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Sensor selection - getting it right for flammable gases

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Abstract

In gas detection terms, pellistors have been the primary technology for detecting hydrocarbons since the '60s, and rightly so. In most circumstances, pellistors are a reliable, cost-effective means of monitoring flammable levels of combustible gases. However, there are some circumstances in which pellistors should not be relied upon, and infrared (IR) technology considered instead, particularly in the oil and gas industry. In this whitepaper, we review the two technologies and the conditions under which IR sensors should be seriously considered as an alternative to pellistors.

Introduction

There is the risk of explosion or fire in many industrial environments because of the presence of flammable gases or vapours. These gases are frequently hydrocarbons, composed of carbon and hydrogen atoms. Different hydrocarbon molecules are different sizes. The small hydrocarbons are gases which are highly flammable. As molecular size increases, flammability decreases and the compound properties go from volatile liquids to fuel oils, lubricating oils and then to tars and waxes.

For those working in environments where flammable gases[‡] are a threat, be they hydrocarbons, or other flammable gas, such as hydrogen or ammonia, gas detection is necessary to alert the user to a hazard. Using the most appropriate sensor technology is an essential part of ensuring safety.

This paper discussion is primarily for portable gas detectors/monitors, but similar analogues apply for fixed point detection. It will provide information on pellistor and IR technology that should assist the user in determining the right technology for their hazards.

Detection Technology

Pellistor sensors use combustion of a gas to detect it, so they provide a direct measure of flammability. A pellistor is based on a Wheatstone bridge circuit (Fig 1), and includes two "beads", both of which encase platinum coils. One of the beads (the active bead) is treated with a catalyst, which lowers the temperature at which the gas ignites around it. This bead becomes hot from the combustion, resulting in a temperature difference between this active and the other "reference" beads. This causes a difference in resistance, which is measured; the amount of gas present is directly proportional to it, so gas concentration can be determined[‡‡]. In high gas concentrations, the combustion process can be incomplete, resulting in a layer of soot on the active bead.

Fig 1: Wheatstone bridge circuit diagram

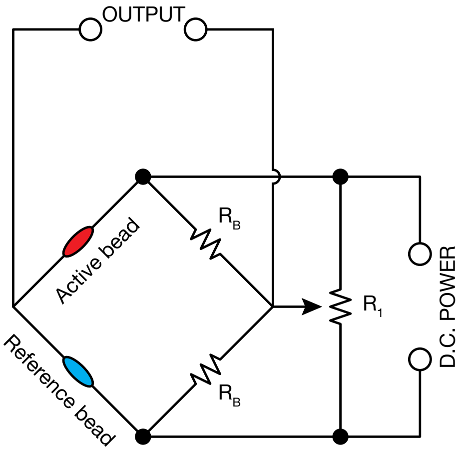
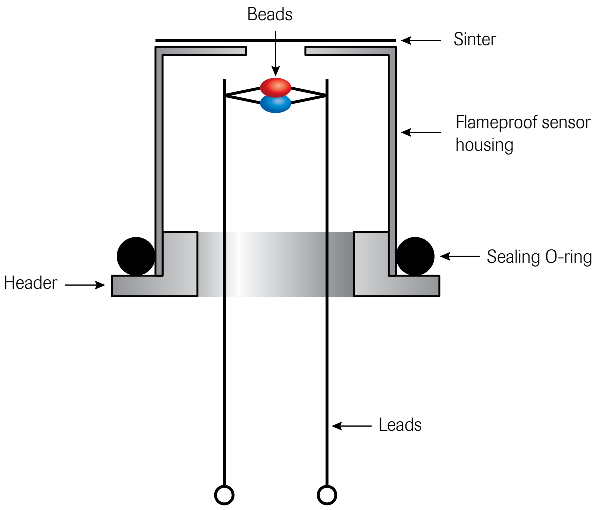


Fig 2: Pellistor sensor construction



While the use of combustion to detect flammable gases may sound unwise, the design of pellistor sensors ensures the safety of the method. The hot bead and electrical circuitry are contained in a flameproof sensor housing (Fig 2), behind the sintered metal flame arrestor (or sinter) through which the gas passes. Confined within the sensor housing, which maintains an internal temperature of 500°C controlled combustion can occur, isolated from the outside environment by the sinter.

Infrared technology sensors use the absorption of IR by hydrocarbon gas molecules in order to detect it. Infrared is part of the electro-magnetic spectrum that sits between visible light and microwaves, with frequencies that range from 0.003×10^{14} to 4×10^{14} cycles/sec (or 1000 to 0.75µm). This technology can be employed in different ways to detect flammable gases. Here, we consider Non-Dispersing Infrared (NDIR) technology, commonly used in personal gas detection.

