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.

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 (CH_4) is exposed to 50% LEL CH_4, the instrument shows a reading of 50% LEL. However, if that same instrument is exposed to 50% LEL pentane, (C_5H_{12}) 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 (H_2), methane and propane (C_3H_8) 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 (CH_4) compared to hexane (C_6H_{14}). Saturated hydrocarbons larger than nonane (C_9H_{20}) 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% O_2 in order for the LEL sensor to detect gas accurately. Readings are increasingly affected as the concentration drops below this level. In zero percent O_2

Figure 2: Multi-sensor instruments are able to use a wide range of sensors and detection technologies including O_2, standard pellistor LEL, NDIR combustible gas and CO_2, PID and over 20 different substance-specific electrochemical sensors for toxic gas measurement.

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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 (PH_3) and high concentrations of H_2S.

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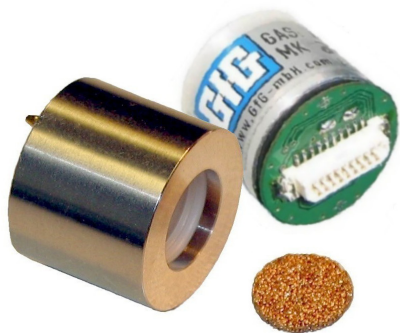
Figure 3: Pellistor type LEL sensor with flame arrestor (sinter) removed from stainless steel housing

T_{alarm} (10%LEL) = 4 seconds
T_{50} = 8 seconds
T_{90} = 14 seconds
T_{100} = 20 seconds
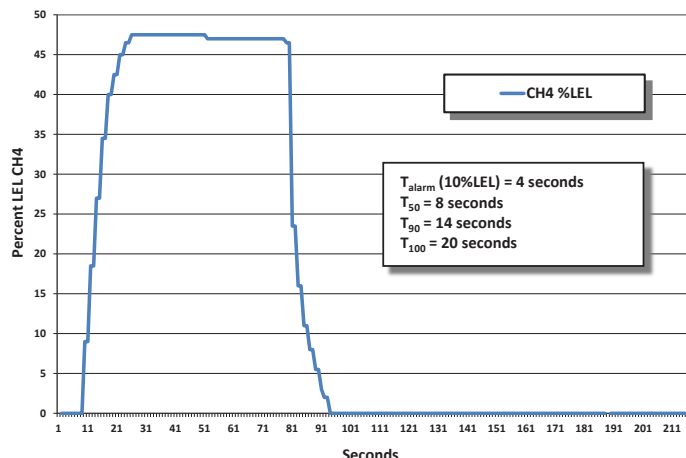
Figure 4: Pellistor type LEL sensor response to 50% LEL methane (2.5% Volume). Note that the "time to alarm" (10% LEL) is about 4 seconds.

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.

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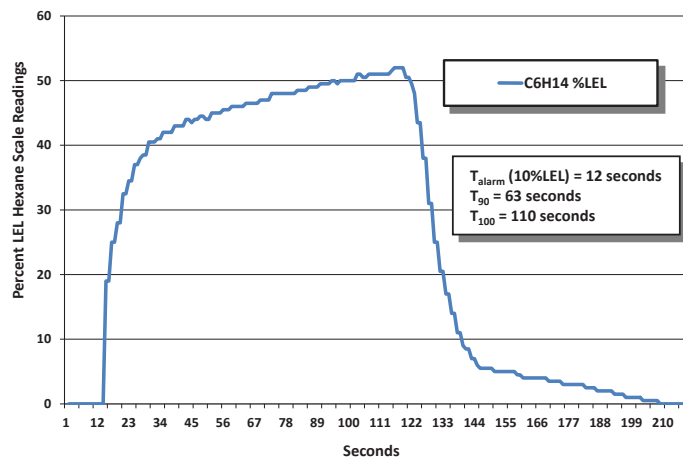
Figure 5: Pellistor type LEL sensor response to 50% LEL hexane (0.6 % Volume). Note that the "time to alarm" (10% LEL) is about 12 seconds.

• 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.

