Choosing the Best Technologies for Combustible Gas and VOC Measurement

Bob Henderson, GfG Instrumentation
Contact Europe: GfG Europe, Gavin Boorman • Phone: +44 (0)1371 874447 • Fax: +44 (0)1371 879904
Email: sales@gfgeurope.com • Web: www.gfgeurope.com

Most multi-sensor gas detectors include sensors used to measure the four most commonly encountered hazards: oxygen deficiency (and enrichment), LEL combustible gas, carbon monoxide and hydrogen sulphide. However, in some cases, these basic sensors are not capable of measuring the atmospheric hazards that are actually present.

Hundreds of thousands of these basic "four-gas" atmospheric monitors are used every day. The sensors utilised in these portable gas detectors are extremely good at detecting what they are designed to measure. As good as the sensors are, however, they still have limitations. It is critically important for instrument users to understand what the sensors in their instrument cannot properly measure as well as what they can. In most cases the types of sensors installed in these basic instruments are well suited to the hazards to be measured. However, specific conditions and hazards may require the use of more specialised sensors, or a specialised calibration strategy that will provide more accurate readings for the gases actually present. Combustible gas sensors are particularly subject to limitations that can materially affect their ability to detect certain types of combustible gases and vapours. 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. Oxygen, carbon monoxide and hydrogen sulphide 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 minimise 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 vapours produced by alcohol, 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 sulphide 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 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 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 oxidising or "burning" the gas on an active bead or "pellistor" located within the sensor. The heating effect on the bead is proportional to the amount of combustible gas present in the atmosphere. 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 oxidised 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.

Pellistor type sensors generally include a flame arrestor that can slow, reduce or prevent larger hydrocarbon molecule from entering the sensor (Figure 1).

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.

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 pellistor 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 vapours 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 vapour. However, the TLV (Threshold Limit Value) for diesel vapour 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!

Figure 1: Combustible pellistor type sensor showing housing and detached flame arrestor

Figure 2: The G460 atmospheric monitor can support a wide variety of sensors including pellistor type LEL, PID and infrared combustible gases

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 oxidise 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 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.

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 pellistor type LEL sensors. 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), photoionisation detectors (PIDs) and non-dispersive infrared (NDIR) sensors.

• **Thermal conductivity (TCD) sensors**

Thermal conductivity sensors are a specialised 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 ceramic material to form beads.

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. 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. The difference in temperature between the two beads is proportional to the amount of combustible present in the atmosphere being monitored. 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.

• Photoionisation Detectors (PID) 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. 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. The amount of energy needed to remove an electron from the target molecule is called the ionisation energy (IE). Larger and / or more reactive molecules have lower ionisation energies than smaller less reactive molecules. Thus, in general, the larger the 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 photoionisation 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 wave-length 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. 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. 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.

It is the chemical bonds in the molecules being measured that actually absorb the infrared light. While pellistor type LEL sensors are more sensitive to small molecules like methane than to larger molecules like pentane or nonane; the sensitivity of NDIR sensors depends on how well and how many chemical bonds in the molecule absorb IR light at the measurement wavelength.

Since larger molecules have more chemical bonds holding the atoms in the molecule together, they provide more opportunities for infrared radiation to be absorbed. Thus, an NDIR sensor is very sensitive to molecules such as octane, nonane and the larger molecules in diesel vapor (Figure 3).

NDIR combustible gas sensors have a number of other advantages when compared to pellistor type sensors.

NDIR sensors do not have a flame arrestor that limit the ability of large molecules to diffuse into the optical sensing chamber.

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.

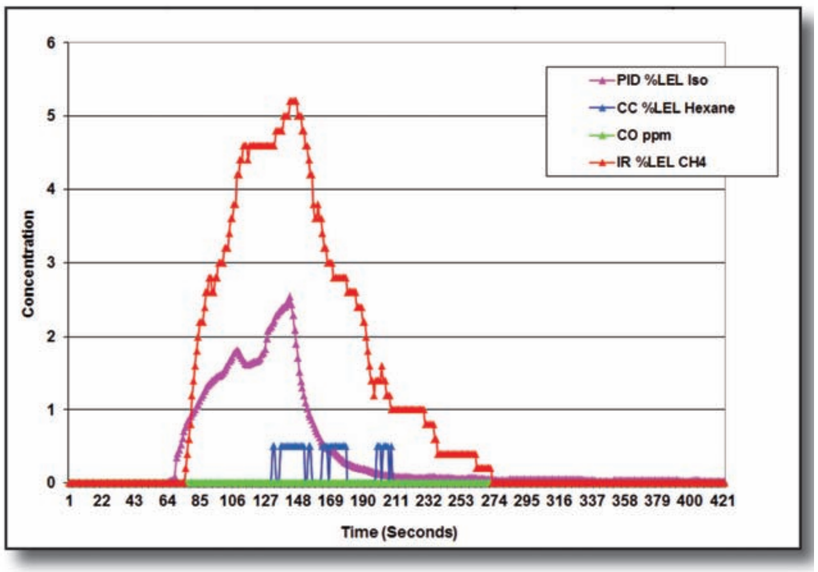

Figure 3: Response of PID, pellistor type LEL and NDIR combustible gas sensors to warm 130°F (54°C) diesel vapor. Readings for all three sensors displayed on LEL scale. PID and IR LEL sensor show strong response. Pellistor LEL sensor shows almost no response.

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

Depending on the design, NDIR sensors may or may not be capable of measuring acetylene and certain VOC molecules that do not absorb infrared well at the measurement wavelength. Consult the manufacturer for specific details.

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 of the potential hazards. Table 1 summarises the advantages and limitations of each type of sensor discussed.

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.

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, hepane, octane, nonane)	Able to accurately detect LEL range heavy fuel vapours (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, tetraethy lead, H_2S, etc.)	Able to use for high range combustible gas measurement (100% LEL and higher)	Able to measure hydrogen (H_2)
Standard 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

Table 1: Sensor technology selection chart

** 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 vapours, 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.*