of a hot-bead pellistor type combustible gas sensor. Pellistor sensors detect gas by oxidizing the gas on an active bead located within the sensor. Oxidization of the gas causes heating of the active bead. The heating is proportional to the amount of gas present in the atmosphere being monitored, and is used as the basis for the instrument reading.

Most combustible gas reading instruments display readings in % LEL increments, with a full range of 0 – 100% LEL. Typically these sensors are used to provide a hazardous condition threshold alarm set to 5% or 10% of the LEL concentration of the gases or vapors being measured. Readings are usually displayed in increments of 0.5 or 1.0% LEL. Hot-bead pellistor combustible gas sensors are unable to differentiate between different combustible gases.

Hot-bead pellistor sensors that provide $\pm 1.0\%$ LEL accuracy are excellent for gases and vapors that are primarily or only



Figure 2: Hand-held multi-sensor instruments are compact, easy-to-use and capable of being equipped with an increasing number of substance-specific as well as broadly responding sensors.

of interest from the standpoint of their flammability. For these gases using a sensor that expresses readings in percent LEL increments is an excellent approach. But many other combustible vapors fall into a different category. Although VOC vapors may be measurable by means of a hot-bead sensor, they may also have a permissible exposure limit (PEL) that requires taking action at a much lower concentration.

Hexane provides a good example. The American Conference of Governmental Hygienists (ACGIH®) Threshold Limit Value® (TLV®) and the United States National Institute of Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) reference an 8-hour TWA for hexane of 50 PPM.

The lower explosive limit concentration for hexane is 1.1%. Below 1.1% volume hexane the concentration of hexane vapor to air is too low to form an ignitable mixture. Assuming the combustible sensor alarm is set at 10% LEL, with a properly calibrated combustible gas reading instrument, it would take a concentration of 10% of 1.1% = 0.11% volume hexane to trigger an alarm. Since 1% volume = 10,000 parts-per-million (ppm), every 1% LEL increment for hexane is equivalent to 110 ppm.

It would therefore take a concentration of 1,100 ppm hexane to trigger an alarm set to the standard 10% LEL hazardous condition threshold. Even if instruments are set to alarm at 5% LEL, it still would still require a concentration of 550 ppm to trigger the alarm.

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Table 1:
Exposure Limits and Physical Constants for Ten Common VOCs

Contaminant	LEL Concentration (Vol %)	Flashpoint Temp (°F)	OSHA PEL	NIOSH REL	TLV	5% LEL expressed in PPM
Acetone	2.50%	-4°F	1,000 PPM TWA	250 PPM TWA	500 PPM TWA	1250 PPM
Diesel (No. 2) vapor	0.60%	125°F	None Listed	None Listed	15 PPM	300 PPM
Gasoline vapor	1.30%	-50°F	None Listed	None Listed	300 PPM TWA	650 PPM
n-Hexane	1.10%	-7°F	500 PPM TWA	50 PPM TWA	50 PPM TWA	550 PPM
Isopropyl alcohol	2.00%	53°F	400 PPM TWA	400 PPM TWA	200 PPM TWA	1000 PPM
Kerosene/ Jet Fuel vapor	0.70%	100 – 162°F	None Listed	100 mg/m ³ TWA (approx. 14.4 PPM)	200 mg/m ³ TWA (approx. 29 PPM)	350 PPM
MEK	1.40%	16°F	200 PPM TWA	200 PPM TWA	200 PPM TWA	700 PPM
Styrene	0.90%	88°F	100 PPM TWA	50 PPM TWA	20 PPM TWA	450 PPM
Toluene	1.1	40°F	200 PPM TWA	100 PPM TWA	20 PPM TWA	550 PPM
Turpentine	0.8	95°F	100 PPM TWA	100 PPM TWA	20 PPM TWA	400 PPM

Using a standard LEL sensor to measure VOC vapors presents a number of other potential problems. To begin with, most combustible sensors have poor sensitivity to the large molecules found in fuels, solvents and other VOCs, with flashpoint temperatures higher than 38°C (100°F). But even when the span sensitivity of a properly calibrated instrument has been increased sufficiently to make up for this inherent loss of sensitivity, an instrument that provides readings incremented in 1.0% LEL steps cannot resolve changes in concentration smaller than ± 1.0% of the LEL concentration of the substance being measured. Because percent LEL detectors are poor indicators for the presence of many VOCs, lack of a reading is not necessarily proof of the absence of hazard.

Reliance on hot-bead type LEL sensors for measurement of VOC vapors means in many cases that the OSHA permissible exposure limit (PEL), NIOSH REL or TLV® is exceeded long before the concentration of vapor is sufficient to trigger the combustible hazardous condition threshold alarm. When toxic VOCs are potentially present it is necessary to use additional or different detection techniques that are better suited for direct measurement of VOCs at ppm toxic exposure limit concentrations. Photoionization detectors are becoming increasingly popular for this application.

It should be noted that non-PID detectable combustible gases and vapors (such as methane) may be present at the same time as toxic VOCs. Although catalytic-bead sensors may have limitations with concern to the measurement of toxic VOCs at exposure limit concentrations, they are by far the most widely used and dependable method for measuring methane, hydrogen, ethane and other combustible gases and vapors with smaller, lighter molecules.

Increasing concern with the toxicity of VOCs has led to a number of newly revised exposure limits, including the TLVs®, those for diesel vapor, kerosene, jet fuel (JP-8) and gasoline. The ACGIH® TLV® for kerosene and JP-8 is approximately 30 ppm vapor. The TLV® for total diesel hydrocarbons (vapor and aerosol) is 100 mg/m³ (8-hour TWA). This is equivalent to approximately 15 parts-per-million diesel vapor, a very low exposure limit concentration.

Diesel vapor has always been regarded as a potential fire hazard but largely ignored as a potential toxic vapor hazard. Diesel fuel is an NFPA Class II Combustible Liquid with a typical lower explosive limit of 0.6 percent (6,000 PPM). For diesel vapor, 1.0% LEL is equivalent to 60 PPM. Even if the instrument is properly calibrated for the detection of diesel – which is not possible for many designs – a reading of only 1.0% LEL would exceed the TLV® for diesel by 400 percent!

Table 1 lists ten common VOCs, their LEL concentration, flashpoint temperature, and their exposure limits per the OSHA PEL, NIOSH REL and ACGIH® TLV®. The table also identifies those contaminants (highlighted in red) with toxic exposure limits lower than 5% LEL.

It goes beyond the scope of this article to argue how long it might be permissible to remain at 5% or 10% LEL without actually exceeding the 8-hour TWA. What is most striking about the list is how few (if any) VOCs have 8-hour TWA exposure limits higher than 5% LEL.

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Importance and use of “broad-range” sensors

The more unpredictable the hazards, the more important it is to use sensors that are capable of providing alarm notification for a wide range of potential contaminants. Substance-specific sensors, like the ones used to measure oxygen, carbon monoxide and hydrogen sulfide are deliberately designed to limit the effects on readings of other contaminants which may be simultaneously present. In contrast, broad-range sensors provide an overall reading for a general class or group of chemically related contaminants. Broad-range sensors are particularly suited for use during initial screening or in situations where the actual or potential contaminants have not been identified because they enable instrument users to obtain an overall reading of the contaminants present in the space. Both traditional LEL and PID sensors are broad-range sensors. They can’t determine which type of flammable gas or VOC is being detected, but they are excellent at determining when either of these classes of contaminants is present.

How do PIDs detect VOCs?

Photoionization detectors use high-energy ultraviolet light from a lamp housed within the detector as a source of energy used to remove an electron from neutrally charged VOC molecules, producing a flow of electrical current proportional to the concentration. The amount of energy needed to remove an electron from the target molecule is called the ionization energy (IE) for that substance. The larger the molecule, or the more double or triple bonds the molecule contains, the lower the IE. Thus, in general, the larger the molecule, the easier it is to detect. On the other hand, small hydrocarbon molecules such as methane are not detectable by means of PID. A PID is only able to detect substances with ionization energies lower than the energy of the ultraviolet photons produced by the PID lamp.

Photoionization detectors may be equipped with a number of different types of lamps that produce photons of various energy ranges. The energy range of the photons produced by the lamp is expressed in “electron volts” or “eV” units of measurement. The most common types of PID lamps produce photons in the 9.8 eV, 10.6 eV or 11.7 eV energy range. The energy required to detect hydrogen, methane and ethane exceeds the energy of the ultraviolet light produced by any available PID lamp.

By far, the most commonly used PID lamp is one that produces photons in the 10.6 eV energy range. 10.6 eV lamps generally have much longer service lives, and frequently last one to three years in normal operation. At the same time, 10.6 eV lamps have an energy output sufficient to detect a wide range of VOCs. As a consequence, 10.6 eV lamps tend to be the most widely used.

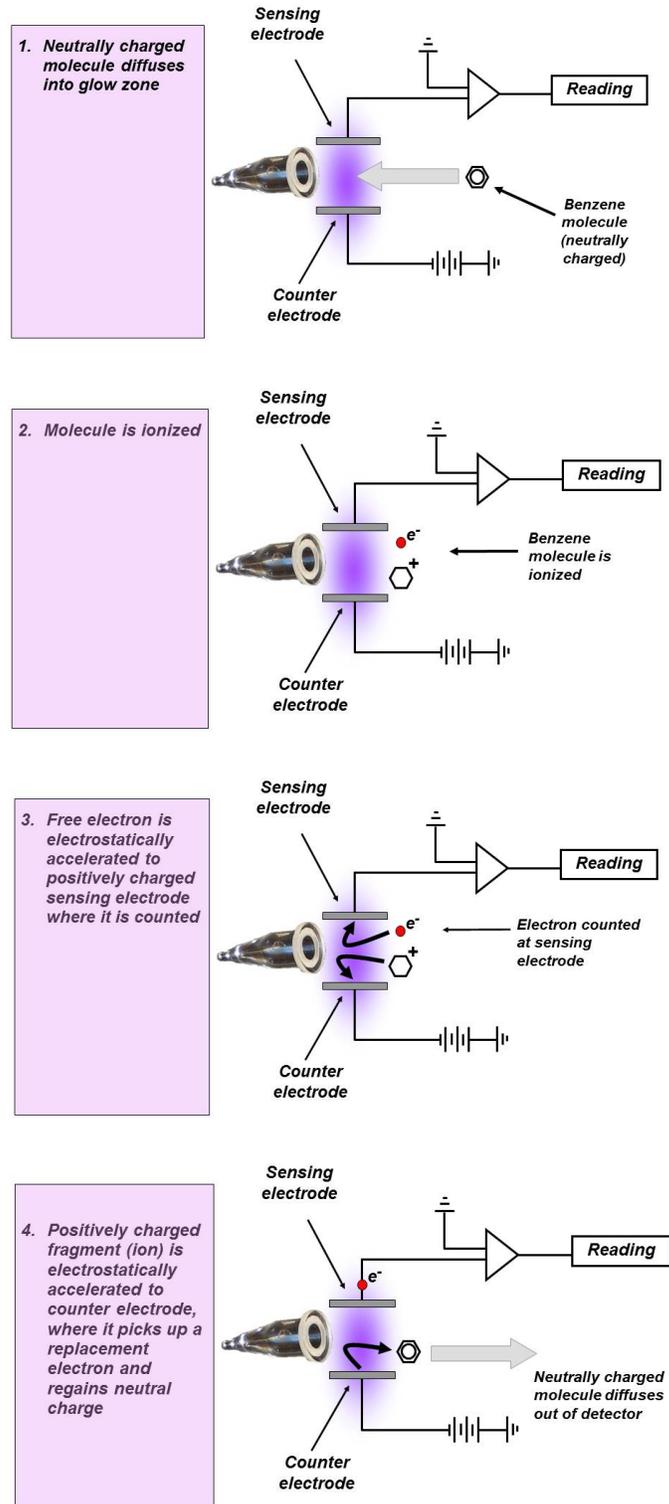


Figure 3: PID detection sequence.

Table 2:
Representative Correction Factors for Several Brands of Photoionization Detectors*

	RAE	BW	Ion Science	GfG	Ionization Energy (eV)
Acetaldehyde	5.5	4.6	4.9	N/A	10.21
Acetone	1.1	0.9	0.7	1.2	9.69
Ammonia	9.7	10.6	8.5	9.4	10.2
Benzene	0.5	0.6	0.5	0.5	9.25
Butadiene	1	0.9	0.9	0.7	9.07
Diesel Fuel	0.8	0.9	0.8	0.9	N/A
Ethanol	12	13.2	8.7	10	10.48
Ethylene	10	11	8	10.1	10.52
Gasoline	0.9	0.7	1.1	1.1	N/A
n-Hexane	4.3	4	3.3	4.5	10.18
Jet Fuel (JP-8)	0.6	0.5	0.7	0.5	N/A
Kerosene	N/A**	1.1	0.8	N/A	N/A
Methyl-ethyl-ketone (MEK)	0.9	0.8	0.8	0.9	9.53
Naphtha (iso-octane)	1.2	1.2	1.1	1.3	9.82
Styrene	0.4	0.5	0.5	0.4	8.47
Toluene	0.5	0.5	0.5	0.5	8.82
Turpentine	0.4	0.5	0.5	0.5	N/A
Vinyl chloride	2	2.2	2.2	1.8	10
Xylene	0.4	0.5	0.4	0.5	8.5

*The values listed are from technical notes and manuals previously published by the identified manufacturers. Never use the correction factors provided by one manufacturer for a different brand of instrument. Manufacturers routinely update their technical support documentation. Consult the manufacturer directly to obtain the latest version.

** "N/A" does not necessarily indicate the PID is unable to detect this substance. "N/A" only indicates that a CF for the vapor was not included in the technical support documentation. Instrument users should consult the manufacturer directly for guidance as to the detectability of a particular chemical.

What are the differences between PID and LEL sensors?

PID and LEL sensors are based on entirely different detection techniques. Most LEL range sensors detect gas by catalytically oxidizing the gas on a pellistor-bead located within the sensor. Oxidation of the gas causes heating of the active pellistor-bead. The heating is proportional to the amount of gas present in the atmosphere being monitored, and is used as the basis for the instrument reading. Pellistor sensors are excellent for the detection of hydrogen, methane, propane, pentane and other small hydrocarbon molecules. However, catalytic-bead sensors, at least when operated in the percent LEL range, are not readily able to detect "heavy" or long-chain hydrocarbons or the vapors from high flashpoint temperature liquids such as turpentine, diesel fuel or jet fuel. The number of carbon atoms in a hydrocarbon molecule is referred to as the "carbon number." Most manufacturers warn that standard pellistor LEL sensors should not be used for measurement of hydrocarbons

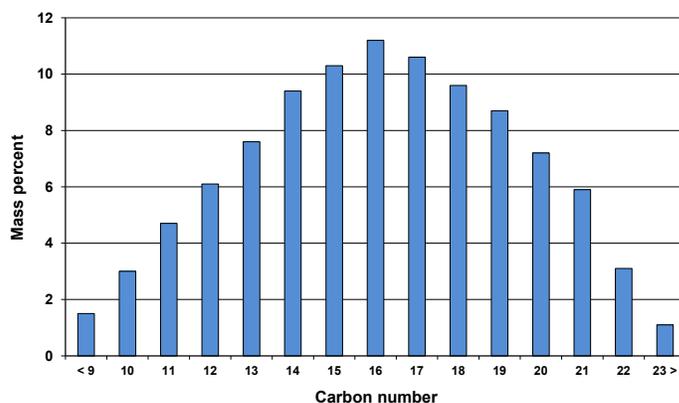


Figure 4: Carbon number distribution of the molecules in No. 2 Diesel Fuel (liquid). Less than 2.0% are small enough (C9 or smaller) to be measurable by a standard pellistor LEL sensor.

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Figure 5: Miniaturized photoionization detectors are the same size and have similar power requirements to traditional pellistor type LEL sensors .

larger than octane (C8) or nonane (C9) sized molecules. Instrument users should consult the Operator's Manual, or contact the manufacturer directly to verify the capabilities of the instrument design when using a catalytic-bead LEL sensor to monitor for the presence of these types of contaminants.

Limitations of broad-range sensors

Both pellistor-bead LEL and PID are broad-range sensors. They cannot distinguish between the different contaminants they are able to detect. The reading provided represents the aggregate signal from all of the detectable molecules present in the monitored environment. Unless an additional separation technique is used (such as a filter tube or separation column) broad-range detectors are not able to provide substance-specific readings.

Using correction factors

Many manufacturers include a user selectable library of correction factors (or "CFs") for the combustible gas sensor in the instrument design. In this case, the user simply selects "methane" or "propane" or any other correction factor in the library, and the instrument automatically recalculates readings according to the selected relative response. Changing the CF ONLY changes the scale used to calculate the displayed readings. Selecting the "propane" CF does not prevent the sensor from responding to methane. It just reinterprets the readings as if they were entirely due to propane.

Most PID equipped instruments also include a built-in library of correction factors. The same principles apply. Changing the PID correction factor (CF) or choosing a chemical from the on-board library does not make the instrument readings specific for that substance! Choosing the "hexane" correction factor does not make the PID a substance-specific detector for hexane. The PID will continue to respond to other detectable VOCs (such as benzene or toluene) which may be simultaneously present. Using the hexane CF simply tells the instrument to display the readings calculated as hexane measurement units.

PIDs are usually calibrated using isobutylene. Thus, the most commonly used measurement scale for most PIDs is isobutylene. It is very important to understand that no matter how comprehensive the list of correction factors, choosing the CF for any particular chemical does not make the readings exclusive or substance-specific for that contaminant.

Also, if the specific nature of the VOC or mixture of VOCs is not known, PID readings are not truly quantified. Unless you are able to determine the precise nature of the VOCs being measured, readings should be thought of as "isobutylene units", or "PID units", or units of whatever measurement scale has been selected from the instrument's library of correction factors.

Generally speaking, if a VOC is detectable by one manufacturer's PID when equipped with a 10.6 eV lamp, the same substance will be detectable by any other manufacturer's PID when equipped with a similar lamp. However, the correction factors may be quite different between different instrument designs. The reason is primarily due to the specific energy ranges of the photons produced by the lamp. Not all of the photons produced by a 10.6 eV lamp are actually 10.6 eV photons. The majority of the photons produced are actually in the 10.03 eV energy



Figure 6: The GfG G460 instrument pictured is equipped with a standard LEL, O₂, dual-channel COSH sensor for CO and H₂S, and a miniaturized PID for VOC measurement.

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range. Only about 20 % to 25% of the photons produced (depending on the design of the lamp) are in the 10.6 eV energy range. All of the photons produced by a 10.6 eV lamp are capable of ionizing and detecting VOCs with ionization energies less than 10.0 eV. But only the higher energy photons are able to ionize and detect VOCs with ionization energies between 10.1 and 10.6 eV. Thus, correction factors may differ widely between manufacturer designs. PID users should never use the correction factors from one instrument for another manufacturer’s design.

Correction factors may also change as the lamp ages and the signal strength declines. As well, the signal strength of the PID may also be affected by the temperature and humidity in which the instrument is used. The best approach is to use correction factors cautiously, and to take action at a deliberately conservative concentration when using corrected readings.

Using broad-range readings to make decisions

Instrument users frequently worry that they can’t use a broad-range PID for VOC measurement because they need substance-specific readings for the contaminants present.

PIDs provide a single reading for the total detectable volatile organic contaminants (TVOC) present. In point of fact, many of the most common VOCs do not consist of a single type of molecule. They are comprised of a mixture of, in some cases, a very large number of individual molecular species. For instance, the size distribution of molecules in diesel fuel ranges from molecules with nine carbons (or smaller), to molecules with twenty-three carbons (or larger). However, the ratios of the various molecules present are fairly similar from one batch of diesel to the next. That allows PID manufacturers to experimentally determine a CF for use with this fuel. You don’t have to go after the individual molecular types that may be present as a minor fraction of the diesel (such as benzene, toluene, xylenes, etc.) to provide a quantified reading. If you have a CF for the mixture you can use this to quantify the readings for the entire range of molecules present.

Dealing with single-component VOC contaminants or mixtures is easy. Once you know which contaminant you are dealing with, simply assign the correct CF, and set the alarms to the appropriate take action thresholds for that VOC. Dealing with varying mixtures can be a little more challenging. In this case the secret is to identify which chemical is the “controlling” compound.

Every mixture of VOCs has a compound that is the most toxic and / or hardest to detect, and thus “controls” the alarm set-point that should be used for the entire mixture. Once the controlling compound has been identified, it is possible to determine a hazardous condition threshold alarm that will ensure that the exposure limit for any contaminant potentially present is never exceeded.

The first step is to calculate (or look up) the exposure limits in isobutylene units for the VOCs of interest. Remember to leave the PID scale (correction factor) set to isobutylene units when using this measurement technique.

The exposure limit in isobutylene units (EL_{ISO}) is calculated by dividing the exposure limit for the VOC by the correction factor (CF_{ISO}) for the substance. For instance, the TLV[®] for turpentine is 20 ppm. If the CF for turpentine is 0.45, the EL_{ISO} = 20 ppm divided by 0.45 = 44.5 ppm. Many PID manufacturers include a table of EL_{ISO} values either in the owner’s manual or in a separate applications note.

Consider a situation where you have three VOCs of interest:

Table 3: Example correction factors	
Chemical Name	CF _{ISO} (10.6 eV lamp)
Ethanol	10.0
Turpentine	0.45
Acetone	1.2

ethanol, turpentine and acetone. Let’s say the owner’s manual of the PID shows the following set of correction factors for the three chemicals of interest:

Correction factors higher than 1.0 indicate that the PID is less sensitive to the substance than to the isobutylene used to calibrate the PID. Correction factors of less than 1.0 indicate that the PID is more sensitive to the chemical than to the isobutylene used to calibrate the detector.

Although turpentine has the lowest exposure limit, it is also the most easily detected substance of the three. Acetone is close to isobutylene in terms of detectability, with an exposure limit that is intermediate between those of the other two chemicals. Although ethanol has the highest exposure limit, it is also the least detectable of the three chemicals.



Table 4:
Example correction factors and exposure limits

Chemical Name	CF _{ISO} (10.6 eV lamp)	OSHA PEL (8 hr. TWA)	EL _{ISO} (PEL)	TLV® (8 hr. TWA)	EL _{ISO} (TLV)
Ethanol	10	1000	100	1000	100
Turpentine	0.45	100	222.3	20	44.5
Acetone	1.2	1000	833.4	500	416.7

The following table lists the Correction Factors, the OSHA Permissible Exposure Limit (PEL), the ACGIH TLV®, and the exposure limit or each of chemicals recalculated in isobutylene measurement units (EL_{ISO}):

If OSHA PEL exposure limits are followed, ethanol is the controlling chemical when the “EL” exposure limits are expressed in equivalent “isobutylene units”. Setting the PID to go into alarm at 100 ppm isobutylene units ensures that no matter which of the three chemicals, or combination of chemicals, is actually present, the exposure limit will never be exceeded.

On the other hand, if ACGIH® TLV® exposure limits govern your entry procedures, turpentine is the controlling chemical when exposure limits are expressed in isobutylene units. In this case the alarm must be set at 44 ppm isobutylene units to ensure that the exposure limits are never exceeded for any one (or all) of the three chemicals.

Use PIDs together with LEL sensors when monitoring atmosphere

Catalytic hot-bead combustible sensors and photoionization detectors represent complementary, not competing detection techniques. PIDs are not able to detect methane and hydrogen, two of the most common combustible gases encountered in industry. On the other hand, catalytic pellistor-bead sensors are excellent for the measurement of methane, propane, and other common combustible gases. And of course, PIDs can detect large VOC and hydrocarbon molecules that are effectively undetectable by hot-bead sensors, even when they are operable in PPM measurement ranges. The optimal strategy for measurement of combustible range concentrations of combustible gases and VOCs is to include both types of sensors in the same instrument.

Limitations of PID sensors

Humidity and moisture can have a serious effect on PID performance. Water molecules can absorb UV light without becoming ionized, and thus quench the PID signal. The

susceptibility of the sensor to humidity is very design dependent. One of the most important determinants is the distance of the sensing electrode in the PID from the surface of the window of the PID lamp. Most PID designs deliberately position the sensing electrode as close as possible to the surface of the lamp window to reduce the effects of humidity. PID manufacturers also provide tables of correction factors that can be used to correct readings for humidity at various temperature and RH conditions. Alternatively, it easy to correct for these ambient conditions simply by calibrating the PID in the temperature and humidity conditions in which the instrument is actually used.

A second related issue is the condensation of water on the inside of the PID detector. When dirt or dust particles accumulate on the surface of the lamp, electrodes or PID sensing chamber, they provide points of nucleation around which water vapor can coalesce to produce misting similar to the fog that develops on a bathroom mirror. In two electrode PID designs this can lead to surface electrical current flows directly between the sensing and counter electrodes. This “moisture leakage” can result in a rising signal or positive drift in the PID readings. The potential for moisture leakage can be reduced by cleaning the lamp and / or detector.

Some PID designs include a third electrode that serves as a short circuit path that mechanically interrupts current flow between the sensing and counter electrodes. In the case of three electrode designs, condensation of water vapor does not tend to produce a positive drift, or interfere with the ability of the PID to obtain proper readings.

Pump versus diffusion

Whether or not the PID requires a pump or fan to move the sample through the sensing chamber is a function of the manufacturer’s design. Many PID designs include a built-in pump or fan. Other designs allow the addition of a motorized pump to obtain samples from areas that are remote from the detector. The easiest way to determine whether or not a pump is required is to evaluate the instrument before purchase. Most manufacturers and distributors are more than willing to make instruments available to potential customers for field trial.

