Sensor Selection for Hand-Held Portable Gas Detectors

V.R. Brown, PhD, ENMET Corporation

Introduction

Hand-held portable gas detectors often may be configured to have 4, 5, or even 6 different sensors installed by the factory. The sensor selection should be made by the prospective purchaser based on the intended application of the instrument after they take possession of the device. The prospective user needs to convey to the factory such possible applications as Confined Space Entry, HazMat Response, Waste Site Remediation, Indoor Air Quality, etc. The selection of on-board sensors should match up with the most likely gases and vapors associated with the customer's application. A prospective instrument buyer should be leery of an instrument "in stock" at a local safety equipment dealer since it will probably be a common "4-Gas" unit (i.e. CO, H2S, O2, and LEL) for confined space entry applications. These devices are often severely deficient when the owner tries to apply the device to HazMat or Indoor Air Quality applications. In addition, instrument manuals, product flyers, and quickie sales presentations by local sales people often do not convey the full story of performance features as well as limitations of the instrument. Information about interference gas phenomena, cross sensitivity, lower limit of detection, correction factors, and total failure to detect are often left up to the owner to discover on his own after the purchase. Prudent prospective purchasers should first talk to sales engineers or product managers at the factory before ordering portable gas detectors.

The following discussion summarizes 6 different sensor technologies that might be found on a portable gas detector with a brief description of the operating principle, sometimes with its normal useful ranges, and often closing with a caution as to certain limitation to the use of that sensor.

Sensor Options for Portable Gas Detectors

Photoionization Detectors (PID)

Industrial hygienists, safety and environmental professionals, and others have used PhotoIonization Detector (PID) technology for evaluating atmospheric hazards in the workplace since the 1960's. The PID uses an ultraviolet (UV) lamp that contains an elemental gas such as oxygen, nitrogen, hydrogen, or argon under low pressure. When electric current excites the internal gas, it generates UV radiation of 8.5 to 11.7 electron volts (eV), a unit used in measuring the energy of electrons. As it leaves the lamp, the light is then focused into a powerful, narrow beam. The UV light shines onto the sample compound entering the detection compartment via a motorized sample pump. The gas molecules then become positively charged (ionized) and are detected as a current at a negative electrode. The detected charged species creates a small electrical current proportional to the ionized molecule concentration which then is processed though electrical circuits to activate audible/visual alarms and display readings in PPM (parts per million) levels. Water vapor as steam, droplets, or ambient humidity scatters the light, allowing less UV light to reach contaminants that are ionized and results in a lower meter reading. Each element or chemical compound has its own ionization potential (IP) and is measured in electron volts (eV). Compounds with IPs greater than the energy emitted by the lamp cannot be ionized and thus cannot be detected. Most manufacturers typically use 9.6 to 10.6 eV lamps in their PIDs and are not capable of detecting compounds having eV energies greater than their values. Among the gases not detected with these common lower eV lamps include carbon monoxide (14.1 eV), hydrogen cyanide (13.91 eV), methylene chloride (11.35 eV), xylene (11.4 eV), ethane (11.65 eV), and others. The highest eV lamp costs more and has the shortest field service life. Life expectancy of these sensors is 1-3 years and costs may range between $200.00 and $900.00 for lamp replacement. High electron-volt lamps use a salt crystal window that can be damaged by certain corrosive gases. In addition, water vapor can cause substantial errors when using a PID instrument. Modest methane LEL levels of several % by volume can suppress a PID detector's response to VOCs by over 60%! That's right: a 100ppm toluene sample will read out as less than 40ppm when there is 50% LEL methane gas in the sample! PIDs can operate in the range of fractional PPMs all the way up to thousands of PPMs.

Solid State Metallic Oxide Semiconductor (MOS) or Broad Range Hydrocarbon (BRH)

Solid State Metallic Oxide Semiconductor (MOS) sensors have also been used by industrial hygienists, safety and environmental professionals, and others for evaluating atmospheric hazards in the workplace since the 1970's. Solid State sensors are among the most versatile of all broad range sensors. They are uniquely different from other gas sensors discussed in this article. They can be used to detect a variety of gases and vapors in low PPM (parts per million) or even combustible ranges. The MOS sensor is quite different from conventional " hot wire/catalytic combustion" sensing elements discussed in a later section. The sensor is made up of a mixture of metallic oxides of iron, zinc, and tin. They are then heated up to a temperature between 150 and 300 degrees Celsius depending on the gas or gases to be detected. The temperature of operation as well as the recipe of mixed oxides determines the sensor selectivity to various toxic gases and vapors. Electrical conductivity greatly increases as soon as a diffusion process allows the gas or vapor molecules to come in contact with the sensor surface. Water vapor, high ambient humidity, and low oxygen levels can result in higher (upscale) readings. Manufactures using this sensor operate it at a higher temperature allowing it to detect the widest range of halogenated, oxygenated, and aromatic hydrocarbons, solvents, fuels, refrigerants, and volatile organic compounds. Inorganic gases including carbon monoxide, ammonia, hydrogen sulfide are usually detected by different MOS sensors operating at a lower surface temperature or by "substance-specific" sensors described in the next section. The life expectancy of these sensors is 3-5 years with a re-

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placement cost of under $100.00. Like the PID discussed previously, MOS sensors do not have a high degree of chemical specifically (selectivity) to any single gas or vapor.

