

Photodiode-Driven Infrared Sensors: Shining New Light on LEL Gas Measurement for the Oil & Gas Industry and Confined Space Entry Applications

Oil and gas production and work in confined spaces expose field personnel to a variety of toxic and explosive gases in everyday drilling, processing, transport and municipal operations. Explosive gas build-ups can endanger not only the workers nearby, but also a widespread area beyond the working area; making fast, accurate measurement of combustible gases below LEL levels is critical to maintaining safety. Today, there are two main sensor technologies used for detecting explosive gases: catalytic bead and infrared. Let's take a close look at the differences.

Catalytic Bead Sensors

Catalytic bead, or "pellistor", sensors were developed in the 1950's as a more accurate replacement to canaries as early warning systems for toxic and explosive gases in mines. The sensor design features a platinum coil embedded in a catalyst-coated alumina bead (Figure 1). A gas sample oxidizes, or combusts, upon contact with the catalyst causing the temperature of the bead to increase, which in turn causes the resistance of the platinum coil to change. The measured change in resistance indicates the amount of combustible gas present.

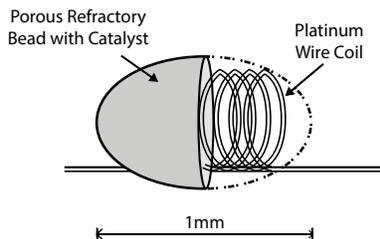


Figure 1: Pellistor Image from City Technology:
<http://www.citytech.com/technology/pellistors.asp>

The sensor responds differently to different types of combustible gases due to four main causes:

1. **Heat of combustion.** Different gases burn, or combust, at different temperatures causing different amounts of heat to be transferred to the bead, and thus different changes in resistance through the platinum coil.
2. **Lower Explosive Limit (LEL) volume.** Each combustible gas has a particular concentration in air at which it becomes explosive. When a sensor displays a percentage of LEL readout, it is based on the LEL concentration for a specific reference gas. It is no surprise that the gases with a higher v/v percentage required for their LEL also have higher signal outputs on catalytic bead sensors.
3. **Diffusion due to Brownian motion.** Gas molecules diffuse through air and filters, with the speed largely dependent on their molecular size. Large gas molecules, such as the long hydrocarbon chains, diffuse more slowly than smaller molecules, such as methane gas.
4. **Catalyst-gas reactivity.** Combustible gases react differently to different catalyst coatings. One coating may react strongly to a particular gas, but only weakly to another gas.

Though they've been in use for over 70 years, catalytic bead sensors have changed very little over time. Most improvements have been focused on the catalyst materials used to coat the alumina beads, along with the reduction in bead size to reduce required power, but the majority of the design remains unchanged.

During normal sensor operation, gases reacting with the catalyst can consume the catalyst coating gradually degrading sensitivity, causing signal drift and reducing the lifespan of the sensor. Because of this, catalytic bead sensors have a typical lifespan of 3-5 years (most are warranted for two years) and must be calibrated every 90 - 180 days for accuracy, and daily testing (bump testing) is necessary to ensure continuous and safe functionality.

Catalytic bead sensors are also susceptible to poisoning by a variety of materials commonly found in oil and gas applications, including silicone vapors, sulfur compounds, such as hydrogen sulfide (H₂S), and halogenated hydrocarbons, such as those used in fire suppression. These chemicals continuously reduce, and eventually completely degrade, the sensitivity of the catalytic bead sensor until it fails to react to gas at all, a potentially hazardous condition.

Because catalytic bead sensors combust the target gas within the sensor cell, they are not typically intrinsically safe and a flame arrestor must be used to prevent ignition of environmental gases. This flame arrestor significantly reduces sensor response to large hydrocarbons, such as those found in diesel gasoline and jet fuel. The sensor will read low, even in high concentrations of those gases. Oxygen must also be present in the environment for the target gas to combust. Pellistor sensors will not work in the inert, oxygen-depleted atmospheres found in many oil and gas operations.

Catalytic bead sensors require around 225mW of power to operate. For the average portable four-gas detector, the catalytic bead type LEL sensor typically accounts for more than half of the total power draw of the unit, which results in typical run times of 10-20 hours, before a detector must be charged.