The best approach includes use of both substance-specific and broad-range sensors

PIDs are able to detect a wide variety of VOC and other toxic chemicals including hydrogen sulfide, ammonia, phosphine, chlorine and others. However, PIDs cannot discriminate between a specific toxic contaminant and other detectable chemicals that may be simultaneously present. When a highly



Table 6:
Fractional concentration of benzene as a function of total VOC

Cargo Tank	PPM TVOC (isobutylene)	PPM TVOC (gasoline)	PPM Benzene	%TVOC from benzene
No (1) Port Cargo Tank	33.9	37.3	0.0	0 %
No (2) Port Cargo Tank	40.1	44.1	0.1	0.23%
No (3) Port Cargo Tank	48.9	53.8	0.2	0.37 %
No (4) Port Cargo Tank	43.8	48.2	0.1	0.21%
No (5) Port Cargo Tank	62.3	68.5	0.4	0.58 %
No (1) Stbd Cargo Tank	12.0	13.2	0.0	0 %
No (2) Stbd Cargo Tank	26.4	29.0	0.0	0 %
No (3) Stbd Cargo Tank	52.8	58.1	0.1	0.17%
No (4) Stbd Cargo Tank	44.3	48.7	0.2	0.41 %
No (5) Stbd Cargo Tank	57.5	63.3	0.3	0.44%

toxic specific contaminant like H₂S is potentially present, it is better to use a substance-specific sensor that responds only to that particular hazard.

Fortunately, PID equipped multi-sensor instruments are available that include up to six or even seven channels of detection, allowing users the latitude of choosing exactly the combination of sensors they need to keep their workers safe.

Case study: Using the controlling chemical approach for setting the TVOC(ISO) alarm for benzene

Because of its very low exposure limits, benzene is frequently seen as the “controlling chemical” in many oil industry and VOC monitoring applications.

Except for facilities that manufacture this chemical, benzene is rarely encountered in pure form. Generally the benzene is present as a minor constituent in the products being manufactured or transported.

The ACGIH® has published TLV® exposure limits for several

Table 5:
ACGIH® TLV® exposure limits in isobutylene units

Substance	TLV® mg/m ³ (8 hr. TWA)	TLV® ppm (8 hr. TWA)	CF _{ISO}	EL _{ISO} ppm (8 hr. TWA)
Gasoline	890 mg/m ³	300 ppm	1.1	273 ppm
Kerosene	200 mg/m ³	30 ppm	0.5	60 ppm
Jet Fuel (JP-8)	200 mg/m ³	30 ppm	0.5	60 ppm
Diesel	100 mg/m ³	15 ppm	0.9	16.7 ppm

VOC liquids known to include benzene. Generally speaking, the higher the fractional concentration of benzene the lower the exposure limit for the liquid.

An easy way to deal with many VOC monitoring applications is to simply set the TVOC alarm (in isobutylene units) at the published exposure limit for the substance. The overall exposure limit takes into account not only the fractional concentration due to benzene; it takes into account the fractional concentrations of other toxic VOCs (such as hexane, toluene and xylenes) that may be present in the mixture.

Unfortunately, in many jurisdictions in North America the local regulations do not include exposure limits for these fuel mixtures. On the other hand, in all jurisdictions the exposure limits for benzene are strictly defined. In this case it may be necessary to directly assess the fractional concentration of TVOC due to benzene.

Table 6 lists actual readings obtained from the cargo tanks of a fuel barge being used to transport fresh gasoline. The fuel barge included five “port side” and five “starboard side” cargo tanks. The cargo tanks had been emptied (drained) and ventilated prior to the following readings being taken. A PID calibrated to isobutylene was used to provide the “Total VOC” (TVOC_{ISO}) readings for each tank. The instrument manufacturer’s correction factor (CF) for gasoline was 1.1. This value was used to convert the TVOC readings from isobutylene units to ppm gasoline.

A substance-specific benzene analyzer was used to measure the actual ppm concentration of benzene in each hold. The percentage concentration of TVOC from benzene was then calculated for each cargo tank.

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The fractional percentage of benzene as a function of the total VOC reading ranged from 0.0% (in the “Number 1 Port Cargo Tank”) to a maximum of 0.58% (found in the “Number 5 Port Cargo Tank”). Thus, in terms of the fractional percentage of benzene, the “worst case” (highest) percentage concentration of benzene was found to be 0.58%.

It is easy to use these measured data to calculate a “worst case” hazardous condition threshold alarm for benzene based on TVOC by using the following formula:

Alarm setting = The desired exposure limit (EL) divided by the “worst case” percentage of TVOC from benzene:

Thus, if the desired exposure limit (EL) for benzene is 1.0 ppm then:

$$1.0 \text{ ppm} / .0058 = 172 \text{ ppm}$$

Setting the TVOC alarm at 172 ppm (gasoline units) ensures that even in the worst case encountered, the exposure limit will not be exceeded.

$$172 \text{ ppm TVOC (gasoline)} \times .0058 = 0.9976$$

Make sure to pay attention to the measurement scale (correction factor) you will be using during your VOC monitoring. The 172 ppm TVOC limit is in gasoline measurement units. In other words, this is the limit to use when the “gasoline” has been selected from the instrument’s built in library of correction factors.

If you leave the correction factor set to isobutylene (the default measurement scale) you will need to convert the alarm setting to isobutylene measurement units. This is done by dividing the TVOC alarm setting in gasoline units by the correction factor for isobutylene.

$$CF_{ISO} \text{ for gasoline} = 1.1$$

The CF(gasoline) for isobutylene is simply the reciprocal of the number:

$$CF(\text{gasoline}) \text{ for isobutylene} = 1 / 1.1 = 0.9091$$

So, if a take action threshold alarm of 1.0 ppm benzene is desired:

$$(1.0 \text{ ppm} / .0058) / 0.9091 = 172 \text{ ppm} / 0.9091 = 189.7 \text{ ppm}$$

It is easy to take action at a lower concentration for benzene simply by dropping the TVOC_{ISO} alarm to a lower concentration.

Table 7: Experimentally determined benzene concentration as a function of total VOC		
Desired exposure limit for benzene	TVOC _{gasoline} alarm setting	TVOC _{ISO} alarm setting
1.0 ppm	172 ppm	190 ppm
0.5 ppm	86 ppm	95 ppm
0.1 ppm	17 ppm	19 ppm

Simplified approach to VOC measurement and alarm settings

Running through calculations similar to those discussed above can seem quite daunting. However, it should be remembered that for most applications this is a one time exercise. Once the controlling chemical has been identified, the rest is easy.

Many refineries and oil production facilities find that using an alarm setting of 15 ppm TVOC_{ISO} is sufficient to ensure that the exposure limits for individual VOCs are never exceeded. Some facilities are able to use an even higher hazardous condition alarm setting of 30 or 50 ppm. In the event that the PID TVOC_{ISO} alarm goes off, workers simply leave the area. Subsequent testing can be used to determine the exact nature of the VOC that triggered the alarm.

In the case of the most conservative VOC monitoring program a substantially lower TVOC_{ISO} alarm may be specified. Fortunately, the sensors in PID equipped in multi-sensor gas detectors are easily capable of being used for take action settings of 0.5 ppm (isobutylene units) or even lower.

Real-time VOC monitoring doesn’t need to be complicated. Simply leave the instrument set to the isobutylene scale and decide on a prudent TVOC alarm setting.

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AP1016: Understanding CO₂ sensors and their applications

Carbon dioxide is one of the most frequently overlooked of all toxic gases. Even to refer to CO₂ as a toxic gas is a surprise to many safety professionals.

Carbon dioxide is the fourth most common gas present in the earth's atmosphere, with an average ambient concentration (in fresh air) of about 350 ppm. Carbon dioxide is one of the most common by-products of living organisms. With every exhaled breath we produce and release CO₂ into the atmosphere (with an average concentration in exhaled breath of about 3.8%). According to one USDA study, an average person produces about 450 liters (900 grams) of CO₂ per day.

Liquid and solid carbon dioxide (dry ice) are widely used as refrigerants, especially in the food industry. Carbon dioxide is also used in many industrial and chemical industry processes. Carbon dioxide is particularly associated with the beer and wine making industries, where it is produced by yeast during the fermentation process that converts sugar into alcohol. Carbon dioxide in the headspace of fermentation vessels can easily reach 50% by volume or even higher concentrations. Carbon dioxide is also widely used in the oil industry, where it is commonly injected into oil wells to decrease the viscosity and aid in the extraction of oil from mature fields. It is also one of the most common atmospheric hazards encountered in confined spaces.

Carbon dioxide is a primary by-product of bacterial decomposition. As with people, "aerobic" or oxygen using bacteria produce carbon dioxide as a primary metabolic by-product. In many confined spaces there is a direct relationship between low concentrations of oxygen and elevated concentrations of CO₂. In the case of a confined space where CO₂ is generated as a by-product of aerobic bacterial action, a concentration of 19.5% O₂ (the hazardous condition threshold for oxygen deficiency in most jurisdictions) would be associated with an equivalent concentration of at least 1.4% (= 14,000 ppm) CO₂. This is substantially higher than the generally accepted workplace exposure limit for CO₂ (5,000 ppm calculated as an 8-hour TWA).

The true concentration of CO₂ could be substantially higher if the oxygen deficiency is due to displacement rather than consumption of the oxygen in the confined space. Fresh air contains only 20.9% oxygen by volume. The balance consists

mostly of nitrogen, with minor or trace concentrations of a wide variety of other gases including argon, water vapor and carbon dioxide. Because oxygen represents only about one-fifth of the total volume of fresh air, every 5% of a displacing gas that is introduced into a confined space reduces the oxygen concentration by only 1%. As an example, consider an oxygen deficiency due to the introduction of dry ice into an enclosed space. In this case a reading of 19.5% O₂ would not be indicative of 1.4% CO₂, it would be indicative of 5 X 1.4% = 7.0% (= 70,000 ppm) CO₂.

The bottom line is that if you wait until the oxygen deficiency alarm is activated, and the deficiency is due to the presence of CO₂, you will have substantially exceeded the toxic exposure limit long before leaving the affected area.

In spite of these considerations, in the past the majority of atmospheric monitoring programs have treated CO₂ as only a "simple asphyxiant". An asphyxiant is a substance that can cause unconsciousness or death by suffocation (asphyxiation).



Figure 1: Compact multi-sensor instruments are capable of providing direct CO₂ measurement during confined space and other atmospheric monitoring procedures



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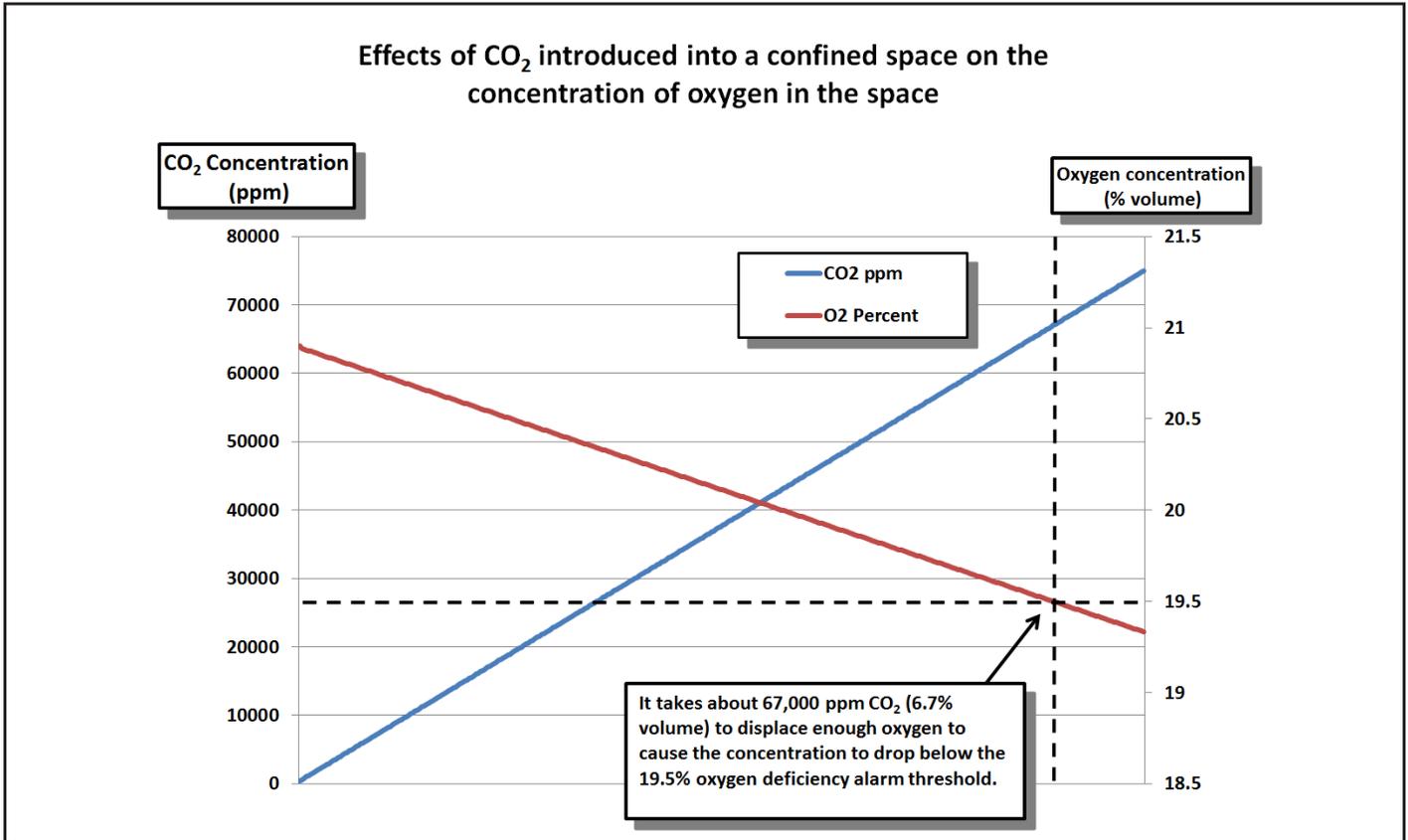


Figure 2: Every 5% of displacing gas introduced into a confined space reduces the O₂ concentration by about 1%.

Asphyxiants which have no other health effects are referred to as “simple” asphyxiants. Because CO₂ was not considered to be a toxic hazard, rather than directly measuring the CO₂ in the confined space or workplace environment, it was seen as adequate to simply measure the oxygen concentration. This attitude is changing as it becomes more feasible (and affordable) to directly measure CO₂ by means of compact, portable multi-sensor gas detectors equipped with miniaturized infrared sensors for the direct measurement of this gas.

- **Carbon dioxide is a toxic contaminant with strictly defined workplace exposure limits**

Carbon dioxide is listed as a toxic contaminant with strictly defined occupational exposure limits in almost every country. The most widely recognized exposure limits for CO₂ reference an 8-hour Time Weighted Average (TWA) of 5,000 ppm, with a 15-minute Short Term Exposure Limit (STEL) of either 15,000 ppm or 30,000 ppm. The following table lists several of the most commonly cited workplace exposure limits:

Standard / Country	8-hour Time Weighted Average	15-minute Short Term Exposure Limit
USA NIOSH REL	5,000 ppm	30,000 ppm
USA OSHA PEL	5,000 ppm	None Listed
ACGIH® TLV®	5,000 ppm	30,000 ppm
United Kingdom WEL	5,000 ppm	15,000 ppm

Carbon dioxide is heavier than air, with a density of 1.5 times that of fresh air. When carbon dioxide is released into an enclosed or confined space it tends to settle to the bottom of the space, reaching the highest concentration in the lowest parts of the space. Because of this tendency to settle, as CO₂ is produced it can reach higher and higher concentrations in localized regions of the space (such as the head space immediately above the liquid in fermentation vats).

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While present as a natural component in fresh air, at higher concentrations exposure symptoms include headaches, dizziness, shortness of breath, nausea, rapid or irregular pulse and depression of the central nervous system. Besides displacing the oxygen in fresh air, high concentrations of CO₂ may exacerbate or worsen the symptoms related to oxygen deficiency, and interfere with successful resuscitation. Even moderately elevated concentrations associated with poorly ventilated indoor spaces can produce physiological symptoms. According to NIOSH chronic exposure to elevated indoor CO₂ concentrations have been linked with the following symptoms:

Concentration	Symptom
250 – 350 ppm	Normal background concentration in outdoor ambient air
350 – 1,000 ppm	Concentrations typical of occupied indoor spaces with good air exchange
1,000 – 2,000 ppm	Complaints of drowsiness and poor air
2,000 – 5,000 ppm	Headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present
5,000 ppm	Workplace exposure limit (as 8-hour TWA) in most jurisdictions
> 40,000 ppm	Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma and even death

According to NIOSH concentrations of 40,000 ppm or higher should be regarded as immediately dangerous to life and health. Exposure to very high concentrations (e.g. exposure to 6% volume CO₂ for several minutes or 30% volume CO₂ for 20-30 seconds), has been linked to permanent heart damage, as evidenced by altered electrocardiograms.

Concentrations greater than 10% are capable of causing loss of consciousness within 15 minutes or less.

- **How NDIR (non-dispersive infrared) CO₂ sensors detect gas**

The most widely used technique for real-time measurement of carbon dioxide is by means of non-dispersive infrared (NDIR)

sensors that measure CO₂ as a function of the absorbance of infrared light at a specific wavelength.

Molecules can be conceptualized as balls (atoms) held together by flexible springs (bonds) that can vibrate (stretch, bend or rotate) in three dimensions. Each molecule has certain fixed modes in which this vibratory motion can occur. Vibrational modes are dictated by the nature of the specific bonds that hold the molecule together. The larger the molecule, the greater the number of modes of movement. Each mode represents vibrational motion at a specific frequency. The modes are always the same for a specific molecule. Chemical bonds absorb infrared radiation. The bond continues to vibrate at the same frequency but with greater amplitude after the transfer of energy. For infrared energy to be absorbed (that is, for vibrational energy to be transferred to the molecule), the frequency must match the frequency of the mode of vibration.

Specific molecules absorb infrared radiation at precise wavelengths. When infrared radiation passes through a sensing chamber containing a specific contaminant, only those wavelengths that match one of the vibration modes are absorbed. The rest of the light is transmitted through the chamber without hindrance. The presence of a



Figure 3: IR CO₂ sensors detect gas as a function of absorbance of infrared light at a specific wavelength

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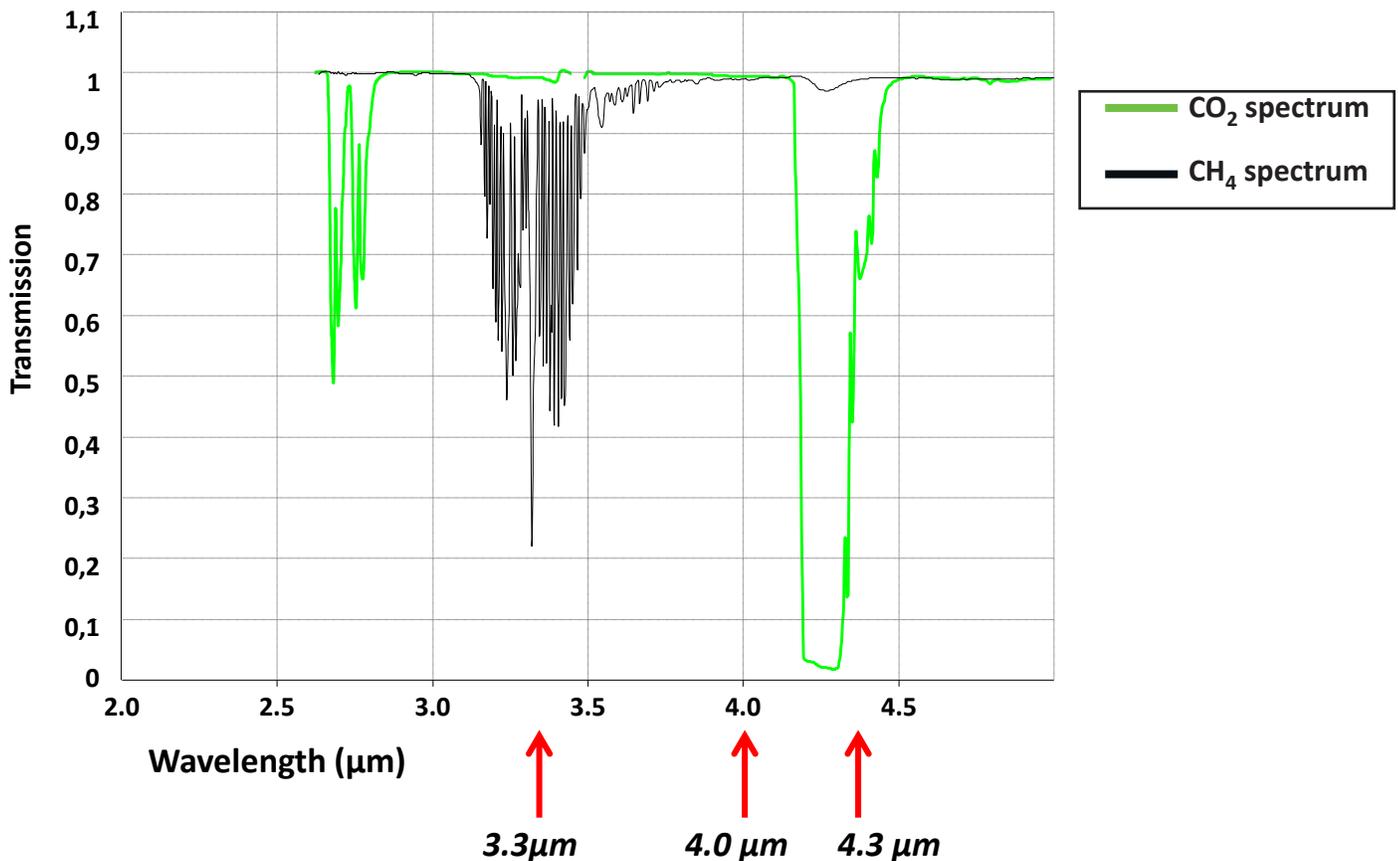


Figure 4: Infrared transmittance spectra for methane and carbon dioxide. IR sensors usually measure CO₂ at a wavelength of 4.3 μm (= 4,300 nm). IR CO₂ sensors usually use 4.0 μm (= 4,000 nm) as the reference since neither CO₂ or water absorbs much IR light at this wavelength. Combustible gases like methane are usually measured around 3.3 μm (= 3,300 nm).

particular chemical group within a molecule thus gives rise to characteristic absorption bands. Since most chemical compounds absorb at a number of different frequencies, IR absorbance can provide a "fingerprint" for use in identification of unknown contaminants.

Alternatively, for some molecules it may be possible to find an absorbance peak at a specific wavelength that is not shared by other molecules likely to be present. In this case absorbance at a particular wavelength can be used to provide substance-specific measurement for a specific molecule. Carbon dioxide has such an absorbance peak at a wavelength of 4.3 microns (μm). Absorbance of infrared light at this wavelength is proportional to the concentration of CO₂ present in the sensing chamber of the sensor. The absorbance is not linear per concentration unit, but is mathematically predictable and easily calculated by microprocessor equipped portable gas detectors.

Miniaturized NDIR CO₂ sensors include an infrared light source (typically a tungsten filament lamp) capable of emitting light in the desired wavelengths. Optical filters are used to limit the light transmitted through the sensing chamber to a narrow range of wavelengths. Most NDIR CO₂ sensors are dual detector systems that provide both a reference and an active signal. Pyroelectric detectors capable of measuring absorbance at the specific wavelengths of interest are used to provide the measurement and reference signals. The active detector in a CO₂ sensor measures the amount of light in the 4.3 μm range that reaches the detector after passing through the sensing chamber. The reference detector measures the amount of light at another wavelength (or range of wavelengths) where there is no absorbance for the gas of interest. The greater the concentration of CO₂, the greater the reduction in the amount of light that reaches the active detector when compared to the reference signal.

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Figure 5: Infrared CO₂ sensors are also available for use in continuously operational “fixed” detection systems.

In the past, infrared based instruments have tended to be bulky, expensive, and required a high level of operator expertise to obtain accurate readings. A new generation of miniaturized NDIR sensors has permitted the development of infrared based instruments for an ever widening variety of atmospheric hazards including carbon dioxide, Freons®, ammonia, and methane, as well as generalized hydrocarbon combustible gas detection.

The regulations are already changing. Recent fatalities in the wine industry in California and Oregon have heightened concerns, and increased the obligation for direct CO₂ measurement during workplace procedures that may expose workers to this contaminant in the wine making industry. In Germany and Austria regulations already require direct measurement of CO₂ during most confined space entry procedures. It is clear that with the increased availability, and increasingly affordable cost of miniaturized NDIR CO₂ sensors, more and more atmospheric monitoring programs will include the direct measurement of this dangerous atmospheric contaminant.

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Portable Gas Detectors for Landfill Gases

The key to success is understanding the monitoring environment, and the specific benefits and limitations of the sensors selected



Anyone who has ever visited or driven by a sanitary landfill is aware that they are frequently associated with the presence of (often) very smelly gases. As unpleasant as the odours can be, there is far more going on than can be detected by human senses.

Landfill gas is potentially explosive, oxygen deficient and often highly toxic. Unfortunately, many of the most dangerous gases associated with landfills have very poor warning properties or are completely invisible to human senses. One of the most common protective measures at landfill sites is to utilise portable atmospheric monitors to keep workers safe. Choosing the best instrument requires a good understanding of the gases that need to be measured, as well as the

capabilities and limitations of the sensing technology used by the instrument to obtain readings.

What is landfill gas composed of?

'Landfill gas' is a complex mixture of hundreds of different types of individual gases and vapours. However, by far the most common components are methane (CH_4) and carbon dioxide (CO_2). According to the USA Agency for Toxic Substances and Disease Registry (ATSDR), landfill gas typically contains 45% to 60% methane and 40% to 60% carbon dioxide. Landfill gas often also includes small amounts of ammonia, sulphides (such as hydrogen sulphide and mercaptans), carbon monoxide, hydrogen, and volatile organic compounds (VOCs)

such as trichloroethylene, benzene, and various solvent vapours. Besides the importance of what landfill gas contains, it's equally important to understand what's missing. Landfill gas includes very little oxygen and nitrogen. Besides the explosion threat due to the presence of very high levels of methane, landfill gas also represents a significant threat of asphyxiation to unprotected workers.

How is landfill gas produced?

Sanitary landfills are sites where waste is isolated from the environment until it is safe - in other words, when it has completely degraded biologically, chemically and physically. Typically, non-hazardous waste landfills are confined to as small an area as possible, compacted to reduce their volume, and covered (usually daily) with layers of soil to reduce nuisance odours and facilitate microbial decomposition.