The carbon and hydrogen atoms that make up a hydrocarbon molecule are held together by covalent bonds (Fig. 3). These bonds have a natural frequency at which they vibrate. When exposed to IR, the covalent bonds in hydrocarbon molecules absorb the IR of the same cycles/sec as the natural frequency of the bonds. The amount of IR absorbed can be used to measure the concentration of gas present.

In practice, two IR emitters within the sensor each generate a beam of IR light (Fig 4). Each beam is of equal intensity and is deflected by a mirror within the sensor on to a photo-receiver, which measures the level of IR received. The “measuring” beam, with a frequency of around 3.3µm, is absorbed by gas if it is present. So, the beam intensity of this is reduced when it reaches the photo-receiver. The “reference” beam (around 3.0µm) cannot be absorbed by hydrocarbon gas molecules, so arrives at the receiver undiminished. The %LEL of gas present is determined by the difference in intensity between the beams measured by the photo-receiver.

Problems with Pellistors

There are a couple of factors, particularly in oil and gas applications, where pellistors should not automatically be assumed to be suitable. Perhaps the most serious drawback of pellistors is they are susceptible to poisoning (irreversible loss of sensitivity) or inhibition (reversible loss of sensitivity) by many chemicals found in the industry.

Fig 3: Methane; one carbon and four hydrogen atoms linked by covalent bonds

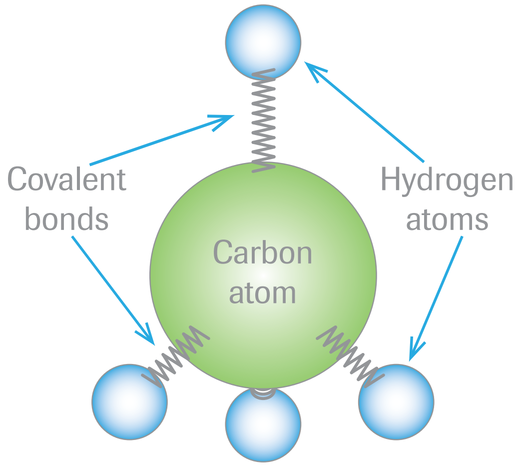
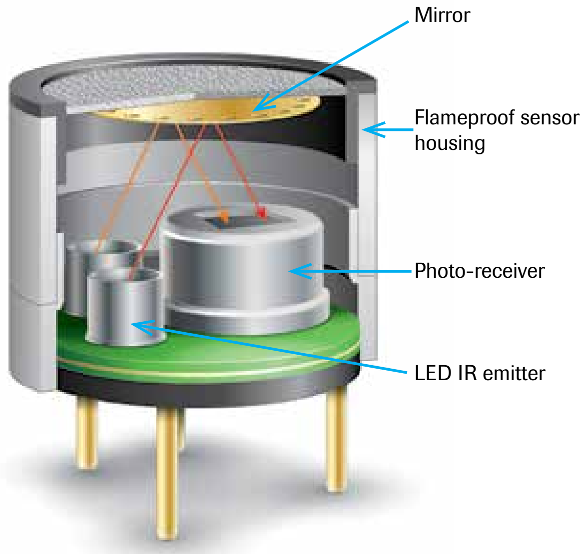


Fig 4: Operation of NDIR technology sensor



Compounds containing silicon, lead, sulphur and phosphates at just a few parts per million (ppm) can impair pellistor performance.

Silicon-based compounds, such as silicones, silanes and siloxanes, (henceforth referred to as “silicons” in this article) are widely used as defoamers and antifoamers, and can significantly increasing efficiencies in many production processes (Fig 5). Silicons are used to reduce waste, maintenance costs and processing time. Problems reduced through use of silicons range from cavitation in pumps to excessive process fouling.

For further information about silicons as potent pellistor poisons, see illustrations 1 and 2, below.

Pellistor-based sensors are also unsuitable for functions such as the filling or purging of tanks with either flammable or inert gases, where either low oxygen or high levels of flammable gases may cause them to fail. Pellistors burn gases to detect them, but without oxygen, the gas won’t burn. This completely undermines the pellistor mode of detection.

Exposure to low levels of target gas (50% LEL or below) can actually assist in maintaining the cleanliness of the beads as any soot can be effectively ‘burned off’. However, the sooting caused by even brief exposure to higher gas levels can cause the zero to drift, affecting pellistor performance, or even cracking the bead in some cases. Exposure to concentrations in the high percent of LEL† of flammable gas will soot up the pellistor completely and irretrievably. Therefore, pellistor sensors are not suited to detection at %vol levels.