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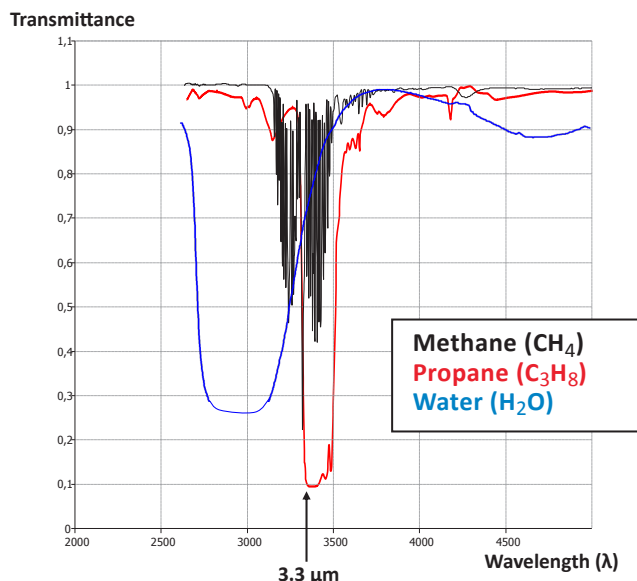
Figure 7: Infrared transmittance spectra for methane, propane and water. IR sensors usually measure combustible gas at a wavelength of 3.3 μm (= 3,300 nm). Since water also absorbs some IR light at this wavelength, the sensor should be zeroed in the ambient atmosphere in which the instrument will be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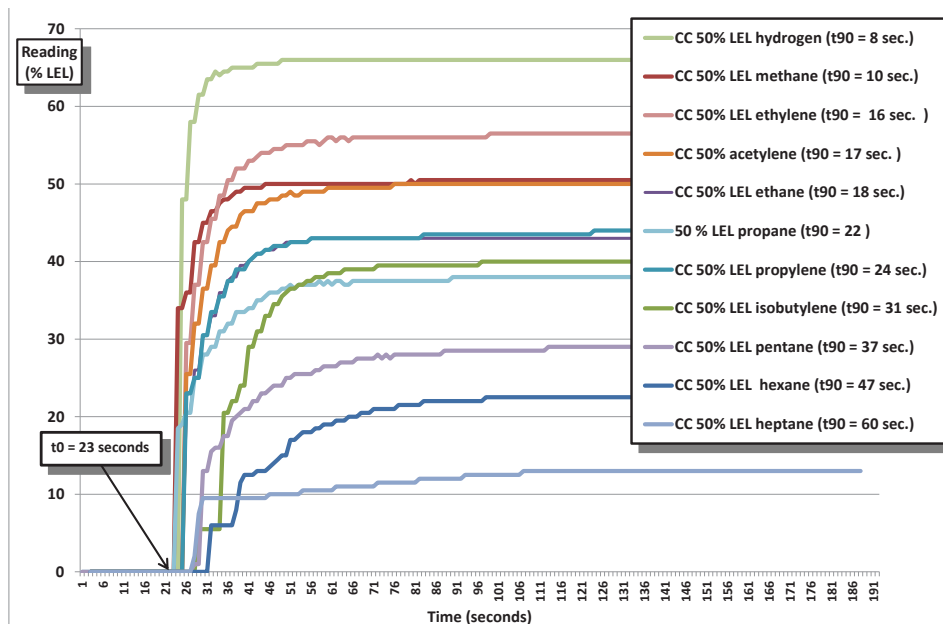

Figure 8: Pellistor type LEL sensors show lower relative responses to larger molecules than to smaller. In the example above the response to methane (CH$_4$) is about two times higher than the response to pentane (C$_5$H$_{12}$), and about four times higher than the response to heptane (C$_7$H$_{16}$). The response to larger molecules is also much slower. It takes only 10 seconds for the methane reading to reach t90 (90% of its final stable response), while it takes a full minute for heptane.
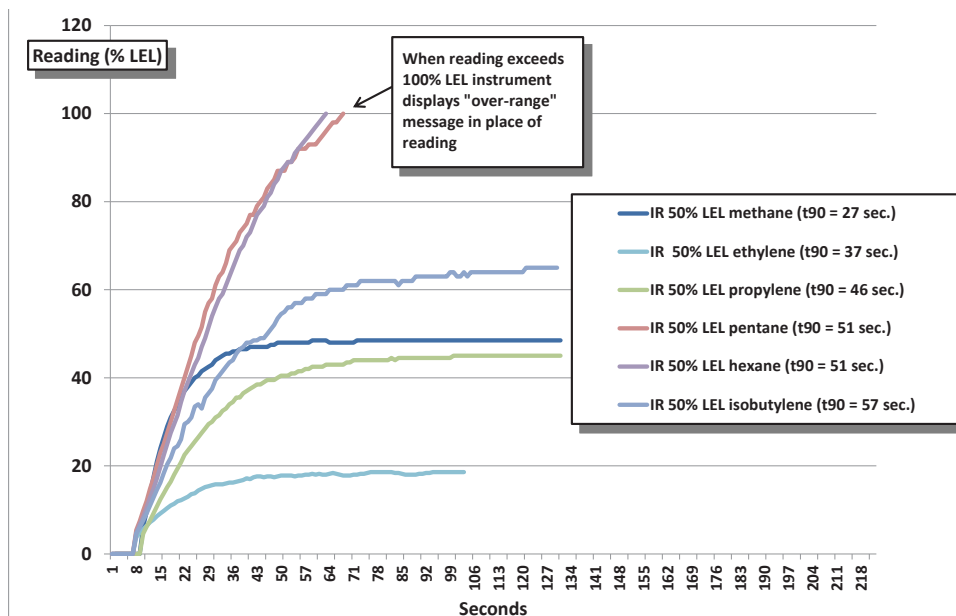