“most landfill gas is produced by bacterial decomposition of organic waste. Bacteria decompose organic waste in four phases, and the composition of the gas changes during each phase”

Most landfill gas is produced by bacterial decomposition of organic waste. Bacteria decompose organic waste in four phases, and the composition of the gas changes during each phase. Since landfills often accept waste over a period of several decades, waste in different locations or vertical layers in the landfill may be undergoing different phases of decomposition at the same time. The gases produced by older waste in one area might be quite different to those produced by more recently buried waste in another area.

Fresh air contains 20.9% oxygen, and about 79% nitrogen. That is the starting point for the atmospheric changes that occur during the decomposition process. During the first phase of decomposition, aerobic (oxygen using) bacteria consume oxygen while breaking down the organic waste. The primary by-product of this process is carbon dioxide. Although nitrogen is not consumed by this process, it tends to be displaced by the heavier than air carbon dioxide and other gases being produced. Over time the concentration of nitrogen in the landfill gas declines to ever lower concentrations.

“waste in different locations or vertical layers in the landfill may be undergoing different phases of decomposition at the same time. The gases produced by older waste in one area might be quite different to those produced by more recently buried waste in another area”

Aerobic decomposition continues until all the oxygen is used up. Depending on environmental conditions such as compaction and the amount of oxygen initially present, the process can take from a few days to months to complete.

Once the oxygen has been used up, the second phase of anaerobic decomposition can begin. Anaerobic bacteria do not require oxygen. In fact, they can only exist in an active state in environments that contain little or no oxygen. Anaerobic bacteria produce a variety of by-products including hydrogen, alcohols (e.g. ethanol and methanol), organic acids (e.g. acetic and lactic acid) and sulphides (e.g. H₂S and mercaptans). During this phase of decomposition the landfill becomes increasingly acidic. The primary by-products during phase two are hydrogen and carbon dioxide.

In the third phase other types of anaerobic bacteria consume the organic acids produced in the second phase to produce acetate as their main metabolic by-product. This has the effect of lowering the acidity of the landfill, and creating the conditions necessary for yet another category of anaerobic bacteria, the methanogens, to flourish. Methane producing bacteria consume acetate and carbon dioxide produced by the other types of anaerobic bacteria. The whole process requires a 'healthy' ecosystem of many different types of bacteria that interact with each other through their metabolic by-products. Conditions which are deleterious to the existence of one of the necessary members of this complex ecosystem can slow or even shut down the decomposition process.

In the fourth phase, a stable ecosystem of anaerobic bacteria develops that can persist and produce gas at a steady rate over decades. Phase four landfill gas usually contains approximately 45% to 60% methane by volume, 40% to 60% carbon dioxide, and 2% to 9% other gases including H₂S and other sulphides. Not only does landfill gas represent a significant threat with regards to explosion and asphyxiation hazards, it is also often extremely toxic. A single breath of 1,000 ppm H₂S is enough to kill.

“not only does landfill gas represent a significant threat with regards to explosion and asphyxiation hazards, it is also often extremely toxic. A single breath of 1,000 ppm H₂S is enough to kill”

Besides bacterial action, several other landfill processes can act to produce gas and vapours. Certain wastes, particularly the organic compounds in paints, solvents and other petrochemicals can change over time - especially in the hot underground landfill environment - from a liquid or a solid into a vapour. The process is known as 'volatilisation.' Many volatile organic chemicals (VOCs) are highly toxic. Besides representing an atmospheric hazard, VOCs such as benzene and trichloroethylene can also contaminate the water table, presenting yet another challenge to landfill operators. VOCs and toxic chemicals can also be created by the reactions of chemicals present in the waste. Simple household cleaners, such as ammonia and chlorine bleach, can react together to form highly toxic chemical by-products. Not only are the chemicals potentially toxic to humans, they can also be toxic to the landfill's microbial ecosystem. ➤



What happens to the landfill gas after it is produced?

Lighter than air landfill gases such as methane tend to move upward through interstices or pores in the soil and landfill material, and eventually reach the landfill surface. Once they reach the surface, unless the gas is collected and contained, it diffuses into the general atmosphere. The upward movement can be slowed by compacting and/or covering the landfill with soil. When the path for upward movement is blocked, the gas tends to migrate horizontally. Eventually the gas finds a route to the surface. This could be in another area within the landfill, or in an area outside the landfill. Heavier than air gases such as carbon dioxide also migrate laterally, and are particularly prone to collect in voids or spaces in the landfill, producing pockets of high concentration. CO₂ is particularly prone to collecting in utility vaults, basements and passages around (or adjacent to) the landfill site.

“lighter than air landfill gases such as methane tend to move upward through interstices or pores in the soil and landfill material, and eventually reach the landfill surface”

People can be exposed to landfill gases either at the landfill or in their communities. Once landfill gases reach the surface, they spread into the general atmosphere, where they can be carried by air currents and breezes to anywhere downwind. Gases may also move through the soil underground and enter homes, basements, trenches, vaults and other enclosed or confined spaces. Many landfill sites have systems to collect the gas before it has a chance to escape. Collection systems

can significantly reduce the amount of methane and other gases (and odours) released to the atmosphere.

“when the path for upward movement is blocked, the gas tends to migrate horizontally. Eventually the gas finds a route to the surface. This could be in another area within the landfill, or in an area outside the landfill”

Portable atmospheric monitors for measuring landfill gases

Landfill monitoring applications involve a number of unique requirements. The anaerobic decomposition of the organic material in the buried waste has the potential for generating massive quantities >

G460 sensors





G460 instruments are compact, easy to use and provide a comprehensive solution for all gas detection applications

of methane and carbon dioxide, as well as potentially lethal concentrations of hydrogen sulphide.

'Wheatstone Bridge' type LEL sensors detect gas by catalytically oxidizing or 'burning' the gas on an active bead or 'pellistor' located within the sensor. The 'active' bead is treated with a platinum or palladium-based catalyst that facilitates the oxidation of combustible gas on the bead. Even trace amounts of gas or vapour in the air surrounding the sensor can be catalytically oxidised on the active bead. As oxidation occurs the bead is heated to a higher temperature. A 'reference' bead in the circuit that has not been treated with catalyst provides a comparison value. Since heating due to oxidation of the combustible gas only occurs on the active bead, the difference in temperature between the two beads is proportional to the concentration of gas in the area where the sensor is located.

“Wheatstone Bridge’ type LEL sensors detect gas by catalytically oxidising or ‘burning’ the gas on an active bead or ‘pellistor’ located within the sensor”

An important limitation of this type of sensor is that it requires the presence of oxygen in order to oxidise the gas being measured. Most manufacturers stipulate that the atmosphere must contain at least 10% O₂ in order for the LEL sensor to detect gas accurately. Readings are increasingly affected as the concentration drops below this level. In zero percent O₂ pellistor type combustible sensors cannot detect gas at all. For this reason confined space instruments

that contain catalytic pellistor type LEL sensors should also include a sensor for measuring oxygen.

“landfill instruments need to be able to measure in the percent volume as well as percent LEL ranges. Unfortunately, the ‘high range’ concentrations of methane present in landfill gas (40% or higher) can rapidly damage or destroy catalytic pellistor sensors”

Another concern is the high concentrations of combustible gas that may be present. Landfill instruments need to be able to measure in the percent volume as well as percent LEL ranges. Unfortunately, the 'high range' concentrations of methane present in landfill gas (40% or higher) can rapidly damage or destroy catalytic pellistor sensors.

“an alternative approach is to replace the catalytic pellistor sensor with a non-dispersive infrared (NDIR) sensor that measures gas as a function of the absorbance of infrared light”

An alternative approach is to replace the catalytic pellistor sensor with a non-dispersive infrared (NDIR) sensor that measures gas as a function of the absorbance of infrared light. NDIR sensors measure gas as a function of the absorbance of infrared light at a specific wavelength or range of wavelengths. In the case of combustible gas, the wavelength most frequently used is 3.3 μm (micrometres). An active detector in an NDIR combustible gas sensor measures the amount of infrared light absorbed at this wavelength. A reference >

Portable multi-sensor landfill gas monitors can be equipped with standard pellistor LEL, NDIR combustible gas, NDIR CO₂, PID and a wide range of other sensors for the direct measurement of toxic gases



detector measures the amount of light at another wavelength where there is no absorbance. The greater the concentration of combustible gas, the greater the reduction in the amount of light that reaches the active detector when compared to the reference signal.

The other most prevalent hazard associated with landfill gas is carbon dioxide. It should be noted that CO₂ is not a 'simple asphyxiant' that harms workers only by displacing oxygen. Carbon dioxide is a recognised toxic gas, with an exposure limit of 5,000 ppm (8 hour TWA) in most jurisdictions. Carbon dioxide is much heavier than air, and can easily accumulate in excavations, trenches and other localised areas. Besides the danger to workers, these localised areas of oxygen deficiency may not contain enough O₂ for catalytic bead LEL sensors to accurately detect combustible gas. The most widely used technique for real-time CO₂ measurement is also by means of an NDIR sensor. Carbon dioxide has an absorbance peak at a wavelength of 4.3 microns (µm). Absorbance of infrared light at this wavelength is proportional to the concentration of CO₂ present in the sensing chamber of the sensor.

“no single type of gas detector is perfect for all landfill gas monitoring applications. The key to success is understanding the monitoring environment, and the specific benefits and limitations of the sensors selected”

If the landfill gas is associated with the presence of toxic VOCs, it may be advisable to include a photoionisation detector (PID) in the instrument as well. Photoionisation detectors use high-energy ultraviolet light from a lamp housed within the detector as a source of energy used to remove an electron from neutrally charged VOC molecules, producing a flow of electrical current proportional to the concentration of contaminant. Photoionisation detectors are able to measure VOC concentrations from the parts-per-billion range up to 10,000 ppm.

If the landfill gas is associated with the presence of a specific gas like H₂S, ammonia or carbon monoxide, the instrument should ideally include substance specific electrochemical sensors for the direct measurement of these gases.

Yet another consideration is that landfill instruments are often used to obtain readings from 'bore holes' drilled into the buried material. This type of usage requires the instrument to be available for use with a motorised pump.

An optimal solution in this case would be an instrument equipped with a dual-channel infrared sensor that measures absorbance at two different wavelengths, 3.3µm for combustible gas, and 4.3µm for CO₂. The infrared sensor is 'dual-range' as well as dual-channel. Combustible gas can be measured in either of two user-selectable ranges: 1 - 100% LEL or 1 - 100% volume. Ideally the instrument

should also be equipped with substance-specific sensors for measuring O₂, CO and H₂S, and a photoionisation detector (PID) for measuring toxic VOCs.

No single type of gas detector is perfect for all landfill gas monitoring applications. The key to success is understanding the monitoring environment, and the specific benefits and limitations of the sensors selected. ■

Author

Robert Henderson is President of GfG Instrumentation, Inc. Mr Henderson has been a member of the American Industrial Hygiene Association since 1992. He is a past chair of the AIHA Gas and Vapour Detection Systems Technical Committee, as well as a current member and past chair of the AIHA Confined Spaces Committee. He is also a past chair of the Instrument Products Group of the Industrial Safety Equipment Association.

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AP 1018:

Understanding catalytic LEL combustible gas sensor performance



In spite of the millions of combustible sensor equipped atmospheric monitors in service around the world, there is still a lot of misinformation and misunderstanding when it comes to the performance characteristics and limitations of this very important type of sensor. Understanding how combustible sensors detect gas is critical to correctly interpreting readings, and avoiding misuse of instruments that include this type of sensor.

The potential presence of combustible gases and vapors is one of the most common of all categories of atmospheric hazards. It stands to reason that the sensors used to measure combustible gases are the most widely used type of sensor included in portable atmospheric monitors; especially those used in confined space atmospheric monitoring procedures. In spite of the millions of combustible sensor equipped atmospheric monitors in service in the United States, there is still a lot of misinformation and misunderstanding when it comes to the performance characteristics and limitations of this very important type of sensor. Understanding how combustible sensors detect gas is critical to correctly interpreting readings, and avoiding misuse of instruments that include this type of sensor.

What do percent LEL combustible gas sensors measure?

In order for an atmosphere to be capable of burning explosively, four conditions must be met. The atmosphere must contain adequate oxygen, adequate fuel, a source of ignition, and sufficient molecular energy to sustain the fire chain reaction.

These four conditions are frequently diagrammed as the "Fire Tetrahedron". If any side of the tetrahedron is missing, incomplete or insubstantial; combustion will not occur.

The minimum concentration of gas or vapor in air that will ignite and explosively burn if a source of ignition is present is the Lower Explosive Limit. Different gases and vapors have different LEL concentrations. Below the LEL, the ratio of combustible gas molecules to oxygen is too low for combustion to occur. In other words, the mixture is "too lean" to burn.

Most (but not all) combustible gases and vapors also have an upper limit of concentration beyond which ignition will not occur. The Upper Explosion Limit or UEL is the maximum concentration of combustible gas or vapor in air that will support combustion. Above the UEL, the ratio of gas to oxygen is too high for the fire reaction to propagate. In other words, the mixture is "too rich" to burn. The difference in concentration between the LEL and UEL is commonly referred to as the Flammability Range. Combustible gas concentrations within the flammability range will burn or explode provided that the other conditions required in the fire tetrahedron are met.



Figure 1 : Multi-sensor portable instruments almost always include a sensor for measurement of combustible gas. The G460 is capable of being equipped with sensors designed to measure up to six different atmospheric hazards at the same time.



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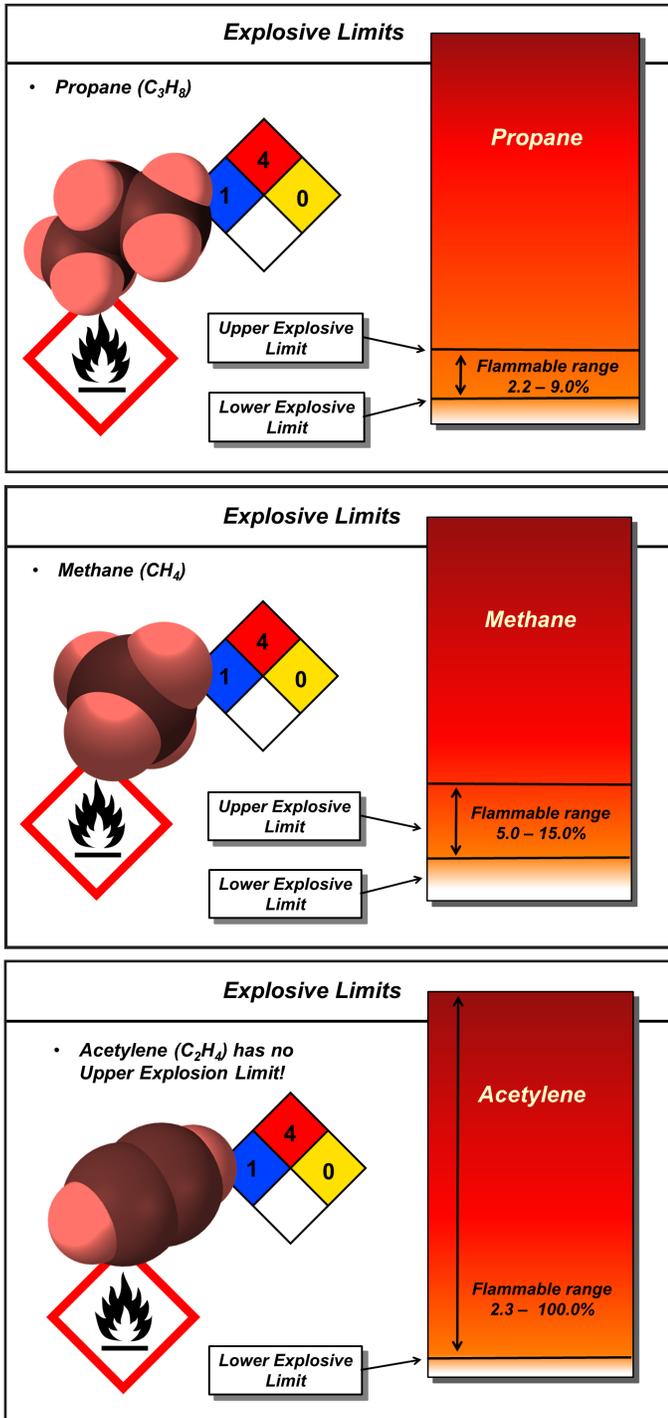


Figure 2: The flammability range varies widely between combustible gases. To avoid confusion gas detecting instruments usually read in percent LEL rather than percent volume increments.



Figure 3: The G460 is able to use wide range of sensors and detection technologies including O₂, standard pellistor LEL, NDIR combustible gas and CO₂, PID and over 23 different substance-specific electrochemical sensors for toxic gas measurement.

Because the flammability range varies widely between individual gases and vapors, most regulatory standards express hazardous condition thresholds for combustible gas in air in percent LEL concentrations.

Most combustible gas instruments read from 0 to 100 % LEL. For this reason, most combustible gas reading instruments also display readings in percent LEL increments, with a full range of 0 – 100% LEL. Typically, these sensors are used to provide a hazardous condition threshold alarm set to 5% or 10% of the LEL concentration of the gases or vapors being measured. Readings are usually displayed in increments of + 1% LEL. Ten percent LEL is the default alarm set point on many instruments.

A fire hazard should always be deemed to exist whenever readings exceed 10 % LEL. This is the least conservative (or highest acceptable) alarm set point for instruments used for monitoring combustible gases and vapors in confined spaces. An important consideration is that many circumstances warrant a more conservative, lower alarm set point. The presence of any detectable concentration of flammable/combustible gas

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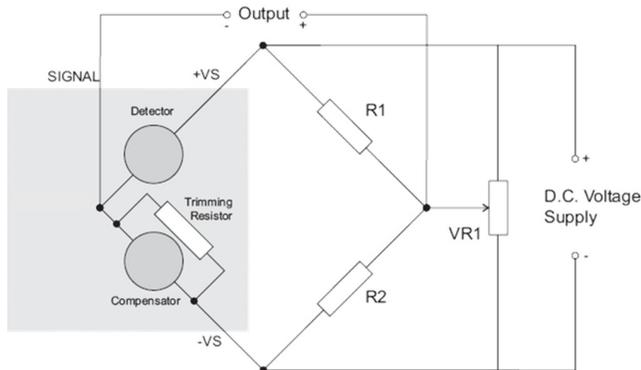


Figure 4: Catalytic “Pellistor” LEL sensors detect combustible gas by catalytic oxidation. When exposed to gas the oxidation reaction causes the “active” bead to heat to a higher temperature. Pellistor LEL sensors require oxygen to detect gas!

in the confined space indicates the existence of an abnormal condition.

The only completely safe concentration of combustible gas in a confined space is 0% LEL. In addition, specific procedures or activities may require taking action at a lower concentration. For instance, the preamble to OSHA 29 CFR 1910.146, “Permit-required confined spaces,” suggests that a maximum “safe for entry” threshold of only 5% LEL should be used for entries conducted according to the “Alternate Entry Procedures” in paragraph (c)(5) of the standard.

How combustible sensors detect gas

Most commonly used combustible gas sensors detect gas by catalytically oxidizing or “burning” the gas on an active bead or “pellistor” located within the sensor.

While there are numerous variations, the underlying detection principle has not changed for the better part of a century. The catalytic-bead sensor contains two coils of fine platinum wire which are coated with a ceramic or porous alumina material to form beads.

The beads are wired into opposing arms of a balanced Wheatstone Bridge electrical circuit. One bead is additionally treated with a platinum or palladium-based material that allows catalyzed combustion to occur on the “active” (or detector) bead. The catalyst is not consumed during combustion. Combustion occurs at concentrations far below the LEL concentration. Even trace amounts of gas or vapor

in the air surrounding the sensor can oxidize catalytically on the active bead. The “reference” bead in the circuit lacks the catalyst material, but in other respects exactly resembles the active bead.

A voltage applied across the active and reference beads causes them to heat. Heating is necessary for catalytic oxidation to occur. The temperature required may be as high as 500°C, or in some cases, even higher. In fresh air the Wheatstone Bridge circuit is balanced; that is, the voltage output is zero.

If combustible gas is present, oxidation heats the active bead to an even higher temperature. The temperature of the untreated reference bead is unaffected by the presence of gas. Because the two beads are strung on opposite arms of the Wheatstone Bridge circuit, the difference in temperature between the beads is registered by the instrument as a change in electrical resistance.

Heating the beads to normal operating temperature requires power from the instrument battery. The amount of power required is a serious constraint on the battery life of the instrument. Recent sensor designs have attempted to reduce the amount of power required by reducing the size of the beads, sometimes operating the beads at a lower temperature, and

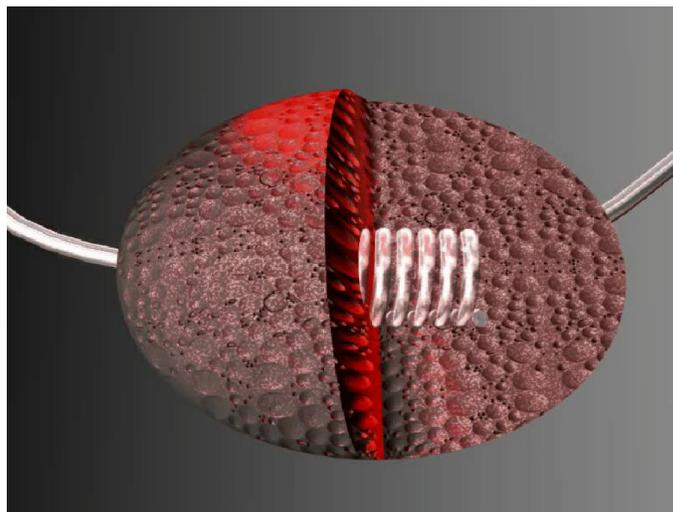


Figure 5: The active “Pellistor” bead is strung onto a coiled platinum filament wire. Most oxidation occurs on inside of the bead rather than the surface. Smaller molecules penetrate and reach active sites where they can be oxidized more easily than larger molecules. In general, larger molecules have a lower relative response than smaller molecules.

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using discontinuous or pulsed power patterns during periods when the beads are not actually responding to gas. While this approach may result in longer battery life, it may also result in the sensor being easier to poison or inhibit. Since smaller beads contain less catalyst, it takes less exposure to poisons or inhibitors to affect the sensor. It is particularly important to verify the calibration of low power combustible sensors by exposure to known concentration test gas on a regular basis. The combustible sensor elements are usually enclosed in a robust stainless-steel housing.

Gas enters the sensor by first passing through a sintered, stainless steel flame arrestor. The sensor may additionally include external moisture barrier and / or other filters designed to remove specific contaminants (such as silicones or hydrogen sulfide).

The sintered flame arrestor acts as a physical barrier that slows or inhibits the free diffusion of gas molecules into the sensor. The smaller the molecule, the more readily it is able to diffuse

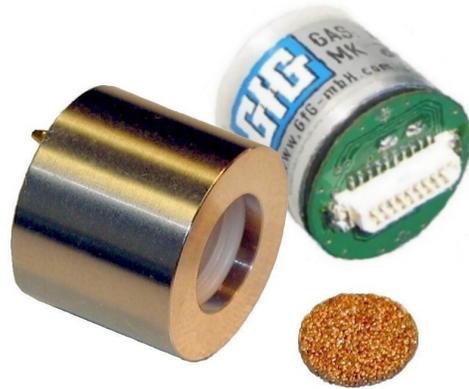


Figure 6: Most catalytic-bead LEL sensors are flame-proof devices housed in a robust, stainless steel housing. A flame arrestor (sinter) prevents energy that could potentially ignite combustible gases from being released by the sensor.

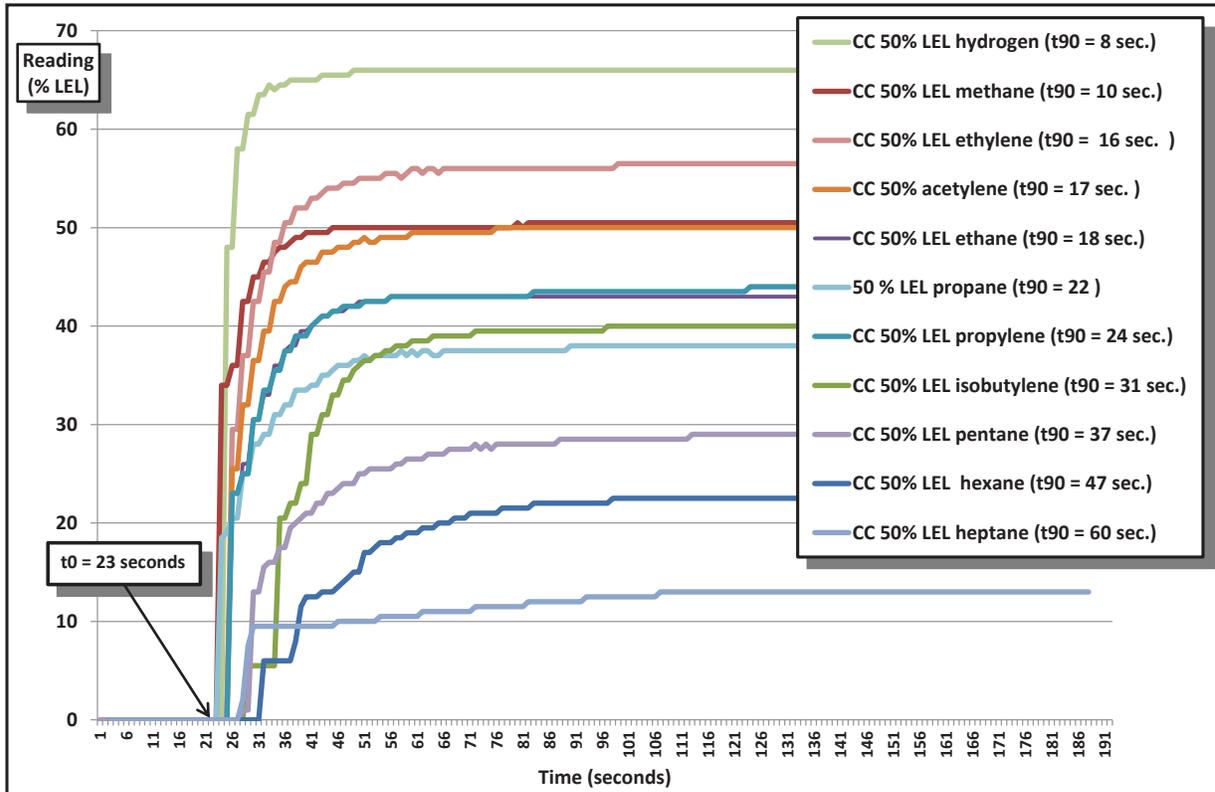


Figure 7: Catalytic type LEL sensors used in portable instruments generally show lower relative responses to larger molecules than to smaller. In the example above the response to methane (CH₄) is about two times higher than the response to pentane (C₅H₁₂), and about four times higher than the response to heptane (C₇H₁₆). The response to larger molecules is also much slower. It takes 10 seconds for the methane reading to reach t90 (90% of its final stable response), while it takes a full minute for heptane.