Electrochemical Sensors (toxic gases)

Electrochemical sensors have been widely used in portable gas detection instruments for confined space entry work since the 1970's. The sensor consists of a sensing electrode and a counter electrode separated by a thin layer of electrolyte solution. Gas molecules that pass through a permeable membrane enter the sensor and react at the surface of the sensing electrode involving an oxidation/reduction reaction. Electrode materials are specifically selected for the gas of interest to catalyze these reactions. A current proportional to the gas concentration is generated, which can be measured to determine the gas concentration. There are about 30 different gases that can be detected with electrochemical sensors. Electrochemical sensors designed to detect toxic gases include carbon monoxide, hydrogen sulfide, sulfur dioxide, ammonia, hydrogen cyanide, and chlorine. These widely used electrochemical sensors with their unique membranes, electrodes, electrolytes, and cell bias voltages are "substance-specific" electrochemical sensors not broad range sensors. The advantages of this type of sensor are its ability to generate signals with low battery requirements and its relatively high specificity. Its major limitation is the possible non-detectability by the chemical sensor in confined space work where unknown toxins or multiple toxins could be present in the form of VOC's, chlorinated solvents, and fuel vapors. These toxic sensors were never designed to detect combustible gases or vapors. The life expectancy of some electrochemical sensors can be less than 12 months (ozone and chlorine) while other (CO & H2S) may last up to three years. The replacement costs could range from $145.00 to $300.00. Oxidizer gases such as ozone (O_3), chlorine (Cl_2), chlorine dioxide (ClO_2), nitric oxide (NO), and nitrogen dioxide (NO_2) can cause electro-negative (downscale) effects on many electrochemical toxic sensors. Almost all electrochemical sensors for oxidizers such as chlorine, ozone, chlorine dioxide, and nitrogen dioxide are so cross sensitive to other oxidizers as to be of little value for true sample analysis. Hydrogen gas has been gremlin (a false positive) interferent for years on electrochemical sensors, but each year its rejection improves as the sensor technology advances. Some toxic sensors can reliably detect fractional PPMs, some in the single digit PPM range, and some up to 1,000 PPM.

Catalytic Combustion, "Hot Wire" Wheatstone Bridge, Pellistor, etc.

This sensor has been widely used in mine and industrial safety applications since the 1940's. These detection elements are primarily designed for combustible gases and vapors at 100's to 1000's of ppm. The sensor is heated up to a temperature of 600 to 800 degrees Celsius. The sensor consists of a pair of coiled platinum beads (wires). One of the beads (the active sensor) is coated with a catalyst to cause gas molecules to burn (i.e. "oxidize") on the surface of the sensor, which causes the sensors temperature to increase. The non-catalytic coated bead acts as a compensator and does not burn the gas molecules. The active sensor change in temperature unbalances the platinum wire "Wheatstone Bridge" resistance, producing a signal proportional to the gas or vapor concentration. Silicone vapors, sulfur compounds, and corrosive gases including chlorine and chlorinated solvents can cause the sensor to deactivate the catalyst and make the sensor non-responsive to gas. This sensor does not measure trace amounts of gases under 200-300 PPM and therefore is of no use in determining toxic levels of many OSHA regulated Volatile Organic Compounds (VOCs). It can also become less responsive when levels of oxygen fall below 15-16% by volume, which would result in lower than normal readings. Below 10% by volume oxygen the sensors are virtually useless for LEL detection. Typical life expectancy is 1-2 years with replacement costs between $175.00 and $285.00. This sensor is very fast in response with response times of less than 5 seconds to 90% of final value. Most factories calibrate their LEL sensors on methane gas due to the large number of below ground public works and natural gas utility customers that they have. However, response to flammable vapors such as gasoline, toluene, alcohol, fuel oil, diesel fuel, and jet fuel is dramatically different from the sensor's methane response - a "correction factor" is needed for such non-methane flammables. High flashpoint/low vapor pressure flammable such as turpentine, jet A, and diesel fuel may have a corrective factor of 5 or more compared to the methane gas response! Thus, when in the methane mode of use, leaking kerosene, diesel or jet fuel might cause a reading of "10" or "15" on the LEL display-but after applying the times 5 correction factor the real concentration is 50% to 75% of the flammable limit of that vapor! You will find this disclaimer in the back of the instrument operational manual-but do your field personnel know this non-fail safe under-response phenomenon, or do they believe all hydrocarbons react the same on the LEL mode of their instruments?