In all these instances, the failed pellistor would produce no output when exposed to gas, so giving the impression of a safe environment. If relying on pellistor detectors in environments where poisons, inhibitors or high gas levels may be encountered, regular and frequent testing prior to use is the only way to ensure that performance is not being degraded.

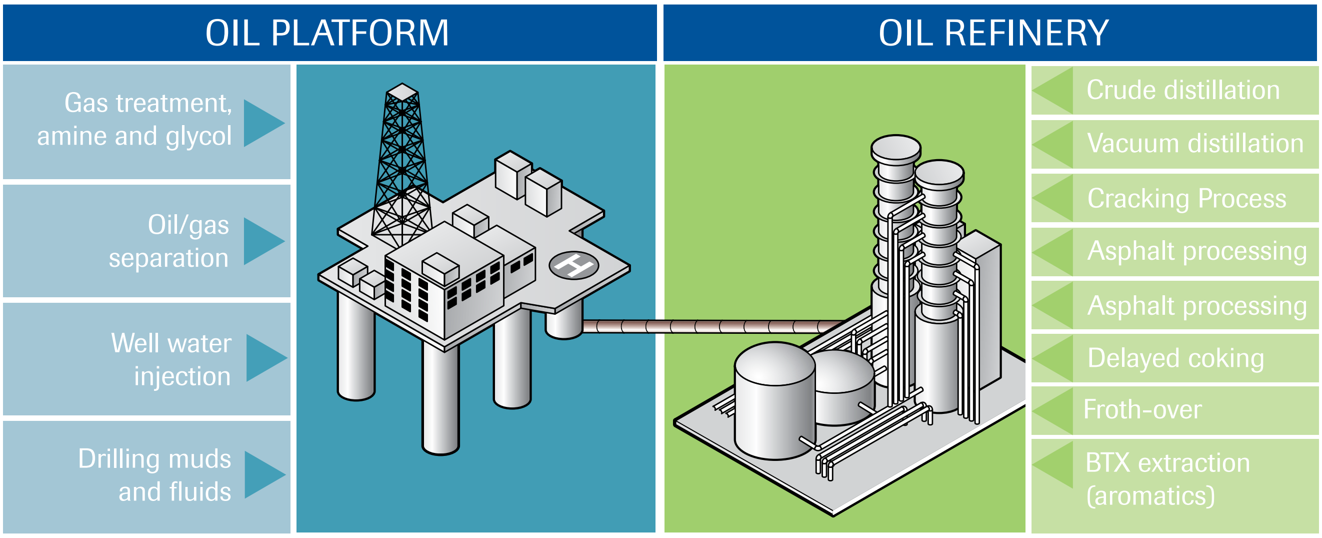


Fig 5. Uses of silicons for antifoaming in oil and gas production

Foam has a significant impact on capacity and efficiency of the oil production and refining processes, from the wellhead, through refining and even during shipment of the finished product. Increased waste, maintenance costs and processing time are caused by process problems, ranging from cavitation in pumps to excessive process fouling. Silicons are widely used as an antifoaming agent to eliminate foaming and increase productivity, and so reduce production costs and save money. This extensive use of silicons need to be taken into account when assessing the gas detection requirements at different points along the production, refining and transportation process.

Imperfect Infrared

Infrared technology is superior to pellistors in the circumstances highlighted so far.

The mode of operation means that IR technology is not susceptible to poisoning or inhibition. So in environments where silicons, lead-, sulphur- or phosphate-based compounds may be encountered, IR sensors can be used with confidence, when pellistors' performance would not be assured.

The sooting of pellistors, caused by exposure to high levels of flammable gas, can partially or completely impair its effectiveness. Again, IR sensors are not affected under these conditions. This feature, combined with their effectiveness in low/no O_2 environments, makes IR sensors ideal for tank filling and purging applications where flammable or inert gases may be in the high percent volume levels and O_2 levels are low.

IR technology also provides fail-safe detection. In normal operation, IR is emitted and received. If either beam fails, the system will register a sensor failure. In normal pellistor operation, conversely, a lack of output is ordinarily an indication of no gas present, but this could also be as a result of a fault. Testing is needed to confirm whether a pellistor is functioning properly.

However, it is important to note that IR technology is not always the best choice, either. Because absorption by hydrogen molecules is at the wrong frequency, IR sensors will not detect this gas.

Hydrogen is highly flammable, and either a pellistor or an electrochemical H_2 sensor is required if it is a possible hazard.