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Relative response of a flammable / combustible gas sensor			
Combustible gas / vapor	Relative response when sensor calibrated to pentane	Relative response when sensor calibrated to propane	Relative response when sensor calibrated to methane
Hydrogen	2.2	1.7	1.1
Methane	2.0	1.5	1.0
Propane	1.3	1.0	0.65
n-Butane	1.2	0.9	0.6
n-Pentane	1.0	0.75	0.5
n-Hexane	0.9	0.7	0.45
n-Octane	0.8	0.6	0.4
Methanol	2.3	1.75	1.15
Ethanol	1.6	1.2	0.8
Isopropanol	1.4	1.05	0.7
Acetone	1.4	1.05	0.7
Ammonia	2.6	2.0	1.3
Toluene	0.7	0.5	0.35
Gasoline (unleaded)	1.2	0.9	0.6

Table 1: Catalytic pellistor LEL combustible gas sensor response curves. The smallest molecules (CH₄ and H₂) have the highest relative responses. The largest detectable hydrocarbon molecules (octane and nonane) have the lowest relative responses.

through the flame arrestor, penetrate the sintered surface of the bead, and interact with the catalyst in the oxidation reaction.

Catalytic combustible gas sensors are unable to differentiate between different combustible gases. They provide one signal based on the total heating effects of all the gases capable of being oxidized that are present in the vicinity of the sensor.

Catalytic-bead sensors respond to a wide range of ignitable gases and vapors. The heating effect on the active bead varies between gases. For this reason readings may vary between equivalent concentrations of different combustible gases. As an example, a 50% LEL concentration of pentane provides only about one-half of the heating effect on the active bead of the sensor as a 50% LEL concentration of methane on the same sensor. Another way of expressing this relationship is as a “relative response” of the sensor to pentane. When the instrument is calibrated to methane, the relative response of the sensor to pentane is only 50%. This means that the readings for pentane will be only 50% of the true concentration.

As a general rule, with regards to the catalytic type LEL sensors used in portable instruments, the larger the molecule, the lower the relative response, and the longer it takes for the sensor to reach a final stable reading.

Role of flash point in monitoring of ignitable gases and vapors

In order for combustion to occur, the vapor of the substance must be present in the atmosphere. As a general rule, it's the vapor, not the liquid that burns. Vaporization is a function of temperature. Increasing the temperature of the liquid increases the rate and amount of vapor that is produced. The flashpoint temperature is the minimum temperature at which a liquid gives off enough vapor to form an ignitable concentration.

Catalytic-bead sensors, at least when operated in the percent LEL range, may not adequately detect “heavy” or long-chain hydrocarbons, or the vapors from high flashpoint temperature liquids such as turpentines, diesel fuel or jet fuel. Use of alternative types of gas detectors, such as a photoionization detector (PID) may be a better approach if you need to monitor for the presence of these types of hydrocarbon vapors. Some manufacturers suggest that their percent LEL sensors should not be used measure volatile aromatic compounds (VOCs) or combustible liquids with flashpoint temperatures higher than 100°F (38°C). Consult the Operator’s Manual, or contact the manufacturer directly to verify the capabilities of the instrument design when using a catalytic-bead LEL sensor to monitor for the presence of these types of contaminants.

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Figure 8: Fixed system LEL sensors are operated by means of line supplied power. Fixed LEL sensors are generally more robust, but also require more power than the sensors used in portable instruments.

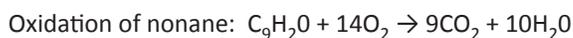
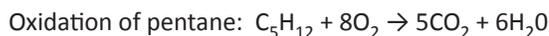
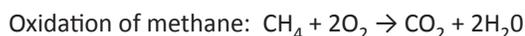
Sensor optimization for specific gases

Fixed pellistor sensors are quite a bit different from the low power LEL sensors used in portable instruments. They have much larger beads, (hence they are a lot harder to poison), take a lot more power to operate, and are built in a way that optimizes performance for certain types of detectable gas.

Ways to modify the sensor to optimize it for a specific category of hydrocarbon vapor (like gasoline) include changing the characteristics of the flame arresting sinter to allow larger molecules to penetrate it more easily, leaving out or changing the characteristics of other internal or external filters, making changes to the catalyst used to oxidize gas, changing the porosity of the bead to allow larger molecules to penetrate more readily, and allowing the molecules created by the oxidization of the flammable gas to escape from the sensor more easily.

Large molecules, when they are oxidized, produce a lot more water vapor molecules than smaller hydrocarbon molecules. The catalyzed oxidation reaction proceeds stoichiometrically, is very clean, and in most cases does not produce soot or other by-products of incomplete oxidation. The oxidation of a typical hydrocarbon consumes the molecule of gas, the necessary molecules of oxygen; and produces CO_2 and H_2O as reaction by-products.

For instance:



Most of the oxidation occurs within the volume of the active bead rather than on the surface. Although oxidation occurs only when the molecules are in physical contact with the catalyst coated surfaces within the bead, the by-products of the reaction, once produced, rapidly diffuse away from the catalyst surface. The very hot CO_2 and H_2O gas molecules produced by the oxidation reaction regionally attenuate the density of the air within the volume of the bead, allowing the bead to shed heat a little more efficiently, thus reducing the heating effect of the oxidation of the gas on the bead. This translates into a lower signal output, since the temperature of the compensator bead is unaffected (or little effected) by these local changes in atmospheric density.

The water vapor produced by the oxidation of larger molecules creates a significant net outward flux of molecules from the active bead. To oxidize one molecule of methane, three molecules enter the sensor, and three molecules are produced as by-products of the reaction. To oxidize one molecule of pentane, nine molecules enter the sensor, and 11 molecules are produced as by-products. With nonane, 15 molecules enter, but 19 need to leave the sensor.

One way to optimize a sensor for the detection of a large hydrocarbon molecule (like nonane) is to etch the bead a little more deeply, creating larger channels (or “chimneys”) through which the gas diffuses to reach the active sites within the bead. The larger channels facilitate both entry and exit of molecules from the bead. Because the heated molecules produced in the oxidation reaction escape more easily, there is less attenuation of the atmosphere within the volume of the bead, and you see a higher relative response of the sensor to the larger molecules of gas being oxidized.

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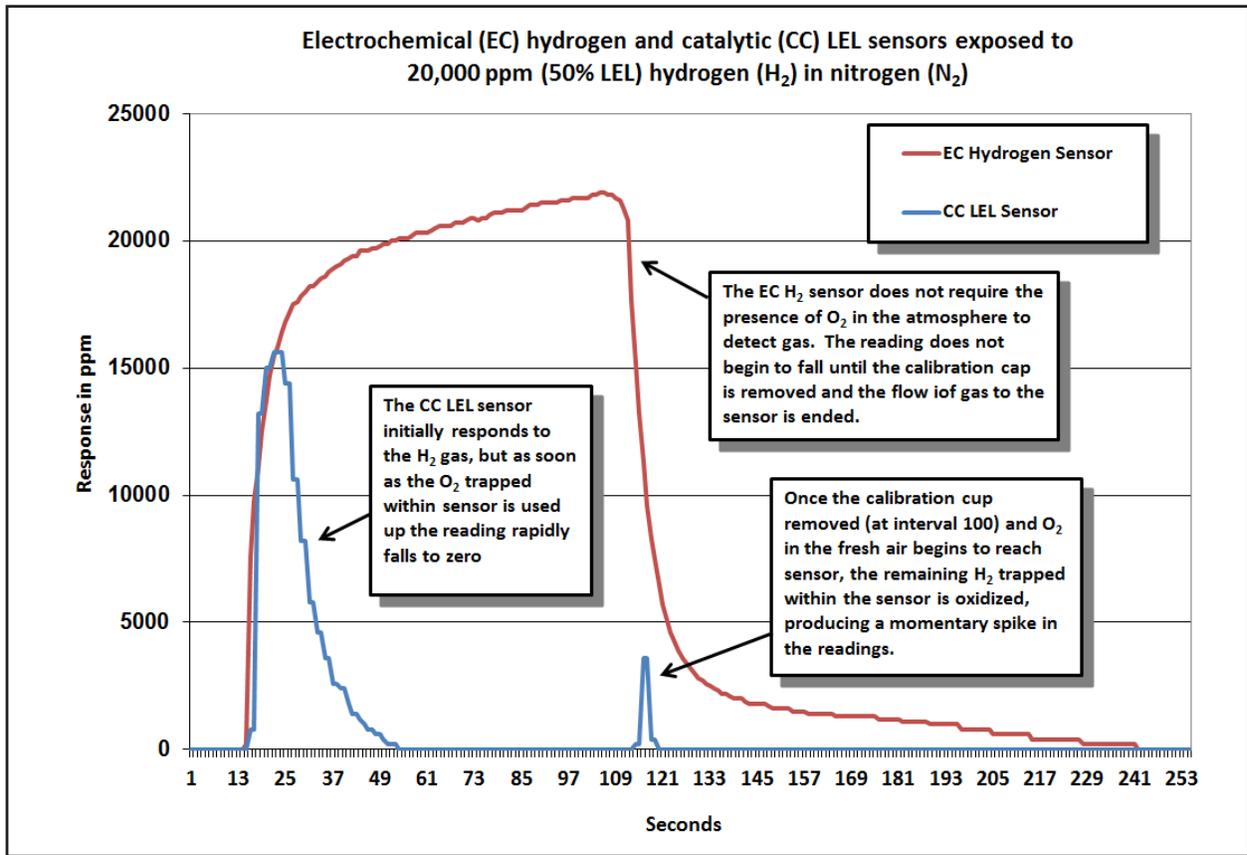


Figure 9: Catalytic LEL sensors require the presence of oxygen to detect gas. In the absence of O₂ readings rapidly fall to zero.

Changing the characteristics of the active bead has a profound effect on the sensor. The relative response curves for a GfG fixed LEL sensor optimized for “hexane” are very different than the response curves for the “methane” optimized version of the sensor. For instance, the relative response of the methane sensor to pentane is about 50% (just like it is for most portable LEL sensors). However, the relative response of the fixed “hexane” LEL sensor to methane is very close to one to one.

Catalytic-bead combustible sensors need oxygen to detect gas

Catalytic-bead sensors require at least eight to ten percent oxygen by volume to detect accurately. A combustible sensor in a 100 percent gas or vapor environment will produce a reading of zero percent LEL. This is the reason that testing protocols for evaluating confined spaces specify measuring oxygen first and

then combustible gases and vapors. For this reason confined space instruments that contain catalytic-bead sensors should also include a sensor for measuring oxygen. If the instrument being used does not include an oxygen sensor, be especially cautious when interpreting results. A rapid up-scale reading followed by a declining or erratic reading may indicate that the environment contains insufficient oxygen for the sensor to read accurately. (It may also indicate a gas concentration beyond the upper scale limit for the sensor, the presence of a contaminant which has caused a sudden inhibition or loss of sensitivity in the sensor, or other condition which prevents the sensor or instrument from obtaining proper readings.) The minimum amount of oxygen that must be present for the sensor to detect accurately is a function of design. Capabilities vary from one manufacturer to another. Users who anticipate using their instruments in potentially oxygen deficient environments should contact the manufacturer for assistance.

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Calibration and relative response of combustible sensors

A combustible gas sensor may be calibrated to any number of different gases or vapors. Where possible, the user should calibrate the instrument to achieve the level of sensitivity required for the substances to be measured.

Calibration is a two-step procedure. In the first step the instrument is exposed to contaminant free "fresh" air (that is, air which contains 20.9 % oxygen and no combustible gas), turned on, and allowed to warm-up fully. The combustible sensor should read zero. If necessary, the combustible sensor is adjusted to read zero. Instrument manuals and other support materials usually refer to this step as the "fresh air zero."

The second step is to expose the sensor to known concentration calibration gas, and (if necessary) adjust the readings to match the concentration. This is called making a "span adjustment". A "span adjustment" sets the sensitivity of the sensor to a specific gas. Always follow the manufacturer's instructions when calibrating or adjusting the instrument.

Instruments used only for a monitoring a single gas should be calibrated with that particular gas. Calibration choices are more difficult when the instrument may be exposed to a variety of different combustible gases because, as noted previously, equivalent concentrations of different combustible gases may produce different readings.

Gases that produce lower relative readings than the gas used to calibrate the instrument can create a potentially dangerous error.

Catalytic-bead poisons and inhibitors

The atmosphere in which an instrument is used can have an effect on catalytic-bead sensors. Poisoning or degraded performance can occur when combustible sensors are exposed to certain substances. Commonly encountered substances that degrade LEL sensor performance include silicones, lead

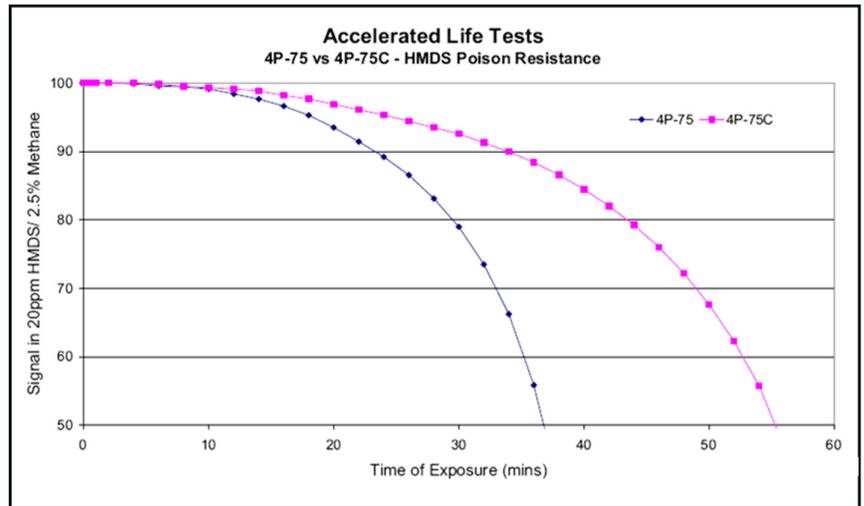


Figure 10: Effects of hexa-methyl-di-siloxane (HMDS) on catalytic pellistor sensors. HMDS is a virulent LEL sensor poison. Other examples of combustible sensor poisons include H2S, PH3, other silicon containing vapors and tetraethyl lead.

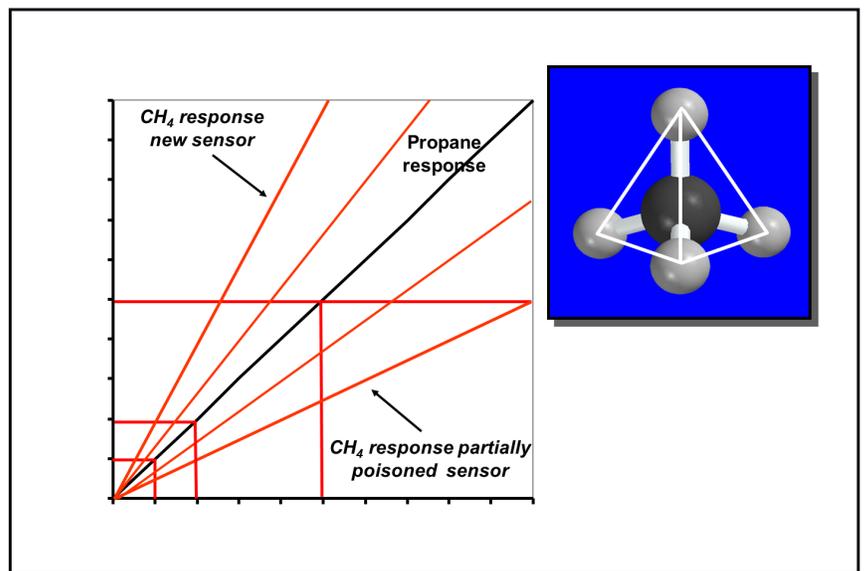


Figure 11: Relative response of the combustible sensor to methane can shift significantly over the life of the sensor.

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Methane based equivalent calibration gas mixtures		
Combustible Gas / Vapor	Relative response when sensor is calibrated to 2.5% (50% LEL) methane	Concentration of methane used for equivalent 50% LEL response
Hydrogen	1.1	2.75% Vol. CH4
Methane	1.0	2.5% Vol. CH4
Ethanol	0.8	2.0% Vol. CH4
Acetone	0.7	1.75% Vol. CH4
Propane	0.65	1.62% Vol. CH4
n-Pentane	0.5	1.25% Vol. CH4
n-Hexane	0.45	1.12% Vol. CH4
n-Octane	0.4	1.0% Vol. CH4
Toluene	0.35	0.88% Vol. CH4

Table 2: Methane based "equivalent" calibration mixtures can be used to calibrate catalytic LEL sensors to a variety of different gas sensitivity scales

containing compounds (especially tetraethyl lead), sulfur containing compounds, substances containing phosphorus and halogenated hydrocarbons. Combustible sensors can also be affected by exposure to high concentrations of ignitable mixtures.

Any conditions, incidents, experiences, or exposure to contaminants that might adversely affect the combustible sensor should trigger immediate verification of the proper performance of the sensor before continued use. This can be done very simply by flowing known concentration test gas over the sensor, and noting the response. If the readings are accurate, the sensor is safe to use. If the readings are inaccurate or out of calibration, the sensor must be recalibrated before further use.

Potential for loss of sensitivity to methane

Age and usage can affect the sensitivity of combustible sensors. Chronic exposure to low levels of poisons or inhibitors acts cumulatively. This usually means that the sensitivity must be increased when calibration occurs. In the extreme, the sensor may require replacement. This again demonstrates that regular calibration is essential to the safe use of combustible sensors.

For many combustible sensors, if sensitivity is lost due to poisoning, it tends to be lost first with regards to methane.

This means that a partially poisoned sensor might still respond accurately to other combustible gases while showing a significantly reduced response to methane. This is a particularly important concern for instruments used to monitor atmospheres associated with confined spaces, where methane is by far the most commonly encountered combustible gas.

There are several calibration strategies used by manufacturers to guard against incorrect readings due loss of sensitivity to methane. The first is to calibrate the instrument using the calibration gas which provides the best level of sensitivity (for instance propane or pentane) and then expose the sensor to a known concentration of methane.

The relative response factor for methane can then be used to verify whether there has been loss of sensitivity. This approach increases the time needed to calibrate the instrument and complicates the logistics. Another problem is what to do if there has been a loss of sensitivity to methane.

The second approach is to calibrate the instrument directly to methane. An instrument "spanned" to methane will continue to detect methane accurately even when loss of sensitivity develops. Spanning the instrument during calibration simply makes up for any loss in sensitivity. However, when the sensor is calibrated with methane, readings for most other substances tend to be lower than actual.

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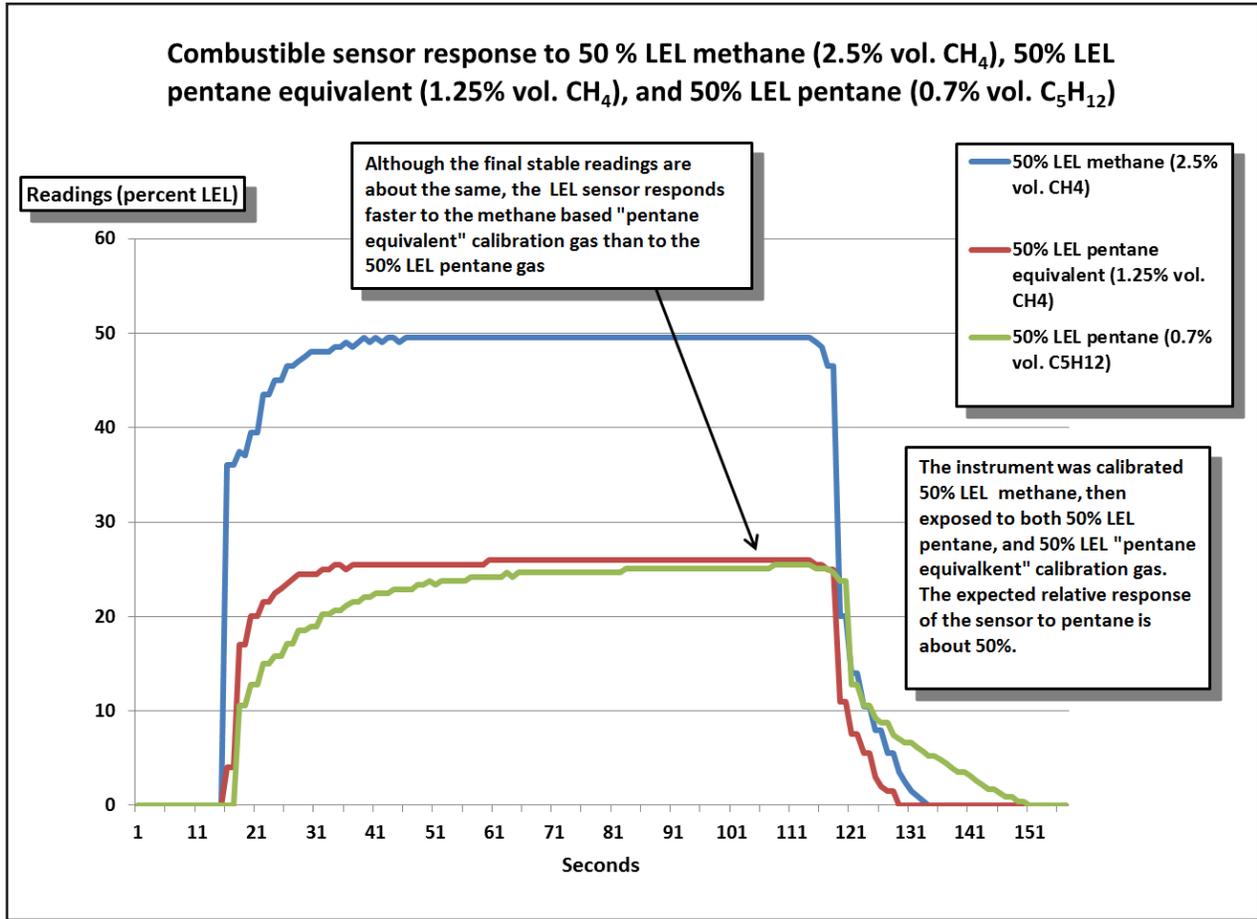


Figure 12: Methane based mixtures can be used to simulate the desired gas sensitivity scale, but remember that the diffusion characteristics of larger gas molecules may change the speed of response of the sensor. Always wait for the readings to stabilize completely before using them as the basis for decisions.

The third approach is to calibrate using methane at a concentration that produces a level of sensitivity equivalent to that provided by the gas of greatest interest. Several manufacturers offer "equivalent" or "simulant" calibration mixtures based on methane, but in concentrations that provide the same span sensitivity as direct calibration using propane, pentane or hexane calibration gas. As previously discussed, 50% LEL pentane produces one-half the heating effect on the active bead in a normally functioning sensor as a 50% LEL concentration of methane.

This also means that if you use a 25% LEL concentration of methane, but "span" adjust the readings to equal 50% LEL while the sensor is exposed to this gas, you wind up with a

pentane level of span sensitivity, but since you have used methane to calibrate the instrument, you know that the sensor is still responsive to methane.

The fourth approach now offered by many manufacturers is to include a user selectable library of correction factors in the instrument design. In this case, the user simply calibrates using methane, then selects "pentane" or any other correction factor in the library, and the instrument automatically recalculates readings according to the selected relative response. The benefit of this method, once again, is that since methane is used as the calibration gas, incremental loss of sensitivity to methane simply results in the instrument being "over-

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Figure 13: The catalytic LEL sensors in portable gas detectors should be tested by exposure to known concentration calibration gas before each day's use.

spanned”, or producing higher than actual readings for the gas selected from the library of correction factors.

Calibration verifies that sensors remain accurate. If exposure to test gas indicates a loss of sensitivity, the instrument needs adjustment. If the sensors cannot be properly adjusted, they must be replaced before any further use of the instrument. This is an essential part of instrument ownership.

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AP 1019:

Setting the alarms in electrochemical sensor equipped toxic gas instruments



Recently lowered exposure limits have made taking a more conservative approach to setting alarms mandatory for many instrument users.

Recently lowered exposure limit guidelines for H₂S, SO₂ and NO₂ have forced many instrument users to revisit where to set the alarms in their atmospheric monitors. For other gases, although the exposure limits have not changed, corporate policies as well as enforcement agency decisions have made taking a more conservative approach mandatory for many instrument users.

- **Which exposure limits apply?**

The most important obligation for any employer is to ensure that workers are not harmed by exposure to toxic materials or conditions that may be present in the workplace environment. Exposure limits like the OSHA PEL, NIOSH REL and ACGIH® TLV® provide exposure limits, which if exceeded, may lead to immediate or long term harm. These guidelines and standards set the limits above which conditions are deemed to be hazardous. They are not necessarily the concentrations that should be used when setting alarms. For instrument users there are two obligations. The first is ensuring that workers are not exposed to hazardous conditions. The second is ensuring that workers are able to leave the affected area before becoming affected by a hazardous condition. Workers should be

out of the area before rather than after the concentration of toxic gas exceeds the hazardous condition threshold. Unfortunately, the PEL, REL and TLV® are not always in agreement. Which exposure limit is applicable and enforceable depends on where you are, what you are doing, and who is responsible for enforcing your workplace safety requirements. Even when the applicable (and enforceable) hazardous condition threshold concentrations are unambiguous, setting the alarms can still be a challenge.