Figure 9: Two-wavelength infrared type LEL sensors usually measure combustible gas at a wavelength of 3.3 μm. The C-H bond in hydrocarbon molecules absorbs IR radiation at this wavelength. The more C-H bonds in the molecule, the greater the absorbance. In the example above, the response to methane (CH$_4$), which has only four C-H bonds, is much lower than the response of the sensor to larger hydrocarbon molecules like pentane (C$_5$H$_{12}$), 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.
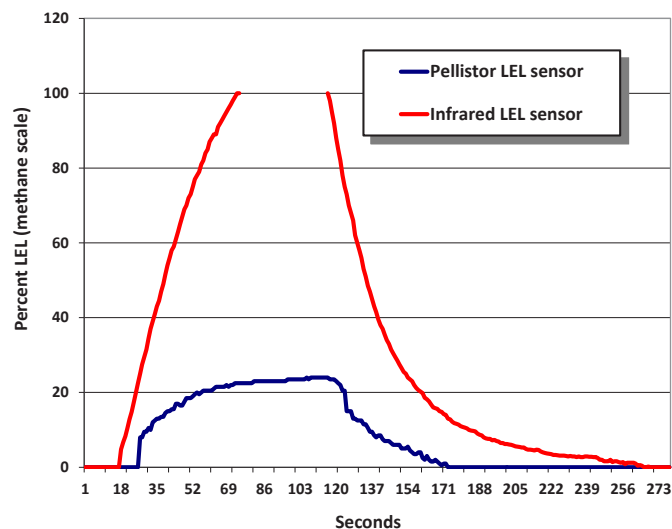
Figure 10: Relative response of pellistor and infrared sensors to n-hexane. Both sensors were calibrated to 50% LEL methane (CH_4), then exposed to 50% LEL n-hexane (C_6H_{14}). The uncorrected readings for the pellistor sensor are much lower than the true concentration (50% LEL); while the uncorrected 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).
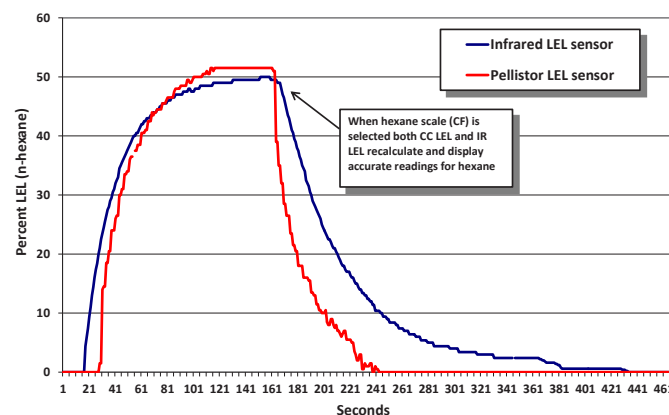
Figure 11: Response of n-hexane calibrated pellistor and IR sensors to 50% LEL n-hexane. The readings for both sensors are now very close to the true 50% LEL concentration applied. The initial response of the IR sensor is slightly quicker than the response of the pellistor sensor. However, the time to 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) H_2 measurement.

- **High range measurement of natural gas from "sour" (high H_2S content) natural gas wells**

The natural gas from many of the older fields in North America is often extremely "sour"; with H_2S 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 H_2S 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 H_2S.