Infrared sensors are susceptible to severe mechanical and thermal shock. They are also strongly affected by gross pressure changes. In circumstances where the mirror can become heavily affected by condensation, the IR beam can deflect away from the photo-receiver. Some fixed systems employ heaters to overcome this last problem, but this option is too power-hungry for routine use on portable units. However, the choice of sensor should not default to pellistor under these circumstances. There could be poisons or other factors that would severely impact pellistors. As part of a site-specific risk assessment, all parameters should be considered to assure best technology is used.

Pellistor technology is considerably less expensive than IR technology, reflecting the comparative simplicity of the detection technology. IR sensors require the use of digital techniques, such as complex signal processing and thermal compensation, in order to obtain the gas reading. This adds to the production cost further.

In working environments where either technology would be suitable, the issue of cost will be an important selection criterion. While IR technology is more costly to purchase, pellistor maintenance costs are liable to be greater, because the sensors tend to require more frequent replacement. The total cost, including the on-going testing and maintenance, should be considered on a site-specific basis to determine the most cost-effective option, coupled with the fail-safe benefits.

Summary

When assessing the best sensor technology to use in your personal gas monitors, there are many factors to consider. Risks to assess include (but may not be restricted to) poisoning, inhibition or sooting; exposure to high flammable gas levels; low oxygen environments; and the need to detect hydrogen. Lifetime ownership costs may also be a factor. Any site may have diverse environments where different sensors are advisable, or a combination of risks that require both pellistor and IR sensor in one device. Ultimately, the prime objective for safety is to select the best detection technology for the hazard and the operating environment. This paper provides guidance on the performance of both pellistor and IR sensors that should enable the users of gas detectors to assess the best technology for their hazards and operating environment.

For information about Crowcon gas detection solutions for the oil & gas and petrochemical industries, visit www.crowcon.com/industries-and-applications/oil-and-gas-exploration-and-production.html

Illustration 1: Potency of silicon as a potent pellistor poison

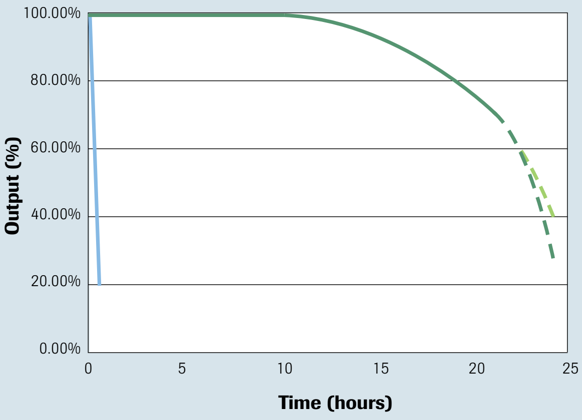
Even at very low levels, silicons act as a poison to pellistor-based sensors. This they do by coating the catalytic surface, so preventing the catalysis of the reaction which is the basis of pellistor sensitivity. To illustrate, an incident occurred when a company replaced a window pane of the room where they stored gas detection equipment. Silicon-based sealant of a standard type was used in the process, and as result, all their pellistor sensors failed their subsequent testing. Happily this company routinely tested all its sensors, or this incident could be well-known and infamous. As it was, the problem was picked up, and no one came to any harm.

Illustration 2: The science of pellistor poisoning

Different chemicals will degrade pellistor performance at different rates. The alumina bead structure used in pellistors is intended to increase resistance. Hexamethyldisiloxane (HMDS) is a volatile organosilicon compound used as a solvent and as a reagent in organic synthesis used to investigate effectiveness.

In Chart 1, the alumina bead significantly improves performance over the platinum coil on it own[1]. Nevertheless, even at levels as low as 10 parts per million (ppm) HMDS, the output of the pellistor with bead is significantly impaired after 20 hours exposure. As time progresses, the level of output degradation accelerates. It seems reasonable to project that after 24 hours (just 3 8-hour shifts), sensor output could easily be at 40% (projection 1) of what it should be, or worse (projection 2). This demonstrates why regular testing is required, and why portable monitors used for personal safety or for proving area environment should be tested prior to use.

Chart 1: Affects of 10ppm HMDS on sensor output



References 1. Reproduced from Combustible gas detector elements, Product data handbook, EEV Ltd. 1977

‡ In this paper, references to"gas(es)" can cover "vapour(s)"

‡‡ An accurate measure of gases present may not be achieved, as this depends on calibration and the gas hazard mixture present

† lower explosive limit (LEL) - the minimum concentration in air at which a gas is flammable

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