United States Occupational Safety and Health Administration (OSHA) regulations use the term Permissible Exposure Limit (PEL) to define the maximum concentration of a listed contaminant to which an unprotected worker may be exposed as an 8 hour time-weighted average (TWA) during the course of his workplace duties. Exposure limits for gases and vapors are usually given in units of parts-per-million (ppm). Limits for mists, fume and particulate solids are expressed in units of mg/m³. In addition to the 8 hour TWA PEL, Ceiling (C), Short Term Exposure Limit (STEL), and peak exposure limits are also specified for some airborne hazards.

OSHA 8 hour TWA PEL and C values are given for some airborne contaminants in Subpart Z (Section 1910.1000), and in substance-specific standards (e.g., methylene chloride, 1910.1052 and benzene, 1910.1028).

OSHA PELs are listed in Subpart Z (Section 1910.1000) of the Code of Federal Regulations, and posted at www.OSHA.gov. Individual states may either follow the Federal regulations, or if they have their own "Approved Occupational Safety and Health Plan" may follow their own, state-specific permissible exposure limits. States may not publish or follow exposure limits that are more permissive than Federal OSHA limits. Twenty-five states (as well as Puerto Rico and the Virgin Islands) have their own approved plan. In many cases the exposure limit in these states for a particular toxic substance is more conservative than the Federal OSHA PEL.

The National Institute of Occupational Safety and Health (NIOSH) develops and periodically revises recommended exposure limits (RELs) for hazardous substances or conditions in the workplace. The NIOSH REL is an occupational exposure limit that has been recommended by NIOSH to OSHA for adoption as a permissible exposure limit. The REL represents a level of exposure that NIOSH believes would be protective of worker safety and health over a working lifetime if used in combination with engineering and work practice controls. The OSHA PELs listed in Subpart Z are the same values originally promulgated in 1971. Because NIOSH RELs are periodically reviewed and updated, they tend to be more conservative than the OSHA exposure limits. Many states with approved occupational safety and health plans use the NIOSH RELs as the basis for their state specific permissible exposure limits. This



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makes the NIOSH REL the enforceable permissible exposure limit in many states. NIOSH and OSHA exposure limits are included in the "NIOSH Pocket Guide to Chemical Hazards," which can be downloaded at <http://www.cdc.gov/niosh/npg/>

• **What are TLVs®, and why do they matter?**

The ACGIH TLVs® are among the world’s most widely used and respected guidelines for workplace exposure to toxic substances. TLVs® are designed to function as recommendations for the control of health hazards, and to provide guidance intended for use in the practice of industrial hygiene. Although ACGIH TLVs® are not expressly developed for use as legal standards; they are frequently incorporated by reference into state, federal, and many international regulations governing workplace exposure. They may also be cited or incorporated by reference in consensus standards of associations such as the National Fire Protection Association (NFPA), or American National Standards Institute (ANSI). Given the potential for lawsuits, many employers have made the strategic decision to base their corporate health and safety programs on conservative applicable recognized standards. Since ACGIH recommendations are frequently more conservative than OSHA PELs and NIOSH RELs, many programs, especially the programs of multinational or prominent corporations, use the ACGIH TLVs®. ACGIH® publications may be purchased or downloaded at www.ACGIH.org



TLVs are not consensus standards. They are based solely on peer-reviewed toxicological and epidemiological evidence. The expense of implementing workplace controls, and the feasibility of using currently available monitoring technology are not issues central to the decision of whether or not to release or amend a TLV®. The idea is for science to speak with a neutral voice, and for employers and safety equipment manufacturers to respond as necessary to protect workers. This can create problems when there is a significant drop between the old and the new TLV®.

TLVs® Incorporated by Reference in:
• NFPA 306 – Control of Gas Hazards on Vessels
• US Coast Guard regulations (OSHA PEL or TLV, whichever is lower)
• US Army (OSHA PEL or TLV, whichever is lower, or specific Army OEL)
• Some individual state health and safety plans (e.g. California)
• Many international standards and regulations (e.g. Canada)
• Many consensus standards (e.g. ANSI, NFPA)
• Many corporate health and safety plans
• Mine Safety and Health Administration (MSHA) regulations

• **How do instruments determine when to go into alarm?**

Most real-time instruments for toxic gas measurement have at least four user settable alarms for each toxic gas sensor. The alarms are usually referred to as the Low alarm, the High alarm, the STEL alarm, and the TWA alarm. There are usually other non-user adjustable alarms as well, such as an alarm for negative readings, and an alarm for over-range conditions that exceed the sensor’s capability to measure.

Depending on the manufacturer, however, the Low and High alarms are sometimes also referred to as Ceiling or Peak alarms. Whatever they are called by the manufacturer, the Low and High alarms are based on actual, real-time measured values. The alarm is activated the moment the measured reading exceeds the setting.

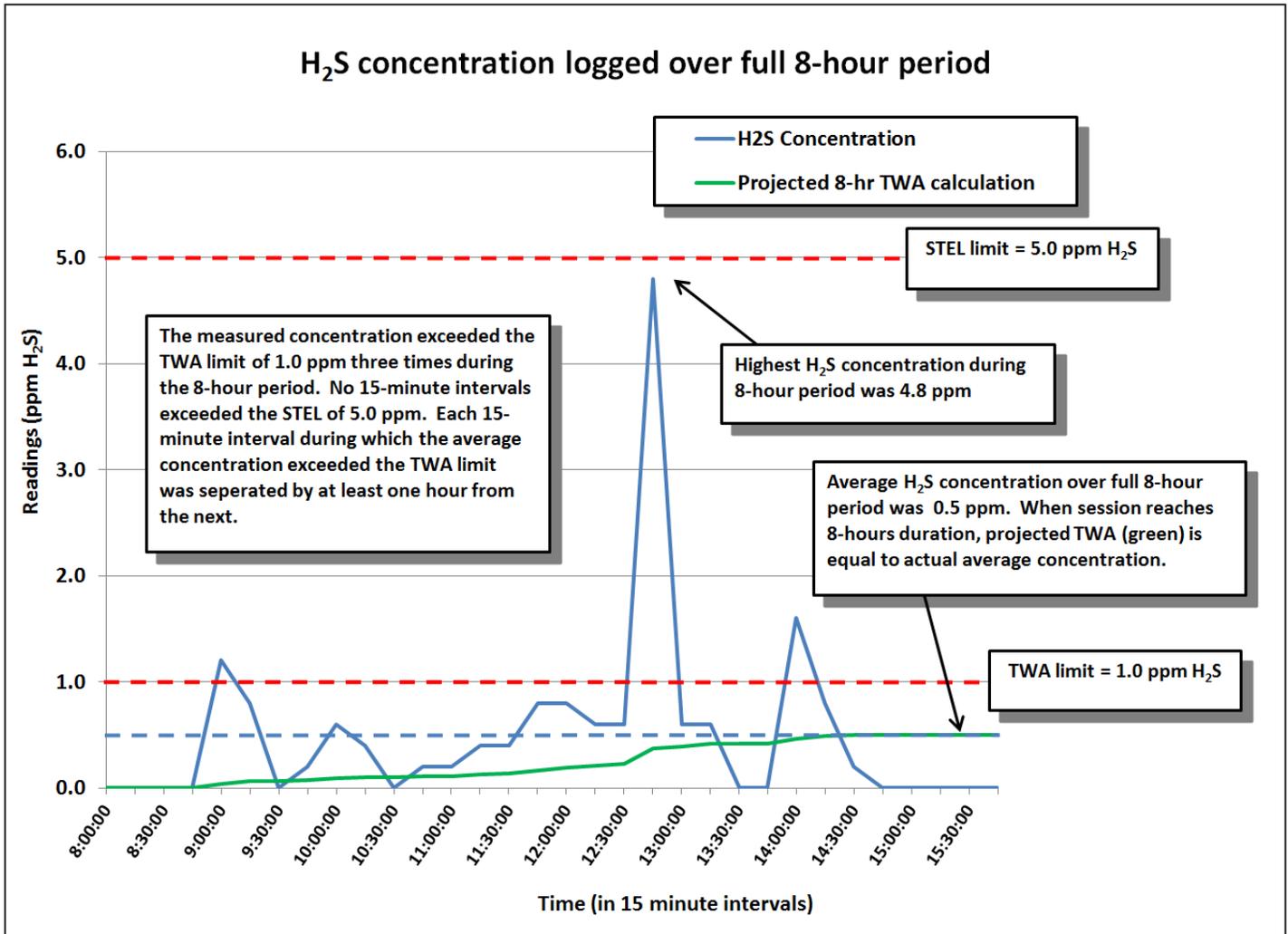
The STEL and TWA alarms are based on time history calculations. STEL alarm calculations are generally based on a 15-minute time weighted average. When the instrument is initially turned on (or the monitoring session is initiated), the microprocessor begins calculating the STEL value based on the actual measured concentration projected over a full 15-minute period. Once the duration of the monitoring session exceeds 15-minutes, the STEL calculation is based on the average concentration over the most

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recent 15-minute interval. The STEL alarm is sounded whenever the most recent 15-minute interval average exceeds the alarm setting.

TWA calculations are generally based on an 8-hour time weighted average (TWA). When the instrument is initially turned on, the microprocessor calculates the TWA based on the actual concentration measured projected over a full 8-hour period. Time not measured is projected as zero exposure in most jurisdictions. Thus, for a worker exposed to 100 ppm of contaminant for four hours, the 8-hour TWA would be equal to only 50 ppm at that time. At the end of a full eight hours at 100 ppm, the 8-hour TWA would be equal to 100 ppm.

Once the monitoring session reaches eight hours in duration, most instruments base the TWA reading on the most recent 8-hour

average. (It should be noted that some instrument designs allow users to specify a different TWA calculation interval to facilitate use with extended work shifts and other special applications.) The TWA alarm is sounded whenever the projected or the elapsed exposure exceeds the alarm setting.

In the above chart, the average measured concentration (in blue) over the full 8-hour session was 0.5 ppm H₂S. After 8-hours the projected TWA calculation (in green) equals the average concentration.

An important aspect of the TWA concept is that concentrations above the limit are permitted as long as they are balanced by an equal amount of time that is spent below the limit. Of course, at no time can the the concentration exceed whatever other limits are specified.

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The ACGIH® provides additional guidance for exposures that exceed the TLV®. According to the ACGIH®, exposure above the TWA up to the STEL should be less than 15-minutes, should not occur more than four times per day; and any 15-minute interval which exceeds the TWA limit should be separated by at least one hour from the next.

A complicating factor is that for many gases the TLV® provides only a single part definition. For instance, the 2012 TLV® for NO₂ is a single part recommendation that consists of an 8-hour TWA limit of 0.2 ppm. Although the NO₂ TLV® does not include a STEL or a Ceiling limit, it is still very important to limit the maximum instantaneous exposure.

The ACGIH® “Excursion Limit” applies to those TLVs® that do not have a STEL. According to the ACGIH®, “Excursions in worker exposure levels may exceed 3 times the TLV-TWA for no more than a total of 30 minutes during a workday, and under no circumstances should they exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded.”¹

Using the Excursion Limit concept, setting the Low instantaneous alarm at 0.6 ppm (= 3 times the TWA), the High alarm at 1.0 ppm (= 5 times the TWA), and the TWA alarm at 0.2 ppm would meet both the spirit and letter of the TLV®.

The above example for NO₂ still begs the question of where to set the STEL alarm. One arguably correct approach might be to turn the STEL alarm off, and depend on the other three alarms. The more common approach is for instrument users to set the STEL alarm at the same concentration as the TWA alarm. In this case, as long as the instrument user leaves the affected area immediately upon the activation of any alarm, it is very unlikely that the TWA alarm will ever be activated. This is a very conservative approach to setting the NO₂ instrument alarms:

- Low = 0.6 ppm**
- High = 1.0 ppm**
- STEL = 0.2 ppm**
- TWA = 0.2 ppm**

• **H₂S exposure limits**

H₂S is an extremely common workplace contaminant associated with microbial decomposition. It is a leading cause of injury and death in the oil industry, during confined space entry, and in many other workplace settings.

The Federal OSHA PEL for H₂S is quite different from, and less conservative, than the NIOSH REL and ACGIH® TLV®. The OSHA PEL for H₂S does not include a TWA or STEL, but stipulates that the acceptable Ceiling (C) concentration is 20 ppm, that the maximum

H ₂ S exposure limits					
OSHA PEL					
	TWA	STEL	Acceptable Ceiling (C) Concentration	Acceptable Maximum Peak above Ceiling for an 8-hour shift Concentration	Maximum duration
	NA	NA	20 ppm	50 ppm	10-minutes once only if no other measurable exposure occurs during shift
NIOSH REL					
	TWA	STEL	Ceiling		
	10.0 ppm	15.0 ppm	NA		
2009 ACGIH TLV					
	TWA	STEL	Ceiling		
	10.0 ppm	15.0 ppm	NA		
2010 ACGIH TLV					
	TWA	STEL	Ceiling		
	1.0 ppm	5.0 ppm	NA		

peak above the Ceiling (C) concentration is 50 ppm, and that the maximum duration of exposures above 20 ppm are limited to no more than 10 minutes once per eight hour shift when no other measurable exposures occur during the shift.

Be aware of specific activities may impose additional monitoring requirements and / or take action thresholds. For instance, OSHA 1910.146, "Permit-required confined spaces," Appendix D provides examples of a Confined Space Pre-Entry Check List and Entry Permit. The examples reference 10 ppm H₂S as the maximum permitted concentration during pre-entry testing (after isolation and ventilation), and 10 ppm (TWA) and 15 ppm (STEL) as the maximum concentrations permitted during an entry.

The 2010 TLV® for H₂S has caused much concern among instrument users. The old (2009) TLV®, as well as the current NIOSH REL, reference the same 15.0 ppm STEL and 10.0 ppm TWA limits. In the past, almost all instrument users set the instantaneous Low and High alarms at the STEL and TWA limit values.

Thus, the typical H₂S alarm settings used in most instruments was (and for most users continues to be):

- Low = 10.0 ppm**
- High = 15.0 ppm**
- STEL = 15.0 ppm**
- TWA = 10.0 ppm**

The latest 2010 TLV® comprises a two part definition, with a 15-minute STEL of 5.0 ppm, and an 8-hour TWA of 1.0 ppm. Where to set the instantaneous Low and High alarms is a particular concern for many instrument users. The fear for many instrument users is that if the instantaneous low alarm is set at the 1.0 ppm TLV®-TWA, frequent alarms due to momentary spikes above 1.0 ppm might



cause workers to lose faith in the instrument, or cease taking the correct protective measures.

For instrument users who are unaffected by the new TLV®, the tendency has been to stick with the old alarm settings. For customers affected by the TLV®, many users find the following settings meet the spirit and requirements of the 2010 TLV limit:

- Low = 3.0 ppm**
- High = 5.0 ppm**
- STEL = 5.0 ppm**
- TWA = 1.0 ppm**

- **Are H₂S sensors capable of measuring at the new TLV® limits?**

The answer is “Yes” BUT with qualifications.....

Different H₂S sensors are optimized for different performance requirements (e.g. cost, life, size, response to interfering contaminants, sensitivity, AND ACCURACY!) No single sensor design is equally optimized along all performance dimensions. In particular, the electrical output per ppm of gas varies widely between sensor models. One of the most widely used “miniature” H₂S sensors has an output signal of 0.105 ± 0.025 µA/ppm. Another H₂S sensor manufactured by the same company is optimized for higher sensitivity, and has an output signal of 0.7 ± 0.25 µA/ppm. Both designs are excellent sensors! However, they are designed for use in very different applications.

For an H₂S sensor to be usable with one or more of the alarms set at the 1.0 ppm limit, it needs to be capable of providing low concentration readings with at least ± 0.2 ppm resolution. Some H₂S sensors are easily capable of providing readings with ± 0.1 ppm or ± 0.2 ppm resolution; while others are limited to ± 1.0 ppm resolution. In general, dual channel “COSH” sensors used to simultaneously measure both CO and H₂S have a smaller measurement signal than substance-specific single-channel H₂S sensors.

Besides the sensor limitations, the instrument programming (firmware) must permit setting the alarms at the desired concentration. Depending on the instrument, it may be necessary to update the firmware or even replace an older instrument with a newer model. Instrument users should consult with the manufacturer as to whether or not the instrument can be used with alarms set to the new TLV®.

- **SO₂ exposure limits**

Prior to 2009, the NIOSH REL and the TLV® agreed on the limits for SO₂. In 2009 TLV for SO₂ was significantly reduced from the previous levels.

SO ₂ exposure limits			
	TWA	STEL	Ceiling (C)
OSHA PEL			
	5.0 ppm	NA	NA
NIOSH REL			
	2.0 ppm	5.0 ppm	NA
2009 ACGIH TLV			
	2.0 ppm	5.0 ppm	NA
2010 ACGIH TLV			
	NA	0.25 ppm	NA

The new TLV®-STEL is an extremely challenging limit. Existing instruments may or may not be able to perform at the new limit. Once again, for instrument users who are unaffected by the new TLV®, the tendency has been to stick with alarm settings at the old NIOSH and ACGIH® limits, (Low = 2.0 ppm, High = 5.0 ppm, STEL = 5.0 ppm, TWA = 2.0 ppm).

For customers affected by the TLV®, many users find the following settings meet the spirit and requirements of the 2010 TLV® limit:

- Low = 0.75 ppm**
- High = 1.25 ppm**
- STEL = 0.25 ppm**
- TWA = 0.25 ppm**

- **What is the effect of the accuracy of the sensor and the calibration gas on the accuracy of readings?**

Many instrument manufacturers list the accuracy of the toxic gas sensors in their products as ± 5% of the reading, or the minimum unit of resolution of the instrument, whichever is greater. Thus, for an instrument capable of providing readings in 0.2 ppm H₂S increments, the accuracy for readings between 0 and 2.0 ppm is ± 0.2 ppm. The accuracy of readings above 2.0 ppm will be ± 5% of the measured value.

This statement of accuracy assumes that the sensors are properly calibrated. The effects of the accuracy of the calibration gas on the accuracy of the toxic gas sensor are additive. The higher the accuracy of the calibration gas, the higher the accuracy of the readings.

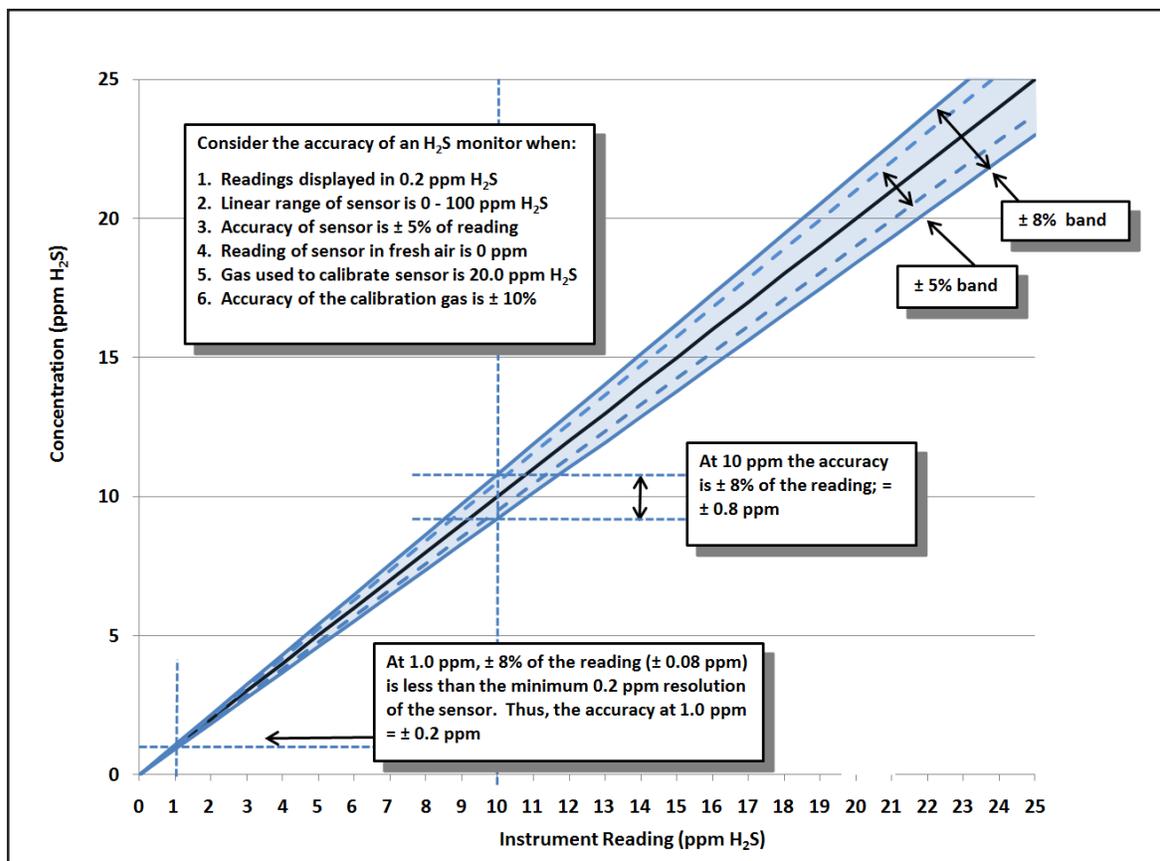
Calibration is minimally a two-point verification of response. In the first step the sensor is zero-adjusted in atmosphere that contains no measurable contaminants. In the second step the instrument is

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adjusted using calibration gas that contains a precise concentration of the toxic gas. Most calibration gas is manufactured and packaged by specialty suppliers to traceable reference standards. The accuracy and the dating (shelf-life) over which the accuracy statement applies are normally printed on the cylinder label. Calibration gas suppliers may offer different levels of accuracy for gas that is used for different purposes. Don't be afraid to ask if you need calibration gas that conforms to a higher level of accuracy.

Several calibration gas manufacturers offer H₂S calibration gas with ±3.0% accuracy with 6-month shelf life dating. They also offer ±10.0% accuracy with up to two-years shelf life dating.

The effect of these relationships on the accuracy of readings can be illustrated graphically. The accuracy of the reading is determined by the accuracy of the sensor (= ±5% of reading) plus the effects of the accuracy of the calibration gas (= ±3% of reading). When the instrument is exposed to 10 ppm H₂S, the concentration is much higher than the minimum unit of resolution (= 0.2 ppm). Thus, at 10 ppm H₂S the accuracy of the reading = ±8% of the reading, or in this case, ±0.8 ppm.

When the instrument is exposed to 1.0 ppm however, the concentration is much closer to the minimum unit of resolution. Since 8% of 1.0 ppm = 0.08 ppm, (which is less than the minimum unit of resolution); at 1.0 ppm the accuracy of the reading becomes ± 0.2 ppm.

• **Conclusion:**

The primary concern for any employer is to ensure that workers are not exposed to hazardous conditions. For many instrument users, recent changes in TLV[®] guidelines may not have a mandatory effect on instrument settings or procedures. Employers whose activities or policies require conformity with TLV[®] exposure limit guidelines may need to evaluate their current monitoring equipment and procedures. If you do need to take action according to the new limits, the equipment is readily available.

¹2012 TLVs[®] and BEIs[®] Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents; ACGIH[®] Worldwide; Signature Publications; 2012; Cincinnati, OH.

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G460 Ozone Calibration

Technical Note 1002

The GfG G460 Multi-gas detector may be configured for the detection of up to 6 gases. Some gases require the use of special procedures and equipment. This includes Ozone (O_3). Special tubing and calibration adapters must be used to prevent the calibration gas from affixing itself to the calibration equipment.

The calibration adapter used to calibrate ozone sensors is a small cup-style adapter that must be held in place manually when performing the calibration. The tubing has a special lining that does not scavenge the gas before it can reach the sensor.

Identifying the Correct Sensor Port

Since this adapter only allows the delivery of gas to a single sensor diffusion port rather than to all sensors, the specific port for the sensor to be calibrated must be identified.

Unlike other sensors ozone sensors do not have a white hydrophobic filter in front of them, but rather a rapid diffusion metal mesh screen. The metal screen is medium gray in color as shown in figure 1.



Figure 1. Ozone sensor port magnified

G460 Ozone Calibration

Calibration equipment

The calibration equipment consists of a handheld cup-style calibration adapter and special lined tubing. See figure 2.



Figure 2. Calibration adapter and tubing

Calibration

Follow the calibration steps outlined in the G460 manual. When you are ready to apply the gas to the ozone sensor attach the supplied tubing to the regulator or to the outlet of the gas generator. Start the flow of gas and hold the calibration adapter firmly in place over the sensor as shown in figure 3.



Figure 2. Calibration adapter and tubing

Additional information

- When calibrating with certain gases, including chlorine the flow rate of the regulator or gas generator must be 1 liter per minute.
- Make sure to keep calibration material clean
- Follow the recommendations outlined in the G460 manual for calibration and verification of accuracy frequencies.
- Ozone sensors are not protected by a hydrophobic filter, so extra care must be taken not to expose these sensors directly to water as it may damage the sensors.
- If you have any question contact GfG technical support at 800-959-0329.

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Networking GfG DS400 Docking Station

Application Note

Corporate users of GfG's G400 series of multi-gas detectors and GfG's DS400 docking stations may want to install DS400 docking stations in multiple locations to allow access to each of the docks over a network (LAN).

Using third-party remote USB hubs in these installations is easy; any number of DS400 can be installed literally worldwide and accessed from one central location.

Technical Background

The GfG DS400 docking station uses a USB connection to communicate with a computer, whereas a network uses an Ethernet connection.

Using a third-party hub such as AnywhereUSB[†] from Digi International[†], allows the installation of remote USB ports on any accessible network; just as if they were part of the local host computer connected to the hub.



[†] Only AnywhereUSB from Digi International has been tested by GfG

Networking GfG DS400 Docking Station



The installation of USB hub(s) generally requires the involvement of your IT team, as there are two technical issues to attend to.

1. For 100% transparent operation, it is strongly advised that each of the USB hubs be assigned a static IP address. This will ensure that the host computer can automatically reconnect to the hub(s) if the network is ever rebooted or reconfigured.