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 H_2S), 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.
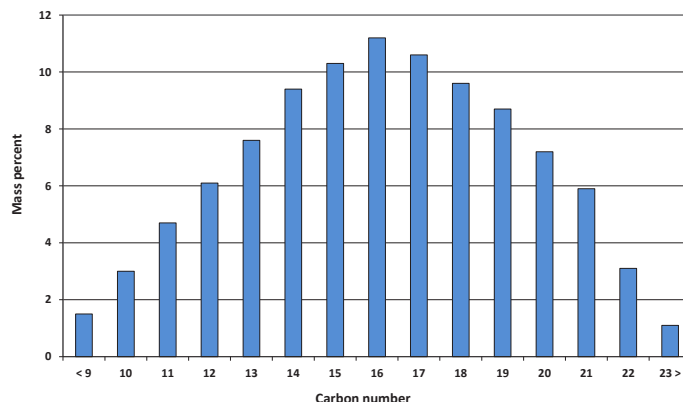
Figure 12: Typical carbon number distribution in No. 2 Diesel Fuel (liquid). Less than 1.5% of diesel molecules are small enough to diffuse through the flame arrestor of a typical pellistor LEL sensor. Less than 4% of molecules present as vapor (STP) are small enough to diffuse through the flame arrestor.
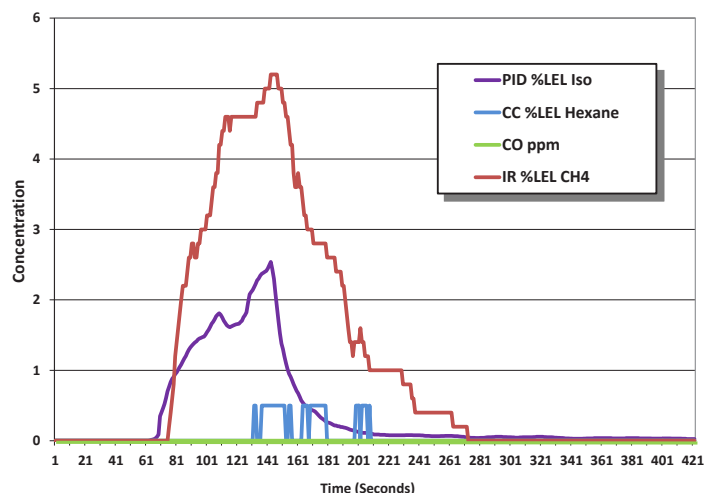
Figure 13: Response of PID, catalytic (pellistor) %LEL, IR %LEL and CO sensors exposed to diesel vapor. The IR LEL sensor shows the most accurate response, while the catalytic LEL sensor barely shows any response at all. PID is the best detection technology for low range ppm detection.

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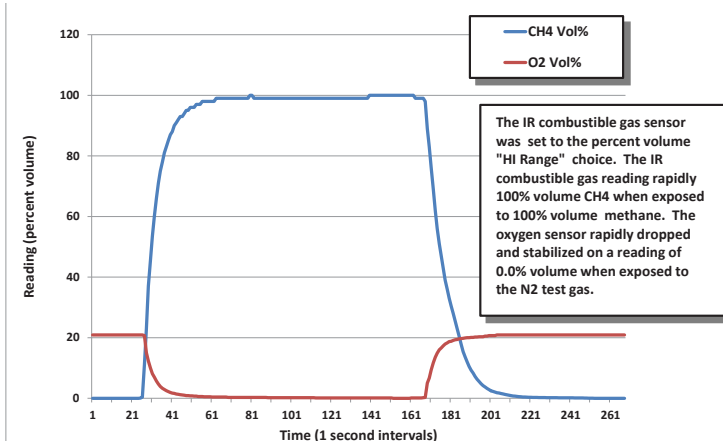
- **Instrument used to measure O₂ and % LEL combustible gas in procedures that include vessel inertion at an oil refinery**

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.

The IR combustible gas sensor was set to the percent volume "HI Range" choice. The IR combustible gas reading rapidly 100% volume CH4 when exposed to 100% volume methane. The oxygen sensor rapidly dropped and stabilized on a reading of 0.0% volume when exposed to the N2 test gas.

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.

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 H_2S. As always, the flame arrestor in the pellistor sensor limits the ability of the sensor to detect hydrocarbon gases larger than nonane (C_9H_{20}).