Electrochemical Oxygen Sensor

The partial pressure oxygen sensor was introduced in the early 1970's to hand-held portable gas detectors preciously for confined space entry atmospheric testing. Although linear for 0% O2 to 99.9% O2, these "micro-fuel cells" was responsive to weather fronts and higher altitudes that would result in lower atmospheric pressure, and thus lower oxygen partial pressure. Many of the deficiencies of the partial pressure cell were resolved by City Technology's introduction of the "capillary diffusion barrier" oxygen sensor in the late 1970's. This sensor is nearly immune to pressure effects, works over the range of 0-30% oxygen (not 100%) and it currently dominates the hand-held portable gas detector market today. Oxygen sensors can have field service life of up to 2 years today and have no significant interferent effects. However, hot moist air (100 degrees F/99.9% RH) will lead to an O2 reading of only about 19.5%Vol since the oxygen concentration is reduced due to the elevated level of water vapor in such a moist sample. This condition is often found in utility tunnels and steam vaults. These O2 cells do not have any known cross sensitivity effect accept for high levels of helium (over 5% Volume).

Non-Dispersive Infrared Sensors (NDIR)

NDIR sensors first received attention in the 1970's as EPA specified detection devices for certain vehicle tailpipe exhaust gases. Miniaturization of the devices with lower power consumption now allow this technique to be offered in certain model hand-held portable gas detectors. When an infrared beam of a certain wavelength resonates the molecular bonds of a gas molecule, energy is absorbed by the molecule and less passes through the detection cell to the detector element. This loss of energy is converted to display the concentration of the gas species by on-board electronics. However, the target gas species must be specified [such as CO2 or methane (CH4)] and the frequency of the IR beam selected appropriately in order to detect any gas or vapor molecule. The result is that NDIR detectors for CO2 are not responsive to methane. Furthermore, methane responsive NDIR detectors are good for C1 through C3 hydrocarbons (such as methane, ethane, and propane) but are not responsive to CO2 or hydrogen. NDIR based detection can be reliable as low as a few hundred PPM of CO2 and through the LEL range of most hydrocarbons.

When an NDIR sensor-based instrument is used for gas evaluation for methane it is imperative that the users understand the lack of response to such gases as hydrogen and acetylene. In addition, the NDIR cell for flammables will need to be factory re-programmed for accurate response to such hydrocarbon vapors as pentane, octane, and benzene. NDIR cells for methane have found use in landfill gas analyzers since, unlike the catalytic combustion sensor (hot-wire), oxygen is not needed for reliable methane detection when using NDIR technology. Power drain when using this sensor is substantial and most instruments using such sensor cells will be larger, heavier, have an internal sample draw pump, and be up to several times more expensive then the basic "4-gas" confined space entry portable gas detector.

Conclusion

Portable gas detectors today are offered worldwide by over 40 firms and may contain 3, 4, 5, or 6 of the sensors described above. However, the majority of sensors are made by only a limited number of independent companies. Thus, if you are dissatisfied with one instrument maker's device, do not switch to another supplier's unit until you extract from its maker (not the local sales agent!) the source of the sensor modules inside the instrument! When possible, ask for a 2-week field trial, at no obligation, of a device you are considering purchasing.

Of the various sensor technologies covered in this discussion, only NDIR, oxygen, and electrochemical toxic sensors can honestly be assigned a reasonable degree of specific response to a single gas. PIDs, MOS, and hot wire/catalytic elements are inherently non-specific and thus cross-sensitive to numerous other compounds. Always check the owner's manual disclaimer for such phenomena. When in doubt of an instruments response for a certain compound, get a statement in writing from the device maker, on letterhead signed by an engineer or technical department head.

Technology marches forward: Sensors get better each year, smaller/lighter batteries appear with higher energy density, micro-processor circuit design enhancements are offered, etc. However, no improved instrument design feature can offset poor or inadequate training of the instrument operator and the possible resultant consequences to your special tactical unit from misunderstanding an instrument's limitations. When buying 6 units or more why not make "onsite/no charge" training by factory personnel a specification on the bid set? A reputable instrument supplier who really deserves your business will be happy to accommodate your request.

Despite the over-zealous assurances of salespersons and marketing managers, one final caution must be emphasized: No combination of any number of the above sensor principles will ever make your hand-held portable gas detector into a true analyzer such as a mass spectrometer or a gas chromatograph. So don't embark on searching for WMD's (weapons of mass destruction) with what is, at best, only a confined space entry safety monitor.

Dr. Verne R. Brown founded ENMET Corporation in 1970 to develop solid state gas and vapor detectors for industrial health and safety applications and is now Predident.

He holds a BS in Electrical Engineering from the University of New Hampshire, a MSE in Electrical Engineering from the University of Michigan, and a MS in Physics and Ph.D in Electrical Engineering from the University of Michigan.

Brown is a frequent speaker to Safety Councils, ASSE Chapters, AIHA, the National Safety Congress, and other gas and vapor detection seminars and conferences throughout the United States and Canada.

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