Your IT team add the MAC addresses (programmed into every AnywhereUSB) to the network protocols allowing automatic assignment(s) of IP static addresses, whenever and wherever they may be installed using DHCP.

2. The IT team needs to make sure that the network locations where the hubs are installed can be “seen” from the host computer.

Because the AnywhereUSB is a third-party product, GfG strongly recommends that the purchase and installation of these devices be left to your IT team. GfG also recommends that the IT team installs and fully tests the AnywhereUSB hub(s) in advance of the installation of the GfG DS400 docking station(s).

DS400 Installation

Once the AnywhereUSB hubs are installed and configured, the installation of the GfG DS400 docking stations is simple.

Prior to purchasing the DS400 docking stations, please advise GfG that the dock(s) will be installed on a network. GfG will then supply each dock with a uniquely programmed connection cable that makes the plug-and-play installation easy.

Simply connect one docking station at a time and allow the automatic installation of the GfG communication drivers on the host computer.

References

AnywhereUSB datasheet and specifications:

<http://www.digi.com/products/usb/anywhereusb.jsp>

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Ionization Potential Too High (>10.6eV)	Correction Factor High (>10)	Ionization Potential Known, CF Unknown	Ionization Potential Varies, CF Good* (< 10)	Ionization Potential Known, CF Good* (< 10)
We cannot provide a solution with the currently available 10.6eV lamp	Detectable, but high CF makes it hard to manage and obtain reliable data	Detectable, however, CF needs to be established, usually done by the customer	Detectable with a CF less than 10. *Correction factors near 10 should be carefully considered based on exposure limits and application.	

Chemical Name	(eV)	CF
A		
Acetaldehyde	10.21	10.8
Acetamide	9.77	
Acetic acid	10.69	11.0
Acetic anhydride	10.00	
Acetone	9.69	1.2
Acetonitrile	12.20	
Acetophenone	9.27	0.59
Acetyl bromide	10.55	
Acetyl chloride	11.02	
Acetylene	11.41	
Acrolein	10.10	3.9
Acrylamide	9.50	
Acrylonitrile	10.91	
Allyl alcohol	9.67	2.5
Allyl chloride	9.90	
2- Amino pyridine	8.00	
Ammonia	10.20	9.4
Amylacetate	<9.9	3.5
Aniline	7.70	
Anisidine	7.44	
Anisole	8.22	
Arsine	9.89	2.6
B		
Benzaldehyde	9.53	
Benzene	9.25	0.53
Benzenethiol	8.33	
Benzonitrile	9.71	
Benzotrifluoride	9.68	
Biphenyl	8.27	
Boron oxide	13.50	
Boron trifluoride	15.56	
Bromine	10.54	
1- Bromo-2-chloroethane	10.63	
1- Bromo-2-methylpropane	10.09	
2- Bromo-2-methylpropane	9.89	
1- Bromo-4-fluorobenzene	8.99	
Bromobenzene	8.98	
1- Bromobutane	10.13	
2- Bromobutane	9.98	
Bromochloromethane	10.77	
Bromoform	10.48	2.3
Bromomethane	-	1.8
1- Bromopentane	10.10	
1- Bromopropane	10.18	
2- Bromopropane	10.08	
1- Bromopropene	9.30	
3- Bromopropene	9.70	
2- Bromothiophene	8.63	
m- Bromotoluene	8.81	
o- Bromotoluene	8.79	
p- Bromotoluene	8.67	
1,3- Butadiene (butadiene)	9.07	0.69
2,3- Butadiene	9.23	
Butane	10.63	
1- Butanethiol	9.14	
2- Butanone (MEK)	9.54	
1- Butene	9.58	

Chemical Name	(eV)	CF
cis-2- Butene	9.13	
trans-2- Butene	9.13	
3- Butene nitrile	10.39	
n- Butyl acetate	10.01	2.4
sec- Butyl acetate	9.91	
n- Butyl alcohol	10.04	3.4
tert- Butyl alcohol	10.04	3.4
n- Butyl amine	8.71	
s- Butyl amine	8.70	
t- Butyl amine	8.64	
n- Butyl benzene	8.69	
s- Butyl benzene	8.68	
t- Butyl benzene	8.68	
n- Butyl formate	10.50	
Butyl mercaptan	9.15	0.55
tert- Butyl mercaptan	9.15	0.55
tert- Butylamine	8.71	0.71
p- tert- Butyltoluene	8.28	
1- Butyne	10.18	
n- Butyraldehyde	9.86	
n- Butyric acid	10.16	
n- Butyronitrile	11.67	
C		
Camphor	8.76	
Carbon dioxide	13.79	
Carbon disulfide	10.07	1.2
Carbon monoxide	14.01	
Carbon tetrachloride	11.47	
Chlorine	11.48	
Chlorine dioxide	10.36	
Chlorine trifluoride	12.65	
1- Chloro-2-methylpropane	10.66	
2- Chloro-2-methylpropane	10.61	
1- Chloro-3-fluorobenzene	9.21	
Chloroacetaldehyde	10.61	
a - Chloroacetophenone	9.44	
Chlorobenzene	9.07	0.4
Chlorobromomethane	10.77	
1- Chlorobutane	10.67	
2- Chlorobutane	10.65	
Chlorofluoromethane (Freon 22)	12.45	
Chloroform	11.37	
1- Chloropropane	10.82	
2- Chloropropane	10.78	
3- Chloropropene	10.04	
2- Chlorothiophene	8.68	
m- Chlorotoluene	8.83	
o- Chlorotoluene	8.83	
p- Chlorotoluene	8.70	
Chlorotrifluoromethane (Freon 13)	12.91	
Chrysene	7.59	
Cresol	8.14	
Crotonaldehyde	9.73	
Cumene (isopropyl benzene)	8.75	0.54
Cyanogen	13.80	

Chemical Name	(eV)	CF
Cyclohexane	9.80	1.5
Cyclohexanol	9.75	
Cyclohexanone	9.14	0.82
Cyclohexene	8.95	
Cyclo-octatetraene	7.99	
Cyclopentadiene	8.56	
Cyclopentane	10.53	
Cyclopentanone	9.26	
Cyclopentene	9.01	
Cyclopropane	10.06	
D		
Decaborane	9.88	
Decane	9.65	1.6
Diazomethane	9.00	
Diborane	12.00	
Dibromochloromethane	10.59	
Dibromodifluoromethane	11.07	
1,1- Dibromoethane	10.19	
1,2- Dibromoethene	9.45	
Dibromomethane	10.49	
1,3- Dibromopropane	10.07	
Dibutylamine	7.69	
1,2- Dichloro-1,1,2,2-tetrafluoroethane (Freon 114)	12.20	
m- Dichlorobenzene	9.12	
o- Dichlorobenzene	9.06	
p- Dichlorobenzene	8.95	
Dichlorodifluoromethane (Freon 12)	12.31	
1,1- Dichloroethane	11.12	
1,2- Dichloroethane	11.12	
cis- Dichloroethene	9.65	
trans- Dichloroethene	9.66	0.45
trans- Dichloroethene 1,2-	9.66	0.45
Dichlorofluoromethane	12.39	
Dichloromethane	11.35	
1,2- Dichloropropane	10.87	
1,3- Dichloropropane	10.85	
2,3- Dichloropropene	9.82	
Diesel fuel #1	-	0.90
Diesel fuel #2	-	0.75
Diethoxymethane	9.70	
N,N- Diethyl acetamide	8.60	
Diethyl amine	8.01	
Diethyl ether	9.53	
N,N- Diethyl formamide	8.89	
Diethyl ketone	9.32	
Diethyl sulfide	8.43	
Diethyl sulfite	9.68	
Diethylamine	8.01	1.00
Difluorodibromomethane	11.07	
Dihydropyran	8.34	
Diiodomethane	9.34	
Diisopropylamine	7.73	
1,1- Dimethoxyethane	9.65	

Ionization Potential Too High (>10.6eV)	Correction Factor High (>10)	Ionization Potential Known, CF Unknown	Ionization Potential Varies, CF Good (< 10)	Ionization Potential Known, CF Good (< 10)
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Chemical Name	(eV)	CF
Dimethoxymethane (methylal)	10.00	11.3
N,N- Dimethyl acetamide	8.81	
Dimethyl amine	8.24	
2,2- Dimethyl butane	10.06	
2,3- Dimethyl butane	10.02	
3,3- Dimethyl butanone	9.17	
Dimethyl disulfide	-	0.30
Dimethyl ether	10.00	
N,N- Dimethyl formamide	9.12	
2,2- Dimethyl propane	10.35	
Dimethyl sulfide	8.69	
n,n- Dimethylacetamide	8.81	0.73
Dimethylaniline	7.13	
Dimethylformamide	9.18	0.80
n,n- Dimethylformamide	9.18	0.80
1,1- Dimethylhydrazine	7.28	
Dimethylphthalate	9.64	
Dinitrobenzene	10.71	
Dioxane	9.19	
p- Dioxane	9.13	
Diphenyl	7.95	
Dipropyl amine	7.84	
Dipropyl sulfide	8.30	
Durene	8.03	
E		
Epichlorhydrin	-	7.6
Epichlorohydrin	10.20	
Ethane	11.65	
Ethanethiol (ethyl mercaptan)	9.29	
Ethanol	10.47	10.0
Ethanolamine	8.96	
Ethene	10.52	
Ethyl acetate	10.11	4.2
Ethyl acetoacetate	<10	0.90
Ethyl acrylate	<10.3	2.3
Ethyl alcohol	10.48	
Ethyl amine	8.86	
Ethyl benzene	8.76	
Ethyl bromide	10.29	
Ethyl chloride (chloroethane)	10.98	
Ethyl disulfide	8.27	
Ethyl ether	9.51	1.2
Ethyl ether (diethyl ether)	9.51	1.2
Ethyl formate	10.61	
Ethyl iodide	9.33	
Ethyl isothiocyanate	9.14	
Ethyl mercaptan	9.29	
Ethyl mercaptan	-	0.60
Ethyl methyl sulfide	8.55	
Ethyl nitrate	11.22	
Ethyl propionate	10.00	
Ethyl thiocyanate	9.89	
Ethylbenzene	8.77	0.51
Ethylene	-	10.1
Ethylene chlorohydrin	10.52	
Ethylene diamine	8.60	
Ethylene dibromide	10.37	
Ethylene dichloride	11.05	
Ethylene glycol	10.16	15.7
Ethylene oxide	10.57	
Ethylene oxide	10.57	19.5
Ethylenimine	9.20	

Chemical Name	(eV)	CF
Ethynylbenzene	8.82	
F		
Fluorine	15.70	
Fluorobenzene	9.20	
o- Fluorophenol	8.66	
m- Fluorotoluene	8.92	
o- Fluorotoluene	8.92	
p- Fluorotoluene	8.79	
Formaldehyde	10.87	
Formamide	10.25	
Formic acid	11.05	
Freon 11 (trichlorofluoromethane)	11.77	
Freon 112 (1,1,2,2-tetrachloro-1,2-difluoroethane)	11.30	
Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane)	11.78	
Freon 114 (1,2-dichloro-1,1,2,2-tetrafluoroethane)	12.20	
Freon 12 (dichlorodifluoromethane)	12.31	
Freon 13 (chlorotrifluoromethane)	12.91	
Freon 22 (chlorofluoromethane)	12.45	
2- Furaldehyde	9.21	
Furan	8.89	
Furfural	9.21	
G		
Gasoline	-	1.1
H		
Heptane	10.08	2.5
2- Heptanone	9.33	
Hexachloroethane	11.10	
Hexane	10.18	4.5
n- Hexane	10.13	
2- Hexanone	9.35	
1- Hexene	9.46	
Hydrazine	8.1	
Hydrazine	8.10	2.6
Hydrogen	15.43	
Hydrogen bromide	11.62	
Hydrogen chloride	12.74	
Hydrogen cyanide	13.91	
Hydrogen fluoride	15.77	
Hydrogen iodide	10.38	
Hydrogen selenide	9.88	
Hydrogen sulfide	10.46	3.2
Hydrogen telluride	9.14	
Hydroquinone	7.95	
I		
Iodine	9.28	
1- Iodo-2-methylpropane	9.18	
Iodobenzene	8.73	
1- Iodobutane	9.21	
2- Iodobutane	9.09	
1- Iodopentane	9.19	
1- Iodopropane	9.26	
2- Iodopropane	9.17	
m- Iodotoluene	8.61	
o- Iodotoluene	8.62	
p- Iodotoluene	8.50	
Isoamyl acetate	<10	1.8
Isobutane (Isobutylene)	9.4	

Chemical Name	(eV)	CF
Isobutanol	10.02	4.7
Isobutyl acetate	9.97	2.6
Isobutyl alcohol	10.12	
Isobutyl amine	8.70	
Isobutyl formate	10.46	
Isobutylene	-	1.0
Isobutyraldehyde	9.74	
Isobutyric acid	10.02	
Isooctane	9.86	1.3
Isopentane	10.32	8.0
Isophorone	9.07	0.74
Isoprene	8.85	0.60
Isoprene (2-methyl-1,3-butadiene)	8.85	0.60
Isopropanol	10.12	5.6
Isopropyl acetate	9.99	2.6
Isopropyl alcohol	10.16	
Isopropyl amine	8.72	
Isopropyl benzene	8.69	
Isopropyl ether	9.20	0.80
Isopropylamine	-	0.90
Isovaleraldehyde	9.71	
J		
Jet A fuel	-	0.40
JP-5 fuel	-	0.48
JP-8 fuel	-	0.48
K		
Ketene	9.61	
L		
2,3- Lutidine	8.85	
2,4- Lutidine	8.85	
2,6- Lutidine	8.85	
M		
Maleic anhydride	10.80	
Mesityl oxide	9.08	0.47
Mesitylene	8.40	
Methane	12.98	
Methanethiol (methyl mercaptan)	9.44	
Methanol	10.85	
n- Methyl acetamide	8.90	
Methyl acetate	10.27	7.0
Methyl acetoacetate	-	1.1
Methyl acetylene	10.37	
Methyl acrylate	9.90	3.4
Methyl alcohol	10.85	
Methyl amine	8.97	
Methyl benzoate	-	0.93
Methyl bromide	10.54	
Methyl butyl ketone	9.34	
Methyl butyrate	10.07	
Methyl cellosolve	9.60	
Methyl chloride	11.28	
Methyl chloroform (1,1,1-trichloroethane)	11.00	
Methyl disulfide	8.46	
Methyl ethyl ketone	9.53	0.90
Methyl formate	10.82	
2- Methyl furan	8.39	
Methyl iodide	9.54	
Methyl isobutyl ketone	9.30	1.1
Methyl isobutyrate	9.98	
Methyl isocyanate	10.67	
Methyl isopropyl ketone	9.32	
Methyl isothiocyanate	9.25	
Methyl mercaptan	9.44	0.6

Ionization Potential Too High (>10.6eV)	Correction Factor High (>10)	Ionization Potential Known, CF Unknown	Ionization Potential Varies, CF Good (< 10)	Ionization Potential Known, CF Good (< 10)
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Chemical Name	(eV)	CF
Methyl methacrylate	9.70	1.5
1- Methyl naphthalene	7.96	
2- Methyl naphthalene	7.96	
2- Methyl propene	9.23	
Methyl propionate	10.15	
Methyl propyl ketone	9.39	
a - Methyl styrene	8.35	
Methyl tert-butyl ether	-	0.86
Methyl thiocyanate	10.07	
2- Methyl-1-butene	9.12	
3- Methyl-1-butene	9.51	
3- Methyl-2-butene	8.67	
Methylal (dimethoxymethane)	10.00	
Methylamine	-	1.2
Methylbenzil alcohol	-	0.80
Methylcyclohexane	9.85	
4- Methylcyclohexene	8.91	
Methylene chloride	11.32	0.85
Methyl-n-amyl ketone	9.30	
2- Methylpentane	10.12	
3- Methylpentane	10.08	
Monomethyl aniline	7.32	
Monomethyl hydrazine	7.67	
Morpholine	8.20	
N		
Naphtalene	8.13	0.37
Naphthalene	8.12	
Nickel carbonyl	8.27	
Nitric oxide, (NO)	9.25	7.2
Nitrobenzene	9.92	
p- Nitrochloro benzene	9.96	
Nitroethane	10.88	
Nitrogen	15.58	
Nitrogen dioxide (11.7 lamp recommended)	9.75	10.0
Nitrogen trifluoride	12.97	
Nitromethane	11.08	
1- Nitropropane	10.88	
2- Nitropropane	10.71	
Nitrotoluene	9.45	
n- Nonane	9.72	1.6
O		
Octane	9.82	2.2
Oxygen	12.08	
Ozone	12.08	
P		
Pentaborane	10.40	
Pentane	10.35	9.7
n- Pentane	10.35	9.7
2,4- Pentanedione	8.87	
2- Pentanone	9.38	
1- Pentene	9.50	
Perchloroethylene	9.32	
Pheneloic	8.18	

Chemical Name	(eV)	CF
Phenol	8.50	1.0
Phenyl ether (diphenyl oxide)	8.82	
Phenyl hydrazine	7.64	
Phenyl isocyanate	8.77	
Phenyl isothiocyanate	8.52	
Phenylene diamine	6.89	
Phosgene	11.77	
Phosphine	9.87	2.8
Phosphorus trichloride	9.91	
Phthalic anhydride	10.00	
2- Picoline	9.02	
3- Picoline	9.02	
4- Picoline	9.04	
Pinene, alpha	8.17	0.40
Pinene, beta	-8	0.40
Propane	11.07	
1- Propanethiol	9.20	
Propargyl alcohol	10.51	
Propiolactone	9.70	
Propionaldehyde	9.98	14.8
Propionic acid	10.24	
Propionitrile	11.84	
Propyl acetate	10.04	3.1
n- Propyl acetate	10.04	3.1
Propyl alcohol	10.20	
Propyl amine	8.78	
Propyl benzene	8.72	
Propyl ether	9.27	
Propyl formate	10.54	
n- Propyl nitrate	11.07	
Propylene	9.73	1.3
Propylene dichloride	10.87	
Propylene imine	9.00	
Propylene oxide	10.22	6.5
Propyne	10.36	
Pyridine	9.32	0.79
Pyrrrole	8.20	
Q		
Quinoline	-	0.72
Quinone	10.04	
S		
Stibine	9.51	
Styrene	8.47	0.40
Sulfur dioxide	12.30	
Sulfur hexafluoride	15.33	
Sulfur monochloride	9.66	
Sulfuryl fluoride	13.00	
T		
o- Terphenyls	7.78	
1,1,2,2- Tetrachloro-1,2-difluoroethane (Freon 112)	11.30	
Tetrachloroethane	11.62	
Tetrachloroethene	9.32	0.56

Chemical Name	(eV)	CF
Tetrachloroethylene	9.32	0.56
Tetrachloromethane	11.47	
Tetrahydrofuran	9.54	1.6
Tetrahydropyran	9.25	
Thiolacetic acid	10.00	
Thiophene	8.86	0.47
Toluene	8.82	0.53
o- Toluidine	7.44	
Tribromoethene	9.27	
Tribromofluoromethane	10.67	
Tribromomethane	10.51	
1,1,2- Trichloro-1,2,2-trifluoroethane (Freon 113)	11.78	
1,1,1- Trichloroethane	11.00	
Trichloroethene	9.45	
Trichloroethylene	9.47	0.50
Trichlorofluoromethane (Freon 11)	11.77	
Trichloromethane	11.42	
Triethylamine	7.50	
Trifluoromonobromo-methane	11.40	
Trimethyl amine	7.82	
2,2,4- Trimethyl pentane	9.86	
Trimethylamine	7.82	0.83
Tripropyl amine	7.23	
Turpentine - crude sulfite	-	1.0
Turpentine - pure gum	-	0.45
V		
Valeraldehyde	9.82	
Valeric acid	10.12	
Vinyl acetate	9.19	1.3
Vinyl bromide	9.80	0.40
Vinyl chloride	10.00	1.8
Vinyl methyl ether	8.93	
o- Vinyl toluene	8.20	
Vinylcyclohexane (VCH)	9.83	0.54
Vinylidene chloride (1,1-DCE)	-	0.80
W		
Water	12.59	
X		
m- Xylene	8.56	0.53
o- Xylene	8.56	0.54
p- Xylene	8.45	0.50
2,4- Xylidine	7.65	

G450 / G460 Battery pack performance and maintenance procedures

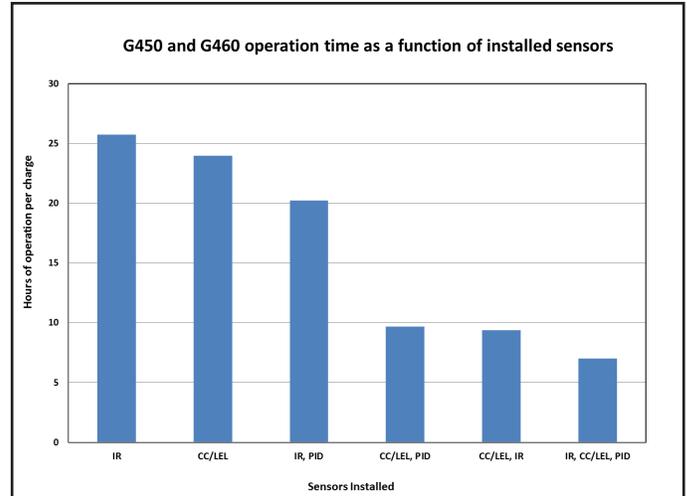


G50 and G460 rechargeable (NiMH) battery packs provide outstanding operation time, cycle life and low temperature performance. Periodic deep discharge ensures the best possible performance.

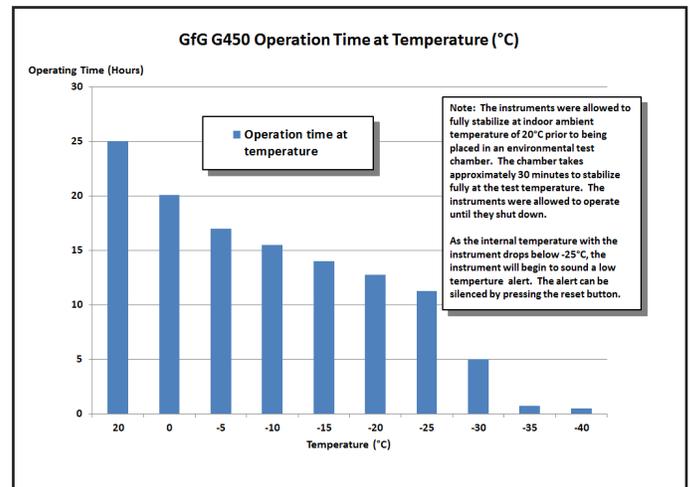
Interchangeable G450 and G460 rechargeable nickel-metal hydride (NiMH) and alkaline battery packs are designed to provide up to 25 hours of continuous operation. NiMH batteries provide excellent cycle life and low temperature performance, and are warranted for 2-years. The typical G450 run-time after two years with a properly maintained NiMH battery pack is usually around 16 hours.

Some types of sensors require more power than others. The highest power consuming sensors are photoionization detector (PID) sensors, followed by standard catalytic LEL sensors and infrared sensors. The power requirements for oxygen and electrochemical toxic sensors (e.g. CO, H₂S, SO₂, NO₂, etc.) are so low that they do not materially affect the instrument run time.

The following chart shows the expected run-times per charge (or set of batteries) for various heavy-power sensor configurations. All configurations include O₂ and CO/H₂S sensors as well as the listed "high power" sensors.



The temperature can also have an effect on the operation time of the instrument. While high temperatures up to 122°F (50°C) do not have an effect on operation time, in very cold temperatures the operation time becomes shortened. Alkaline batteries should be avoided when operating temperatures are below 32°F (0°C). NiMH battery packs provide excellent low temperature performance down to -4°F (-20°C), and can be used for short periods of time down to -40°F (-40°C). The following chart shows the expected run times for a G450 equipped with a rechargeable NiMH battery pack and standard LEL, O₂, CO and H₂S sensors in various temperature conditions:



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NiMH battery packs are designed to last for hundreds of charging cycles without losing capacity, but can be damaged if the charging system allows the batteries to overheat. GfG "Smart Chargers" are sophisticated devices with their own microprocessor and charging software. The charger maintains continuous communication with the instrument and the installed battery pack throughout the charging process. To avoid damage due to overheating, GfG "Smart Chargers" use a two-stage process. When the instrument is initially placed in the cradle the charger starts out in the fast charging mode. The charger will continue in the fast charging mode until the battery pack reaches 90% of its full charge condition (or until the charger verifies that the battery is already fully charged). Once fast charging is complete the charger continues in trickle charge mode. The instrument display indicates how long the instrument has been in fast charging mode, and if fast charging is complete, how long the instrument has been in trickle charging mode.

Completely discharged batteries may require up to 6 hours to reach the trickle charge stage. Instruments should be left on the charger for at least 2 hours in trickle mode AFTER fast charging is complete to reach 100% full charge capacity.

GfG "Smart Chargers" are available in single (DIC1) and double (DIC2) versions. DIC1 "single" charger cradles are designed to charge the instrument only. DIC2 "double" cradles simultaneously charge both the instrument and the MP-2 motorized pump.

The chargers can be used with 110 - 240 VAC power, or can be used with an optional 12 VDC vehicle charging system.



• **G450 / G460 Charging Cycle**

The green LED in the "single" charger cradle indicates power. A solid amber LED indicates fast charging. A flashing amber LED indicates trickle charging. The instrument display indicates how long the instrument has been in each stage of the cycle.



Solid amber LED indicates fast charging, a flashing amber LED indicates trickle charge mode.

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Rechargeable battery packs are black

Alkaline battery packs are gray

- **Changing battery packs**

Use the included tool, or any 2 mm hex key wrench to loosen and remove the two screws securing the battery pack to front of the instrument housing, then **GENTLY** remove the battery pack from the instrument.



Only use fingers when removing the battery pack from the instrument. Never use a screwdriver or other hard tool to remove the battery pack!



Make sure that the vibrator (the flat disc on the top of the battery pack) is at the top when the battery pack is reinserted into the instrument, then reinstall and tighten the screws. Do not force when inserting the pack into the housing! Make sure screws are secure but do not overtighten!