Non-Dispersive Infrared Sensors (NDIR)

In more recent years, non-dispersive infrared (NDIR) sensors have emerged as an alternative for the aging catalytic bead technology. Infrared sensors consist of a gas cell through which infrared radiation passes (Figure 2). Gas molecules in the cell absorb certain frequencies of radiation in the

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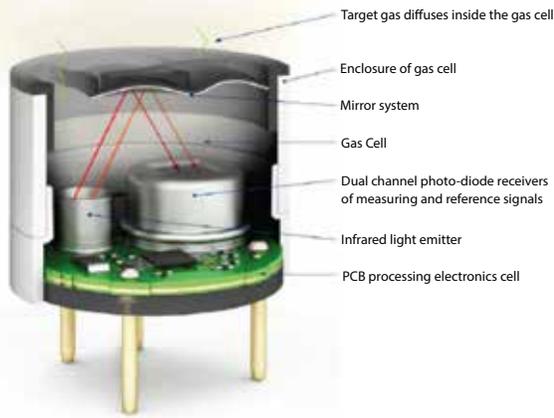


Figure 2: Infrared Sensor Image from OptoSense, LLC

bonds between dissimilar atoms (carbon and hydrogen, for example). Dual infrared radiation detectors within the gas cell measure the amount of radiation transmitted through the gas (active detector). The reference detector measures a specific IR wavelength that is not absorbed by either the target hydrocarbon molecules or possible interfering molecules, such as water vapor, to compensate for any interfering factors such as dust and humidity. The difference in radiation measured by the two detectors indicates the level of gas present.

Photodiode-powered NDIR sensors are intrinsically safe and don't require the use of a flame arrestor. This more easily allows large hydrocarbon molecules to be detected. Since the gas is not reacting chemically, the sensor is immune to poisoning. Additionally, unlike catalytic beads which require oxygen to operate, NDIR sensors can be used in reduced-oxygen or even inert environments. Recent advances in NDIR sensors have replaced the traditional incandescent radiation source with photodiodes (similar to LEDs), significantly reducing the power consumption of the sensor from 100 mW to less than 5 mW.

NDIR sensors are typically tuned to measure the absorption of hydrocarbon (C-H) bonds at 3.4 or 3.3 microns, which are suitable for most hydrocarbon gases. Due to its diatomic structure consisting of only two similar hydrogen atoms, hydrogen (H₂) gas does not absorb infrared radiation and will not be measured by an NDIR combustible gas sensor. Further, since the NDIR sensor is targeted for absorption at a specific micron wavelength, some gases, such as acetylene, will not be detected. However, when an NDIR sensor is used in a multi-gas instrument, both hydrogen and acetylene gas can be detected through cross-sensitivity with the carbon monoxide (CO) sensor, as shown in Table 1:

Table 1: CO cross-sensitivity as %LEL

| Gas | LEL | CO cross-sensitivity | CO reading at 10% LEL |
|-----------|--------------|----------------------|-----------------------|
| Hydrogen | 4% by vol. | 30% | 1200 ppm |
| Acetylene | 2.5% by vol. | 30% | 750 ppm |

Dual-beam/dual-detector sensor designs (Figure 3) provide a fail-safe method to detect when either the transmitter or the receiver components fail. Since the sensor cannot be poisoned like catalytic beads, only a blocked sensor would prevent the sensor from indicating a problem. The redundancy also serves to minimize signal drift, which allows for calibration and maintenance cycles of one year or more.

Sensor Comparison

As previously mentioned, NDIR sensors are generally more responsive to larger hydrocarbons than to smaller ones. This is opposite of catalytic bead sensors which has caused many multi-gas manufacturers to recommend calibrating to pentane or hexane, in order to compensate for the catalytic bead sensor's lack of sensitivity to heavier hydrocarbons. NDIR equipped multi-gas instruments calibrated to methane will allow increased sensitivities to larger hydrocarbon gas while not having to deal with the problems associated with calibrating to an uncommon and non-target gas.