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 H_2 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.
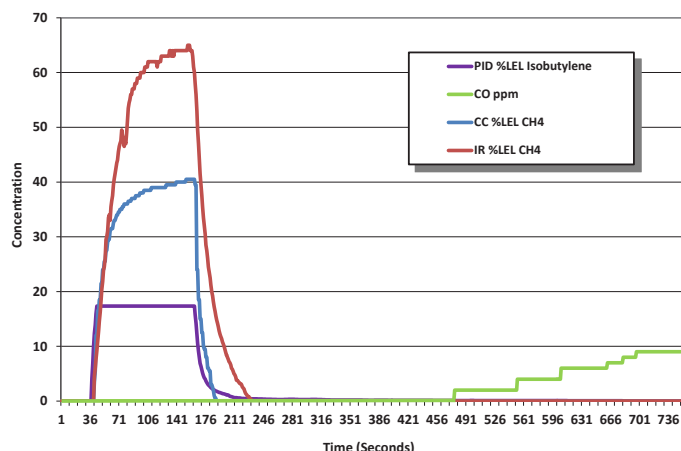

Figure 16: **Response of standard pellistor (catalytic) LEL, O₂, PID and CO sensors exposed to 50% LEL (9,000 ppm) isobutylene. The PID was calibrated to isobutylene. The LEL sensor was calibrated to methane (CH₄). The relative response of the LEL sensor to isobutylene is about 0.8. The maximum over-limit 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.**
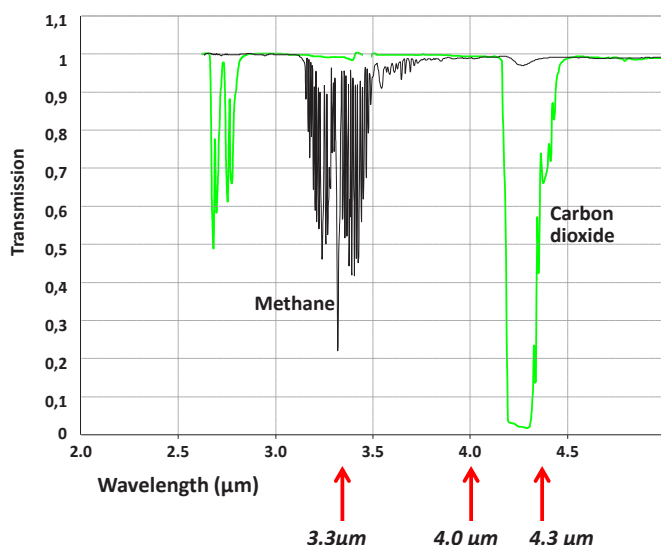

Figure 18: **Transmittance spectra of methane and carbon dioxide. Dual-channel IR combustible gas / CO₂ sensors actually measure absorbance at three wavelengths. Combustible gas is measured at 3.3 μm (= 3,300 nm). CO₂ is measured at 4.3 μm (= 4,300 nm). A single reference wavelength (4.0 μm) is used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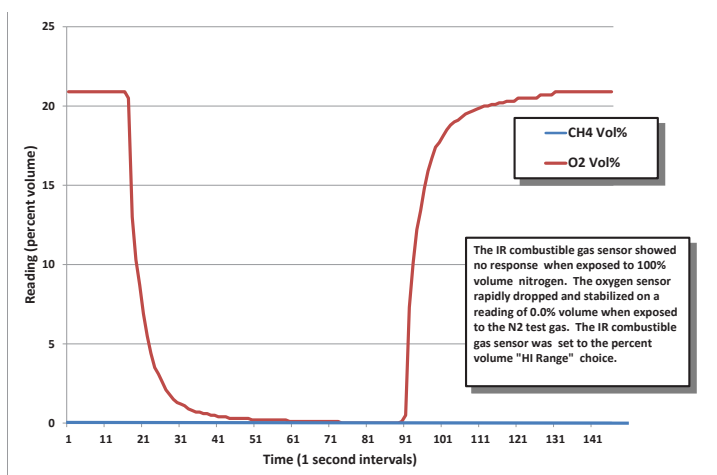

Figure 17: **Response of infrared (IR) combustible gas and oxygen sensors exposed to 100% volume nitrogen (N₂). The IR combustible gas sensor showed no response when exposed to 100% volume nitrogen. The oxygen sensor rapidly dropped and stabilized on a reading of 0.0% volume when exposed to the N₂ test 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 O_2 for pellistor LEL sensors to accurately detect combustible gas. It should be noted that CO_2 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 CO_2 (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 O_2, CO and H_2S. 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 / O_2 / CO / H_2S) 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 hydrocarbon gases (methane, ethane, propane, butane, pentane and natural gas)	Able to detect LEL range C6 – C9 hydrocarbon 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, H2S, 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 H2 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 shipyards	High range CH_4 from "sour" (high H_2S) 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_2S	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_2S	%LEL C1 - C9 gases in low O_2 atmosphere, ppm range VOC, CO and H_2S	%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 H2S 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.