- **Voltage depression due to over-charging**

NiMH batteries do not develop “memories”, however, if they are not exercised they may become “lazy.” Even though the normal amount of power is stored the battery, the peak voltage in “lazy” batteries drops more quickly than usual. The proper technical name for this condition is “voltage depression.”

Voltage depression is caused by the formation of small crystals of electrolyte on the plates, increasing resistance and lowering the voltage of some individual cells in the battery. To the user it appears the battery is not holding its full charge; to the instrument

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the rapid drop in voltage indicates that the batteries are about to run out of energy.

Exercising the battery by putting it through a deep-discharge cycle can break down the crystals, and improve or restore the run time of the instrument.

- **“Anti-lazy battery” deep-discharge cycle**

G450 and G460 instruments with version 3.41 and higher firmware include enhanced “anti-lazy battery” cycle options, as well as other features. GfG recommends updating your instrument firmware to take advantage of these enhanced features.

Fully charged instruments that fail to operate for the expected time should be exercised by means of the “anti lazy battery” deep discharge cycle. Instruments that are left on the charger for prolonged periods between use may benefit from being exercised by being deep discharged on a quarterly basis.

To take full advantage of the latest anti-lazy battery options it is also necessary to have the latest version charger cradle and power adapter. Charger cradle and power adapters sold prior to October, 2011 can be updated at the GfG factory in Ann Arbor to the latest configuration. Charger cradles sold since October, 2011 are already equipped with the latest version hardware and software.



Cradles with serial numbers ending in "D" indicate the latest version.



Power adapter must be equipped with “stereo” type jack with two black stripes.

To perform or schedule an “Anti-lazy battery” deep discharge cycle:

1. Press and hold down “Reset” button until the “Main menu” choices appear, then select “Options.” The “Options” choice is used to adjust display contrast, alarm loudness or activate the “Anti Lazy Battery” deep-discharge cycle.



2. From the “Options Menu” choose “Anti-Lazy-Battery.”



3. To perform a one-time deep discharge cycle for NiMH battery pack, press “Change.” This will activate the deep discharge feature on a one-time basis. The display will show “1X” instead of “Off.”



4. Press “Exit” to return G450 to normal operation. **DO NOT TURN THE INSTRUMENT OFF!** When the power remaining in the battery drops below the “low battery” threshold, instead of sounding the normal alarms, the display will show the “Anti-Lazy-Batt. running” status message.

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5. Allow the instrument to run until the battery is completely drained, then recharge it normally, or **AFTER** the battery icon shows it is down to last 10%, place instrument in the charger cradle.
6. The instrument will display the "Anti Lazy Battery" status message, and continue to discharge the battery while it is in the charger. When the deep discharge is complete the one time (1X) anti-lazy battery cycle is cancelled, and the instrument is recharged in the normal way.



Note: If you place the instrument in the charger before the battery icon shows it is down to the last 10% remaining voltage, the instrument will turn off, cancel the deep-discharge cycle, and begin recharging in the normal charging mode!

- **Other "Anti-lazy battery" cycle options**

It is possible to program the instrument so the deep discharge cycle is always automatically activated whenever the instrument is placed in the charger when the battery is below 10% remaining voltage.

From "Options" menu choose "Anti-Lazy-Battery" then press "Change" to activate the one-time deep discharge cycle (the display will show "1X"). Press "Change" again to choose "Days," then press "Exit" to return to normal operation.



Once the "Days" choice has been activated, anytime the instrument is placed in the charger when there is less than 10% remaining voltage the deep discharge cycle will be activated automatically.

- **Limiting automatic deep discharge cycle to certain days**

Since deep-discharge can take up to 20 hours to complete, it may be advisable to limit automatic deep-discharge to certain days of the week (i.e. enabling the feature for Fridays to give the instrument a full weekend to complete discharging and recharging).

Press the "down arrow" key to highlight the "Anti-Lazy days" choice, then press "Change." The instrument will display the days of the week. Select the desired days for the automatic activation of this feature, then "Exit" to return to normal operation.



TN 2014:

Calibrating GfG Micro IV instruments equipped with hydrogen fluoride (HF) sensors



Sensors used to measure hydrogen fluoride (HF) are dependable and accurate, but require special care during calibration and functional test procedures.

Hydrogen fluoride (HF) is an extremely toxic, colorless, lighter than air gas associated with a number of industries and industrial processes. HF is highly soluble in water where it forms hydrofluoric acid. HF is highly corrosive, and forms hydrofluoric acid upon contact with tissue. HF is extremely irritating to skin and mucous membranes, can cause blindness by rapid destruction of the corneas, and requires immediate medical attention upon exposure.

Aqueous hydrofluoric acid is a contact-poison with the potential for deep, initially painless burns and ensuing tissue death. By interfering with the body's calcium metabolism, concentrated hydrofluoric acid may also cause systemic toxicity and eventual cardiac arrest and fatality, after contact with as little as 160 cm² (25 square inches) of skin.

Hydrogen fluoride is widely used as a catalyst in the petrochemical industry. HF is used in the manufacture of fluoropolymers such as Teflon® (PTFE), semiconductor materials, aluminum, pharmaceuticals, and refrigerants (e.g. Freon®). HF can also be produced as a combustion by-product of fluorocarbon fire-extinguishing agents, and by the combustion of fluoropolymers.

Hydrogen fluoride exposure limits

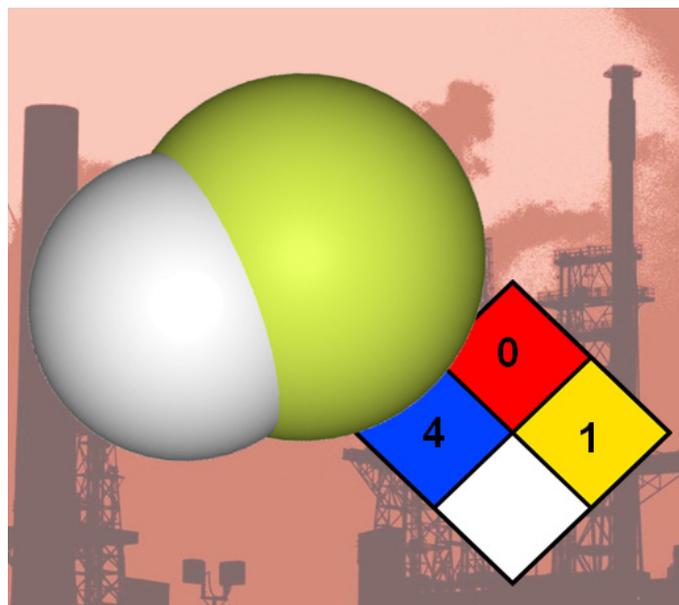
OSHA PEL: The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for hydrogen fluoride is 3.0 ppm as an 8-hour time-weighted average (TWA).

NIOSH REL: The National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) for hydrogen fluoride is 3.0 ppm as an 8-hour TWA, and 6.0 ppm as a 15-minute short-term exposure limit (STEL).

ACGIH® TLV®: The American Conference of Governmental Industrial Hygienists® TLV® is 0.5 ppm as an 8-hour TWA, and 2.0 ppm as Ceiling limit (15-minute).

HF sensor characteristics

GfG uses Sensoric model HF-3E-10-SE substance-specific electrochemical sensors for HF measurement. The linear measuring range is 0 – 10 ppm. The maximum (over-limit) concentration varies by sensor, but is approximately 13.0 ppm. The resolution of the sensor (at 20°C) is ±0.1 ppm. The expected lifespan of the sensor is approximately 18 months. The sensor is warranted for 1.0 year from the date of purchase.



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The HF sensor takes a little longer to reach a final stable reading than other common electrochemical sensors such as those used to measure CO and H₂S. The HF sensor response time at 20°C to 50% of its final stable reading (t50) is approximately 30 seconds. The response time to 90% of its final stable reading (t90) is approximately 90 seconds.

The HF sensor is significantly affected by sudden shifts in humidity, causing momentary shifts or zero reading "transients." However, the sensor rapidly recovers as soon as conditions stabilize. Be careful to avoid breathing on the sensor, or holding the sensor opening against a moist palm or fingers. Give the sensor a few moments to stabilize if you move into an area with a different relative humidity.

The HF sensor responds to a number of acid gases with similar chemistry. The following table lists the relative of some of the most common interfering gases:

HF sensor cross sensitivities at 20° C		
Gas	Concentration applied	HF sensor response
Acetic acid	100 ppm	100 ppm
Alcohols	1,000 ppm	0
Carbon dioxide	5,000 ppm	0
Carbon monoxide	100 ppm	0
Chlorine	1.0 ppm	0.7
Hydrocarbons	Percent (%) range	0
Hydrogen	3,000 ppm	< 1.0
Hydrogen chloride	10.0 ppm	6.0 ppm
Sulfur dioxide	20 ppm	16.0 ppm*

*Short gas exposure in minute range.



Calibrating GfG monitors equipped with HF sensors

1. Calibrating a single-sensor Micro IV instrument:

- Consult the Owner's Manual for complete procedures for fresh air zero-adjusting and span calibrating the Micro IV instrument. You can download a copy of the Micro IV owner's Manual at www.goodforgas.com
- Acid gas sensors such as those used to measure hydrogen fluoride and hydrogen chloride should be activated by a brief exposure to calibration gas prior to the actual calibration procedure.
- Allow at least one full hour after initially turning the instrument on for the sensor to stabilize completely before starting a calibration. A stable sensor should read 0.0 ppm in fresh air without fluctuation.
- If needed, perform a fresh air calibration. It may be necessary to repeat the procedure one or more times.
- After fresh air calibration the monitor must remain stable for at least ½ hour before proceeding to the span calibration step. In all cases allow one hour warm-up after initially turning the instrument on before attempting calibration.
- Connect the gas, regulator, tubing, and Teflon® calibration adapter. Make sure the regulator is designed to flow at a rate of 1.0 lpm (liters per minute) Make sure to use PTFE lined tubing to connect the regulator to the calibration adapter, and use the minimum possible length of tubing to connect the calibration adapter to the regulator.

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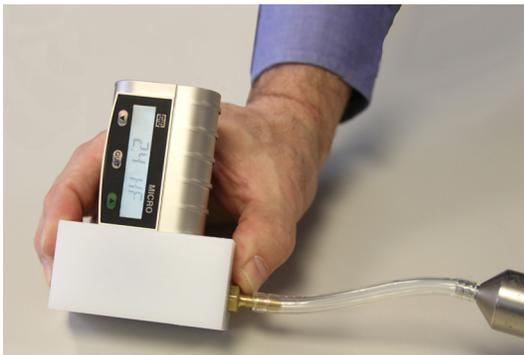
- Remove the protective boot from the instrument, and insert the Micro IV into the Teflon® calibration adapter. Make sure that the Micro IV is inserted so that the sensor is next to the gas inlet in the adapter.



- Start the HCl gas flowing.



- Activation step:** When the reading reaches 4.8 ppm, or has run for five minutes, but not more, turn off the gas flow, remove the instrument from the calibration adapter, and allow the sensor to stabilize in fresh air. Wait at least 15 minutes BEFORE proceeding to the actual calibration step.



- Calibration step:** Insert the instrument into the calibration adapter, and start the HCl gas flowing. When the reading reaches 4.8 ppm, or has run for five minutes, THEN initiate the calibration step. Newer sensors respond more quickly than older and may reach 4.8 ppm, or more, within a couple of minutes.
- The HF sensor has a relative response of about 0.6 to hydrogen chloride (HCl). Use 10.0 ppm HCl in nitrogen calibration gas to calibrate the HF sensor. Make sure the "Cal point" value in the Micro IV is set to 6.0 ppm.



- If the reading does not reach 4.8 ppm within five minutes:
 - Make sure that the regulator has a flow rate of 1.0 lpm.
 - Make sure that the instrument is properly inserted into the calibration adapter, and that the sensor is adjacent to the gas inlet.
 - Make sure that the cylinder contains 10.0 ppm HCl calibration gas, is still within dating, and that the cylinder has sufficient remaining pressure to complete the calibration procedure.
 - Turn the gas flow off, remove the instrument from the calibration adapter, and allow the sensor to recover in fresh air. This may take several minutes.
 - Wait at least 30 minutes, then try again.
 - If the sensor still responds too slowly, or fails to reach a reading of 4.8 ppm, the sensor may need to be replaced.
- If the calibration fails, without turning the gas off, try again.
- If the instrument still fails to calibrate, contact the GfG Service Department for help, or to arrange for the shipment of a replacement sensor.



TN 2015: Electrochemical (EC) sensors: gases measured, ranges and resolution



Substance-specific electrochemical (EC) sensors are available for an increasing number of toxic gases and vapors. Besides the primary gas the sensor is designed to measure, it may be possible to calibrate and use the same sensor to measure other gases with similar chemistries.

Electrochemical (EC) sensors are one of the most common types of sensors used in portable gas detectors. Multi-sensor confined space monitors generally contain an oxygen sensor, a flammable/combustible sensor and one to three additional electrochemical sensors for specific toxic gases. Single-sensor instruments equipped with EC toxic sensors are also extremely popular for use in situations where a single toxic hazard is present.

Electrochemical sensors are available for monitoring for an increasing number of contaminants including hydrogen sulfide (H₂S), carbon monoxide (CO), sulfur dioxide (SO₂), chlorine (Cl₂), chlorine dioxide (ClO₂), ammonia (NH₃), phosphine (PH₃), cyanide (HCN), hydrogen (H₂), ethylene oxide (C₂H₄O), nitrogen dioxide (NO₂), nitric oxide (NO), ozone (O₃), hydrogen fluoride (HF), hydrogen chloride (HCl), phosgene (COCl₂), and others.

EC sensors are usually designed to minimize the effects of interfering contaminants, making the readings as specific as possible for the gas being measured. However, most substance-specific sensors still show some cross sensitivity to at least a few other gases. Alternatively, “broad-range” EC sensors are deliberately designed to provide a measurable response to a wide array of contaminants. Most electrochemical sensors fall somewhere between the two extremes in terms of specificity.

The following tables provide a partial list of the gases and vapors detectable by means of EC sensors in GfG products.

Table 1 lists the types of available EC sensors by the gas they are designed to measure, as well as the standard range and resolution for each sensor.

Table 2 shows other substances which are also detectable by using sensors listed in Table 1.

Always consult the manufacturer before using an EC sensor to measure a different gas from the one it is primarily designed to measure!



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Table 1: Available EC sensors, standard ranges and resolution

Gas	Formula	Sensor model	Resolution	Range(s)	Notes
Ammonia	NH ₃	NH3 3E 5000 SE	1.0 ppm 5.0 ppm 10.0 ppm	0 - 200 ppm 0 - 500 ppm 0 - 1,000 ppm	
Arsine	AsH ₃	AsH3 3E 1 F LT	0.03 ppm	0 - 1.0 ppm	
Carbon monoxide	CO	4CM	0.1 ppm 1.0 ppm 1.0 ppm	0 - 300 ppm 0 - 500 ppm 0 - 1,000 ppm	
Carbon monoxide (CO-H)	CO	2CF	1.0 ppm 1.0 ppm 1.0 ppm	0 - 500 ppm 0 - 1,000 ppm 0 - 2,000 ppm	CO sensor with low H ₂ cross sensitivity
CO / H ₂ S	CO H ₂ S	4COSH	CO: 1.0 ppm H ₂ S: 0.2 ppm	0 to 500 ppm 0 to 100 ppm	Dual channel CO / H ₂ S
Chlorine	Cl ₂	Cl2 3E 10	0.1 ppm	0 - 10.0 ppm	
Chlorine dioxide	ClO ₂	ClO2 3E 10	0.1 ppm	0 - 2.0 ppm	
Diborane	B ₂ H ₆	B2H6 3E 1 LT	0.03 ppm	0 - 1.0 ppm	
Ethylene oxide (EtO)	C ₂ H ₄ O	ETO-A1	0.1 ppm	0 - 20 ppm	
Fluorine	F ₂	F2 3E 1	0.02 ppm	0 - 1.0 ppm	
Hydrazine	N ₂ H ₄	N2H4 2E 1	0.01 ppm	0 - 1.0 ppm	
Hydrogen	H ₂	4HYT	1.0 ppm	0 - 2,000 ppm	
Hydrogen	H ₂	H2 3E 4%	0.01 % vol.	0 - 4.0% vol.	
Hydrogen bromide	HBr	HCl/HBr 3E 30	0.1 ppm	0 - 30 ppm	
Hydrogen chloride	HCl	HCl/HBr 3E 30	0.1 ppm	0 - 30 ppm	
Hydrogen cyanide	HCN	HCN 3E 30 F	0.2 ppm	0 - 50 ppm	
Hydrogen fluoride	HF	HF 3E 10 SE	0.1 ppm	0 - 10.0 ppm	
Hydrogen sulfide	H ₂ S	4HS-LM	0.1 ppm 0.2 ppm	0 - 100 ppm 0 - 500 ppm	
Methyl mercaptan	CH ₃ SH	TBM 2E	0.3 ppm	0 - 25 ppm	
Nitric oxide	NO	4NT	1.0 ppm	0 - 100 ppm	
Nitrogen dioxide	NO ₂	NO2 A1	0.02 ppm 0.04 ppm	0 - 30 ppm 0 - 50 ppm	
Oxygen	O ₂	O2-A3	0.1% vol.	0 - 25.0% vol.	3-year life
Oxygen	O ₂	4OX-V	0.1% vol.	0 - 25.0% vol.	2-year life, vented design
Ozone	O ₃	O3 3E 1	0.02 ppm	0 - 1.0 ppm	
Phosgene	COCl ₂	COCl2 3E 1	0.02 ppm	0 - 2.0 ppm	
Phosphine	PH ₃	PH3 A1	0.1 ppm	0 - 10.0 ppm	
Silane	SiH ₄	SiH4 3E 50 LT	1.0 ppm	0 - 40 ppm	
Sulfur dioxide	SO ₂	4S	0.04 ppm 0.1 ppm	0 - 10.0 ppm 0 - 50 ppm	
Tetrahydrothiophene (THT)	C ₄ H ₈ S	THT 3E	1.5 mg/m ³ (0.3 ppm)	0 - 50 mg/m ³ (0 - 25 ppm)	

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Electrochemical sensors are designed with specific usage requirements in mind. The same manufacturer may offer multiple models of sensor for the detection of the same gas, but that are optimized for different sets of interferences and operating conditions. Thus, cross sensitivities may vary widely between different models and brands of sensors. For instance, a Cl₂ sensor that is deliberately designed for use in atmosphere that contains significant background levels of H₂S may be equipped with filters or electrodes which limit the effects of H₂S on the sensor's readings. Chlorine sensors designed for use in atmosphere that does not contain hydrogen sulfide may have a very different relative response.

Note: Some compounds (e.g. BF₃, BCl₃, BBr₃) can be detected indirectly by using their property to react with the moisture present in the ambient air, thus forming compounds for which a specific sensor is available (e.g. HF, HCl, HBr). Other gases can be detected by using cross-sensitivities of some of the sensors.

Very importantly, use of an electrochemical toxic sensor is not always the best approach. Many volatile organic chemical (VOC) vapors are best detected by a photoionization detector (PID) sensor, while combustible gases and vapors are usually measured by means of catalytic combustion (CC) or non-dispersive infrared (NDIR) sensors. Consult the instrument manufacturer for advice on which type of sensor will provide the best performance for your application.



Table 2: Additional toxic gases detectable with EC sensors from Table 1

Gas	Formula	Sensor (ppm)
Acetaldehyde	CH ₃ CHO	CO
Arsenic trichloride	AsCl ₃	HCl
Arsenic Trifluoride	AsF ₃	HF
Arsenic pentafluoride	AsF ₅	HF
Boron trichloride	BCl ₃	HCl
Boron tribromine	BBr ₃	HCl
Boron trifluoride	BF ₃	HF
Butanethiol	C ₄ H ₉ SH	TBM
Carbonyl fluoride	COF ₂	HF
Chlorine dioxide	ClO ₂	ClO ₂ or O ₃
Chlorine trifluoride	ClF ₃	ClO ₂ or HF
Dichlorosilane	SiH ₄ Cl ₂	HCl
Diethylether	C ₄ H ₁₀ O	EtO
Disulfur decafluoride	S ₂ F ₁₀	HF
Disulfur dichloride	S ₂ Cl ₂	HCl
Formic Acid	HCOOH	CO
Germanium chloride	GeCl ₄	HCl
Hydrogen bromide	HBr	HCl
Iodine	I ₂	Cl ₂ or O ₃
Isopropanol	(CH ₃) ₂ CHOH	CO w/o filter
Methanol	CH ₃ OH	CO w/o filter
Phosphorous trichloride	PCl ₃	HCl
Phosphorous pentachloride	PCl ₅	HCl
Phosphoryl chloride	POCl ₃	HCl
Silicon tetrachloride	SiCl ₄	HCl
Stibine	SbH ₃	AsH ₃
Thiophene	C ₄ H ₄ S	THT
Tin tetrabromide	SnBr ₄	HBr
Tin tetrachloride	SnCl ₄	HCl
Tin tetrafluoride	SnF ₄	HF
Titanium tetrachloride	TiCl ₄	HCl
Trichlorosilane	SiHCl ₃	HCl
Trichlorotriazine	C ₃ Cl ₃ N ₃	HCl
Trifluorotriazine	C ₃ F ₃ N ₃	HF

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Table 3: EC sensors for LEL range explosive gases

Gas	Formula	Sensor (ppm)
Ethanol (LEL range)	C ₂ H ₅ OH	H ₂
Hydrogen (LEL range)	H ₂	H ₂

Changing the type or types of toxic sensors installed in a GfG instrument is generally very easy. However, it's important to let new sensors stabilize for at least 45 minutes after installation, and ALL newly installed sensors MUST be calibrated before use.



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January 3, 2013

Tech Note 2016: G450 Multi-gas Detector Performance Requirements

1. Physical Characteristics	
Size	Instrument shall not exceed 2.5" x 4.3" x 2.0" in total size.
Weight	Less than 10 oz. (280 g) with O ₂ /LEL/CO/H ₂ S sensors
Handling	Unit shall be easily held in one gloved hand.
Case material	Impact proof, rubberized housing.
Environmental protection	Rated to IP-67 protection levels for dust and water ingress (dust and water tight).
Display location	Display shall be top-mounted.
Protective housing	Instrument shall be provided with impact proof, rubberized housing.
Carrying attachments	Unit shall be provided with belt clip and lanyard ring.
Carrying case	An optional protective leather carrying case with shoulder strap shall be available.
RFI / EMI resistance	Complies with EMC Directive 89/336/EEC
Electromagnetic compatibility	Complies with DIN EN 50270

2. User Interface	
Display type	Illuminated full graphic liquid crystal display (LCD) with automatic size adjustment for optimal read out, display of battery capacity, gas concentration, peak readings, STEL, TWA, pump status and explanatory messages . LCD screen shall change colors from green to amber to red according to alarm status.
Display orientation	Display may be inverted 180° by user at any time during normal operation.
Gas readings	Gas readings for all sensors (up to 7 gases) must be displayed simultaneously.
Display legibility	Readings and messages easily legible both in both dim light and bright light conditions.
Display "Zoom" function	User shall be able to increase the size ("zoom") readings at any time in normal operation.
Backlight	Instrument shall include an LCD backlight which is automatically activated in the event of an alarm condition. Backlight may be manually activated from the push of any button, and shall remain illuminated for ten seconds when any button is pressed. User can enable backlight to be continuously activated for use in dim light conditions.
Keypad buttons	Instrument must have no more than three switches or pushbuttons to operate. There shall be no requirements to access hidden or internal switches for any instrument operations.
Data access	Current gas readings, session peaks, STEL, TWA, instrument settings, user and location and other information shall be accessible directly through the instrument LCD. Access to logged gas measurement data shall be via data logging cable. Data may be downloaded either by means of the "smart charging cap", GfG Docking Station or via the drop-in cradle charger.



3. Monitoring Capability	
Number / types of gases	Instrument shall be capable of simultaneously measuring up to 4 gases (depending on the sensors installed).
Sensors	Gas sensors shall be interchangeable, user replaceable plug-in “smart” sensors capable of being automatically recognized by the instrument. It shall not be necessary to manually reconfigure the instrument for use with a new type of sensor.
Sensor warranty	Basic O ₂ , LEL, CO, H ₂ S, COSH, CO with low H ₂ interference (CO-H), and infrared combustible gas and CO ₂ sensors shall warranted for three full years. Sensors replaced under warranty shall be provided free-of-charge to the instrument owner. Manufacturer shall offer option for extended 6-year warranty coverage for all supported sensors including O ₂ , LEL, CO, H ₂ S, and CO with low H ₂ interference (CO-H).
Combustible gas display	The instrument shall be capable of displaying the combustible gas as % Lower Explosive Limit (LEL) or % volume – selectable by user.

4. Basic Operational Features	
Instrument turn-on	The button used to turn the instrument on must be clearly marked and differentiated by feel from the other buttons.
Inadvertent shutoff	The instrument must be designed to protect against accidental shut off. Once activated, a three second button hold is needed to turn the instrument off.
Zero adjustments	It shall be possible for the user to initiate a fresh air zero adjustment at any time from normal operation
Zero adjustment safety lockout	The instrument shall prevent users from zeroing out hazardous readings.
Audible “Instrument On” indicator	The instrument shall be provided with a periodic user enabled audible signal (confidence beep) indicating the instrument is in operation. Instrument will incorporate user programmable confidence beep of intervals 15 to 90 seconds.
Time / date	Instrument must be able to display time and date with or without the optional data logging package. User must be able to reset the time and date without tools. Instrument must include a board mounted battery capable of powering the clock for a minimum of 6 years.