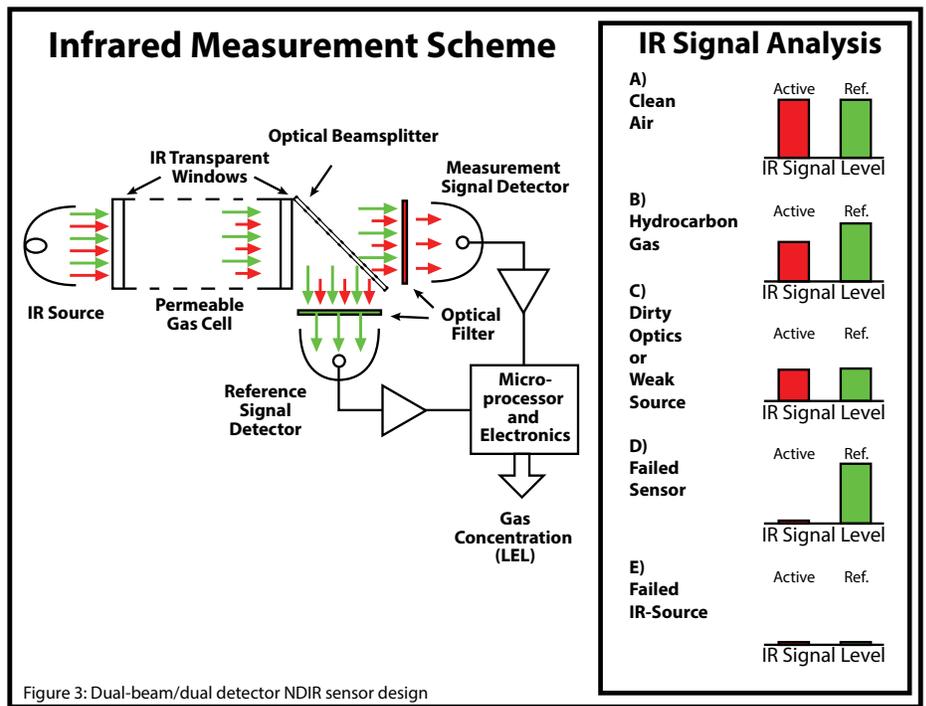


Figure 3: Dual-beam/dual detector NDIR sensor design

Table 2: Sensor Comparison Summary

| Catalytic Bead | LED-Driven Infrared |
|--|--|
| Power hungry - short run time between charges | Low power consumption - 2-month to 3-year run time |
| Not fail-safe - Fails to an unresponsive condition | Fail-safe - Fails to a safe condition |
| Susceptible to poisoning and inhibiting chemicals | Immune to poisoning and inhibiting chemicals |
| Requires oxygen to operate | Can operate in inert atmospheres |
| Typically not intrinsically safe | Intrinsically safe |
| Reduced response to large hydrocarbons | Increased response to large hydrocarbons |
| Testing/calibration interval of 90-180 days | Testing/calibration interval of 1+ years |
| Susceptible to significant signal drift | Minimal signal drift |
| Detects all combustible gases | Detects only hydrocarbons |
| Lifespan of 3-5 years | Lifespan of 10 years |
| Shock-sensitive | Shock-resistant |
| Simple analog circuits | Digital communication |
| Higher long-term cost | Lower long-term cost |

While the initial cost of infrared sensors are similar to that of catalytic bead sensors, the long-term costs are lower with infrared sensors. However, the photodiode-driven NDIR equipped multi-gas detectors are now available with MSRP starting around \$700 (Figure 4) and are more compact and easier to use than those equipped with the catalytic bead sensors previously available. The photodiode-driven infrared sensor fails to a safe condition compared to the catalytic bead which fails to an unresponsive condition, requiring significant field maintenance (frequent bump testing and calibration) to ensure it is still functioning. Catalytic beads can detect more combustible gases which may make it the more appropriate choice in certain applications. NDIR sensors are usable in inert atmospheres, whereas the catalytic beads require oxygen to operate. A summary of the sensor differences is shown in Table 2.

With more workers requiring confined space entry than ever before, safety during these industrial operations is critical. Using the latest, most advanced technology to overcome the limitations of older sensor designs ensures the safest conditions for workers, residents in the surrounding areas and the environment. For combustible gas measurement, photodiode-driven infrared sensors are the next generation of safety.



Figure 4: Gas Clip Technologies Multi Gas Clip Simple Plus with photodiode-driven NDIR sensor