5. Classifications and Certifications	
Intrinsic safety	<p>The detector and motorized pump must have the following certifications and approvals:</p> <ul style="list-style-type: none"> • ATEX Intrinsically Safe II 2G EEX ia d IIC T4/T3 • c-CSA-us Certified as Intrinsically Safe for use in Class 1, Division I, Groups A, B, C and D Hazardous Locations; and Zone 0: Ex ia IIC T3 • CE Marked (Conformite Europeane)



6. Available Sensor Types and Ranges

The Instrument shall be available with the following gas sensing sensors and ranges:

	<u>Gas type</u>	<u>Sensor Type</u>	<u>Range</u>	<u>Resolution</u>
Sensor Types	Combustible gases	Catalytic	0 to 100% LEL / 0 to 5% vol	.5% LEL / .05% vol
	Oxygen	Fuel Cell	0 to 25% Volume	0.1% vol
	Carbon Monoxide	Electrochemical	0 to 500 ppm	1.0 ppm
	Hydrogen sulfide	Electrochemical	0 to 100 ppm	0.1 ppm
Minimum alarm setting for H ₂ S	It must be possible to set the instrument instantaneous low alarm (A1), instantaneous high alarm (A2), TWA and or STEL alarms for H ₂ S as low as 1.0 ppm.			
Minimum alarm setting for LEL	It must be possible to set the instrument LEL low alarm as low as 4.0 LEL while the instrument is calibrated to a pentane level of sensitivity.			

7. Instrument Alarms

Visual alarms	Visual alarms shall consist of bright top-mounted LEDs, a 360° wraparound LED light bar, heterochromatic backlit display that changes color from green to amber to red, numeric readings, and explanatory messages. The display must provide a positive indication as to which gas sensor is in alarm, and the alarm type. Alarms must be visible in all lighting conditions and from a distance of 5 feet.
Over-range alarms	Upwards or downwards pointing arrow icons will be used to indicate sensor readings above or below the over-range limit for the affected sensor.
Audible alarms	The audible alarms shall register at least 103 db at 1 foot. The sound pattern for the low (A1) alarm shall be differentiated from the sound pattern of the high (A2) alarm.
Alarm latch feature	A user settable latching alarm choice must be available for all gas measurement channels. When the alarm latch choice is selected, gas alarms continue to sound until manually cleared.
Oxygen alarms	The oxygen channel shall have alarms for both oxygen deficiency (falling) and oxygen enrichment (rising).
Combustible gas alarms	The combustible (LEL) channel shall have three user adjustable alarms A1 (low), A2 (high) and A3 (approaching LEL). A protective latching over-range alarm shall be activated should the LEL concentration be exceeded.
Toxic gas and PID alarms	Each toxic channel shall have 4 user adjustable alarms, A1 (low), A2 (high), TWA and STEL.
Power alarms	The instrument shall provide audible and visual alarms and messages indicating low battery power and / or impending shut-down. Low battery alarms shall be operable in all environmental conditions.
Vibrating Alarm	Instrument shall include a vibrator alarm.



8. Advanced Display and Software Options	
Industrial hygiene displays	The gas detector must have the capability of displaying session PEAK, STEL and TWA, as well as current gas level readings.
Peak reading mode	It shall be possible to use a single button to activate the "Peak reading mode" and set the instrument LCD to retain the most significant readings for each sensor since the last time the instrument "Peak reading" was reset. Pressing "Reset" restores the displayed readings to the current values. Use of the "Peak reading mode" will not cause the session time history calculations (PEAK, STEL and TWA) to be lost or reset.
Password protection	Instrument will have password protected service and alarm adjustment program.

9. Environmental	
Temperature	-4 to +122°F (-20 to +50 °C): Up to 24 hours continuous operation per charge. -4 to -20°F (-20 to -30°C): Up to 12 hours continuous operation per charge. -20 to -31°F (-30 to -35°C): Up to 8 hours continuous operation per charge -31 to -40°F (-35 to -40°F): Up to 1.5 hours continuous operation per charge
Humidity	0 to 95% RH (non-condensing)
Pressure	700 to 1,300 kPa

10. Datalogging (Instrument Data Storage)	
Datalogging	Instrument shall include datalogging on a standard basis.
Datalogger capacity	The instrument shall be capable of recording and storing data for the most recent 55 hours of monitoring (at 2 minute intervals) without overwriting existing information in normal use. It shall be possible to store up to 10 users and 100 locations in the datalogging memory.
Gas record content	Datalog entries shall contain as a minimum the date, time, and a record of the readings (instantaneous, average or peak values) for each gas sensor for each logged monitoring interval.
Record intervals	The time between data records shall be user selectable (from 1 second to 60 minutes).
Data retention	Monitoring data, as well as programmable instrument settings and choices shall be stored in non-volatile memory, and shall not be lost or corrupted in the event of sudden instrument power loss or removal of the battery pack. A backup battery shall provide a minimum of 6 years of power for the instrument clock.
Activity record content	The instrument shall log significant instrument events including: <ul style="list-style-type: none"> • Gas readings • Gas, pump and battery alarms • Instrument turned on / turned off • Fresh air adjustments and calibrations



11. Instrument Power	
Battery pack options	The instrument shall be powered by interchangeable NiMH and alkaline battery packs. NiMH and alkaline packs will be interchangeable without any setup from user.
Battery life indication	The LCD shall include a gauge depicting estimated remaining battery life. Gauge must be visible when the instrument is on.
Run time	The instrument shall run up to 20 hours on a single charge or one set of alkaline batteries.
Charger	The drop-in cradle charger shall be capable of charging a depleted rechargeable battery pack within 6 hours. The cradle charger shall include LEDs that indicate when charging is underway and when complete.
Deep discharge cycle	The instrument shall allow the user to pre-schedule or manually initiate an automatic deep discharge / recharge cycle to exercise the rechargeable battery pack.
Charger for motorized pump equipped instruments	An optional drop-in cradle charger shall be available for motorized pump equipped instruments such that both the rechargeable battery pack in the instrument and the battery pack in the motorized pump can be recharged at the same time.
Charger input voltages	Chargers must be usable for 110 – 240 VAC, and with optional 12VDC power source.
Flash light battery pack option	The instrument shall be capable of being equipped with an optional rechargeable battery pack with “flash light” LEDs. The flash light LEDs shall be activated by pressing a button on the instrument display. The LEDs shall illuminate in a downward direction to facilitate use during confined space and other activities in which the instrument is operated in the dark.
Cross compatible chargers	The G450 shall use the same chargers as the G460 and G450/G460 motorized pumps.
Multi-unit chargers	A five instrument gang charger will be optionally available. The five charging modules will be mounted to a common back-plate. A single 110 – 240 VAC power source will be used to provide power to the complete five unit array.
12. Calibration	
Calibration tools	Standard accessories for the instrument shall include a calibration adapter used to introduce calibration gas to the instrument. The calibration adapter shall include a “read switch” that automatically tells the instrument when the adapter has been installed, and the instrument is ready to begin calibration.
Automatic calibration	The instrument shall be capable of automatic fresh air and span calibration adjustment.
Calibration history	Instrument must identify all sensors at start-up and indicate their calibration history and pre-set alarm levels appropriate to sensors installed. The instrument must retain and display the last three calibration dates for each installed sensor.
Calibration, bump test and inspection due dates	Instrument shall include programmable bump test, calibration, and inspection due dates. Instrument shall display an explanatory alarm message when any due date is exceeded. It shall be possible for the user to acknowledge the alarm and use the instrument, but the alarm will continue to be displayed each time the instrument is until the necessary procedure is completed turned on.
Docking station	The manufacturer shall offer a fully automatic docking station for bump testing, calibrating and downloading testing and gas monitoring results from the instrument, and transferring the downloaded information to a computer. The docking station shall be able to complete a bump test in 20 seconds. The docking station will include an SD card capable of storing up to 10,000 test records. The docking station shall allow the user to program the types and concentrations of gas used in the calibration procedure. Docking stations shall be available in single calibration gas inlet, and four calibration gas inlet versions.
Test station	The manufacturer shall offer an automatic test station for bump testing and downloading test results from the instrument, and transferring the downloaded information to a computer. The test station shall be able to complete a bump test in 20 seconds. The test station will include an SD card capable of storing up to 10,000 test records.



13. Sampling Systems	
Sampling modes	Instrument may be operated in diffusion mode, with optional attachable motorized pump or with a hand-aspirator (squeeze bulb) type sample draw kit.
Motorized pump	The attachable motorized pump shall include a built-in slide-shutter switch that permits operation in either diffusion or sample draw mode while the pump is attached.
Pump power source	Motorized pump shall include its own separate power supply. The motorized pump shall not be powered by means of the instrument battery pack.
Motorized pump battery pack options	The motorized pump shall be powered by the interchangeable NiMH and alkaline battery packs. The same battery packs must be interchangeably usable in either the instrument or the motorized pump.
Sampling accessories	A polycarbonate sampling wand (probe) with integral, replaceable hydrophobic barrier and particulate filters will be included standard with the motorized pump. Two meter and three meter telescoping stainless-steel probes will be optionally available.
Sampling system filters	The motorized pump must contain user replaceable filters to prevent the ingress of dust into the instrument. The filter must be readily accessible without disassembling the instrument or motorized pump.
Sample line attachment	Sample lines must be attached using an adaptor for secure attachment.
Allowable sample line length	The motorized pump must be capable of drawing a sample from at least 200 feet (65 m) away.
Fluid ingress protection	A sample probe assembly with an inline filter that has provision to prevent water and debris from entering the sample line must be available.

14. Maintenance, Warranties	
Sensor Replacement	Sensors shall be easily accessed and replaced in the field. The only tool necessary shall be a
Warranty	The instrument electronics and mechanical components shall be provided with a lifetime warranty for defect in manufacture.
Warranty, sensors	<ul style="list-style-type: none"> O₂, H₂S, CO, CO-H, and %LEL combustible gas sensors shall be warranted for three full years. An optional extended 6-year warranty plan shall be available for these sensors.
Warranty, consumables	Battery packs and other components consumed or degraded in normal operation (such as filters and pumps) shall have a one-year warranty.



January 3, 2013

Tech Note 2017: G460 Multi-gas Detector Performance Requirements

1. Physical Characteristics	
Size	Instrument shall not exceed 2.5" x 4.3" x 2.0" in total size.
Weight	Less than 10 oz. (280 g) with O ₂ /LEL/CO/H ₂ S sensors Less than 10.3 oz. (292 g) with O ₂ /LEL/CO/H ₂ S and infrared or PID sensors.
Handling	Unit shall be easily held in one gloved hand.
Case material	Impact proof, rubberized housing.
Environmental protection	Rated to IP-67 protection levels for dust and water ingress (dust and water tight).
Display location	Display shall be top-mounted.
Protective housing	Instrument shall be provided with impact proof, rubberized housing.
Carrying attachments	Unit shall be provided with belt clip and lanyard ring.
Carrying case	An optional protective leather carrying case with shoulder strap shall be available.
RFI / EMI resistance	Complies with EMC Directive 89/336/EEC
Electromagnetic compatibility	Complies with DIN EN 50270

2. User Interface	
Display type	Illuminated full graphic liquid crystal display (LCD) with automatic size adjustment for optimal read out, display of battery capacity, gas concentration, peak readings, STEL, TWA, pump status and explanatory messages . LCD screen shall change colors from green to amber to red according to alarm status.
Display orientation	Display may be inverted 180° by user at any time during normal operation.
Gas readings	Gas readings for all sensors (up to 7 gases) must be displayed simultaneously.
Display legibility	Readings and messages easily legible both in both dim light and bright light conditions.
Display "Zoom" function	User shall be able to increase the size ("zoom") readings at any time in normal operation.
Backlight	Instrument shall include an LCD backlight which is automatically activated in the event of an alarm condition. Backlight may be manually activated from the push of any button, and shall remain illuminated for ten seconds when any button is pressed.
Keypad buttons	Instrument must have no more than three switches or pushbuttons to operate. There shall be no requirements to access hidden or internal switches for any instrument operations.
Data access	Current gas readings, session peaks, STEL, TWA, instrument settings, user and location and other information shall be accessible directly through the instrument LCD. Access to logged gas measurement data shall be via data logging cable. Data may be downloaded either by means of the "smart charging cap", GfG Docking Station or via the drop-in cradle charger.



3. Monitoring Capability	
Number / types of gases	Instrument shall be capable of simultaneously measuring up to 7 gases (depending on the sensors installed).
Sensors	Gas sensors shall be interchangeable, user replaceable plug-in “smart” sensors capable of being automatically recognized by the instrument. It shall not be necessary to manually reconfigure the instrument for use with a new type of sensor.
Sensor warranty	Basic O ₂ , LEL, CO, H ₂ S, COSH, CO with low H ₂ interference (CO-H), and infrared combustible gas and CO ₂ sensors shall warranted for three full years. Sensors replaced under warranty shall be provided free-of-charge to the instrument owner. Manufacturer shall offer option for extended 6-year warranty coverage for the basic O ₂ , LEL, CO, H ₂ S, COSH and infrared sensors.
Combustible gas display	The instrument shall be capable of displaying the combustible gas as % Lower Explosive Limit (LEL) or % volume – selectable by user.

4. Basic Operational Features	
Instrument turn-on	The button used to turn the instrument on must be clearly marked and differentiated by feel from the other buttons.
Inadvertent shutoff	The instrument must be designed to protect against accidental shut off. Once activated, a three second button hold is needed to turn the instrument off.
Zero adjustments	It shall be possible for the user to initiate a fresh air zero adjustment at any time from normal operation
Zero adjustment safety lockout	The instrument shall prevent users from zeroing out hazardous readings.
Audible “Instrument On” indicator	The instrument shall be provided with a periodic user enabled audible signal (confidence beep) indicating the instrument is in operation. Instrument will incorporate user programmable confidence beep of intervals 15 to 90 seconds.
Time / date	Instrument must be able to display time and date with or without the optional data logging package. User must be able to reset the time and date without tools. Instrument must include a board mounted battery capable of powering the clock for a minimum of 6 years.

5. Classifications and Certifications	
Intrinsic safety	<ul style="list-style-type: none"> • IEC Ex / ATEX Intrinsically Safe II 2G EEX ia d IIC T4/T3 • c-CSA-us Certified as Intrinsically Safe for use in Class 1, Division I, Groups A, B, C and D Hazardous Locations; and Zone 1: Ex ia IIC T3 • CE Marked (Conformite Europeane)



6. Available Sensor Types and Ranges

The Instrument shall be available with the following gas sensing “Smart Sensors” and ranges:

	<u>Gas type</u>	<u>Sensor Type</u>	<u>Range</u>	<u>Resolution</u>	<u>Warranty</u>
Sensor types	Combustible gases	Catalytic	0 to 100% LEL / 0 to 5% vol.	.5% LEL / .05% vol.	3 year
	Combustible gases	Infrared	0 to 100% LEL / 0 to 5% vol.	0.2% LEL / .05% vol.	3 year
	Combustible gases	Infrared	0 to 100% vol.	0.5% vol.	3 year
	Combustible gases	Infrared	Selectable 0 to 100% LEL / 5 to 100% vol.	1.0% LEL / .05% vol.	3 year
	Oxygen	Fuel Cell	0 to 25% vol.	0.1% vol.	3 year
	Carbon Monoxide	Electrochemical	0 to 500 ppm or 0 – 1,000 ppm	1.0 ppm	3 year
	CO-H (low H ₂ cross sensitivity)	Electrochemical	0 to 500 ppm or 0 – 1,000 ppm	1.0	3 year
	Hydrogen Sulfide	Electrochemical	0 to 100 ppm or 0 to 500 ppm	0.1 ppm	3 year
	COSH (CO and H ₂ S)	Electrochemical	0 to 100ppm H ₂ S, 0 to 300 ppm CO	0.2 ppm H ₂ S, 1.0 ppm CO	3 year
	Carbon dioxide (CO ₂)	Infrared	0 – 50,000 ppm	50 ppm	3 year
	Photoionization detector (PID) with 10.6 eV lamp	PID	0.1 – 500 ppm or 0.5 to 2,000	0.1 ppm 0.5 ppm	Lamp: 2year Detector: lifetime
	Ammonia (NH ₃)	Electrochemical	0 – 500 ppm	1.0 ppm	1 year
	Arsine (AsH ₃)	Electrochemical	0 – 1.0	0.02	1 year
	Chlorine (Cl ₂)	Electrochemical	0 – 10 ppm	0.1 ppm	2 year
	Chlorine dioxide (ClO ₂)	Electrochemical	0 – 10 ppm	0.1 ppm	2 year
	Ethylene oxide (ETO)	Electrochemical	0 – 20 ppm	0.1 ppm	1 year
	Hydrogen (H ₂)	Electrochemical	0 – 2,000 ppm 0 – 40,000 ppm	1.0 ppm 2.0 ppm	2 year
	Hydrogen chloride (HCl)	Electrochemical	0 – 30 ppm	0.1 ppm	1 year
	Hydrogen cyanide (HCN)	Electrochemical	0 – 30 ppm	0.2 ppm	1 year
	Hydrogen fluoride (HF)	Electrochemical	0 – 10 ppm	0.1 ppm	1 year
	Nitric oxide (NO)	Electrochemical	0 – 250 ppm	0.5 ppm	2 year
	Nitrogen dioxide (NO ₂)	Electrochemical	0 – 50 ppm	0.05 ppm	2 year
	Ozone (O ₃)	Electrochemical	0 – 1.0 ppm	0.02 ppm	1 year
	Phosgene (COCl ₂)	Electrochemical	0 – 1.0	0.02 ppm	6 months
Phosphine (PH ₃)	Electrochemical	0 – 10 ppm	0.1 ppm	2 year	
Silane (SiH ₄)	Electrochemical	0 – 50	0.02 ppm	1 year	
Sulfur dioxide (SO ₂)	Electrochemical	0 – 10 ppm	0.05 ppm	2 year	



7. Instrument Alarms	
Visual alarms	Visual alarms shall consist of bright top-mounted LEDs, a 360° wraparound LED light bar, heterochromatic backlit display that changes color from green to amber to red, numeric readings, and explanatory messages. The display must provide a positive indication as to which gas sensor is in alarm, and the alarm type. Alarms must be visible in all lighting conditions and from a distance of 5 feet.
Over-range alarms	Upwards or downwards pointing arrow icons will be used to indicate sensor readings above or below the over-range limit for the affected sensor.
Audible alarms	The audible alarms shall register at least 103 db at 1 foot. The sound pattern for the low (A1) alarm shall be differentiated from the sound pattern of the high (A2) alarm.
Alarm latch feature	A user settable latching alarm choice must be available for all gas measurement channels. When the alarm latch choice is selected, gas alarms continue to sound until manually cleared.
Oxygen alarms	The oxygen channel shall have alarms for both oxygen deficiency (falling) and oxygen enrichment (rising).
Combustible gas alarms	The combustible (LEL) channel shall have three user adjustable alarms A1 (low), A2 (high) and A3 (approaching LEL). A protective latching over-range alarm shall be activated should the LEL concentration be exceeded.
Toxic gas and PID alarms	Each toxic channel shall have four user adjustable alarms, A1 (initial low), A2 (high), TWA and STEL.
Power alarms	The instrument shall provide audible and visual alarms and messages indicating low battery power and / or impending shut-down. Low battery alarms shall be operable in all environmental conditions.
Vibrating Alarm	Instrument shall include a vibrator alarm.

8. Advanced Display and Software Options	
Industrial hygiene displays	The gas detector must have the capability of displaying session PEAK, STEL and TWA, as well as current gas level readings.
Peak reading mode	It shall be possible to use a single button to activate the “Peak reading mode” and set the instrument LCD to retain the most significant readings for each sensor since the last time the instrument “Peak reading” was reset. Pressing “Reset” restores the displayed readings to the current values. Use of the “Peak reading mode” will not cause the session time history calculations (PEAK, STEL and TWA) to be lost or reset.
Password protection	Instrument will have password protected service and alarm adjustment program.

9. Environmental	
Temperature	-4 to +122°F (-20 to +50 °C): Up to 24 hours continuous operation per charge. -4 to -20°F (-20 to -30°C): Up to 12 hours continuous operation per charge. -20 to -31°F (-30 to -35°C): Up to 8 hours continuous operation per charge -31 to -40°F (-35 to -40°F): Up to 1.5 hours continuous operation per charge
Humidity	0 to 95% RH (non-condensing)
Pressure	700 to 1,300 kPa



10. Datalogging (Instrument Data Storage)	
Datalogging	Instrument shall include datalogging on a standard basis.
Datalogger capacity	The instrument shall be capable of recording and storing data for the most recent 55 hours of monitoring (at 2 minute intervals) without overwriting existing information in normal use. It shall be possible to store up to 10 users and 100 locations in the datalogging memory.
Extended datalogger capacity	It shall be possible to install an SD card to add up to 2GB of extended datalogging memory to the instrument.
Gas record content	Datalog entries shall contain as a minimum the date, time, and a record of the readings (instantaneous, average or peak values) for each gas sensor for each logged monitoring interval.
Record intervals	The time between data records shall be user selectable (from 1 second to 60 minutes).
Data retention	Monitoring data, as well as programmable instrument settings and choices shall be stored in non-volatile memory, and shall not be lost or corrupted in the event of sudden instrument power loss or removal of the battery pack. A backup battery shall provide a minimum of 6 years of power for the instrument clock.
Activity record content	The instrument shall log significant instrument events including: <ul style="list-style-type: none"> • Gas readings • Gas, pump and battery alarms • Instrument turned on / turned off • Fresh air adjustments and calibrations
11. Instrument Power	
Battery pack options	The instrument shall be powered by interchangeable NiMH and alkaline battery packs. NiMH and alkaline packs will be interchangeable without any setup from user.
Battery life indication	The LCD shall include a gauge depicting estimated remaining battery life. Gauge must be visible when the instrument is on.
Run time	The instrument shall run up to 20 hours on a single charge or one set of alkaline batteries (when equipped with O ₂ /LEL/CO/H ₂ S sensors).
Charger	The drop-in cradle charger shall be capable of charging a depleted rechargeable battery pack within 6 hours. The cradle charger shall include LEDs that indicate when charging is underway and when complete.
Deep discharge cycle	The instrument shall allow the user to pre-schedule or manually initiate an automatic deep discharge / recharge cycle to exercise the rechargeable battery pack.
Charger for motorized pump equipped instruments	An optional drop-in cradle charger shall be available for motorized pump equipped instruments such that both the rechargeable battery pack in the instrument and the battery pack in the motorized pump can be recharged at the same time.
Charger input voltages	Chargers must be usable for 110 – 240 VAC. Chargers must also be usable with an optional 12VDC power source.
Flash light battery pack option	The instrument shall be capable of being equipped with an optional rechargeable battery pack with “flash light” LEDs. The flash light LEDs shall be activated by pressing a button on the instrument display. The LEDs shall illuminate in a downward direction to facilitate use during confined space and other activities in which the instrument is operated in the dark.
Cross compatible chargers	The G460 instrument shall use the same chargers as the standard four gas G450 instrument and attachable G450/G460 motorized sampling pumps
Multi-unit chargers	A five instrument gang charger will be optionally available. The five charging modules will be mounted to a common back-plate. A single 110 – 240 VAC power source will be used to provide power to the complete five unit array.



12. Calibration	
Calibration tools	Standard accessories for the instrument shall include a calibration adapter used to introduce calibration gas to the instrument. The calibration adapter shall include a “read switch” that automatically tells the instrument when the adapter has been installed, and the instrument is ready to begin calibration.
Automatic calibration	The instrument shall be capable of automatic fresh air and span calibration adjustment.
Calibration history	Instrument must identify all sensors at start-up and indicate their calibration history and pre-set alarm levels appropriate to sensors installed. The instrument must retain and display the last three calibration dates for each installed sensor.
Calibration, bump test and inspection due dates	Instrument shall include programmable bump test, calibration, and inspection due dates. Instrument shall display an explanatory alarm message when any due date is exceeded. It shall be possible for the user to acknowledge the alarm and use the instrument, but the alarm will continue to be displayed each time the instrument is until the necessary procedure is completed turned on.
Docking station	The manufacturer shall offer a fully automatic docking station for bump testing, calibrating and downloading testing and gas monitoring results from the instrument, and transferring the downloaded information to a computer. The docking station shall be able to complete a bump test in 20 seconds. The docking station will include an SD card capable of storing up to 10,000 test records. The docking station shall allow the user to program the types and concentrations of gas used in the calibration procedure. Docking stations shall be available in single calibration gas inlet, and four calibration gas inlet versions.
Test station	The manufacturer shall offer an automatic test station for bump testing and downloading test results from the instrument, and transferring the downloaded information to a computer. The test station shall be able to complete a bump test in 20 seconds. The test station will include an SD card capable of storing up to 10,000 test records.

13. Sampling Systems	
Sampling modes	Instrument may be operated in diffusion mode, with optional attachable motorized pump or with a hand-aspirator (squeeze bulb) type sample draw kit.
Motorized pump	The attachable motorized pump shall include a built-in slide-shutter switch that permits operation in either diffusion or sample draw mode while the pump is attached.
Pump power source	Motorized pump shall include its own separate power supply. The motorized pump shall not be powered by means of the instrument battery pack.
Motorized pump battery pack options	The motorized pump shall be powered by the interchangeable NiMH and alkaline battery packs. The same battery packs must be interchangeably usable in either the instrument or the motorized pump.
Sampling accessories	A polycarbonate sampling wand (probe) with integral, replaceable hydrophobic barrier and particulate filters will be included standard with the motorized pump. Two meter and three meter telescoping stainless-steel probes will be optionally available.
Sampling system filters	The motorized pump must contain user replaceable filters to prevent the ingress of dust into the instrument. The filter must be readily accessible without disassembling the instrument or motorized pump.
Sample line attachment	Sample lines must be attached using an adaptor for secure attachment.
Allowable sample line length	The motorized pump must be capable of drawing a sample from at least 200 feet (65 m) away.
Fluid ingress protection	A sample probe assembly with an inline filter that has provision to prevent water and debris from entering the sample line must be available.



14. Maintenance, Warranties	
Sensor Replacement	Sensors shall be easily accessed and replaced in the field. The only tool necessary shall be a
Warranty	The instrument electronics and mechanical components shall be provided with a lifetime warranty for defect in manufacture.
Warranty, sensors	<ul style="list-style-type: none">• O₂, COSH, H₂S, CO, CO-H, CO₂ catalytic combustible (%LEL) and infrared combustible gas sensors shall be warranted for three full years. An optional extended 6-year warranty plan shall be available for these sensors.• Other available electrochemical toxic sensors shall carry warranty periods as specified in the GfG Instrumentation Gas Detection Product Warranty.
Warranty, consumables	Battery packs and other components consumed or degraded in normal operation (such as filters and pumps) shall have a one-year warranty.