Selecting Gas Detectors For Confined Space Entry

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When I was first approached to write on article for the IAPA on Gas Detector selection (2500 words – no less) I was somewhat at a loss as to what one could say about gas detectors that could possible hold someone's attention to the tune of 2500 words (well that's 51 words – only 2449 to go, are you still with me?).

For those who work in atmospheres that could be hazardous to your health, selecting the right gas detector could be the single most important decision you ever make. Your life could hinge on that decision so it is critical that the user/purchaser make him/herself aware of the hazards that could be encountered and the proper sensors to protect them. Data gathered in the late seventies and early eighties indicated that 65% of all those who died in confined spaces were unaware that the space they were entering was a potential hazard. Over 50% of confined space deaths occur to the *rescuers* and over one third of the fatalities occurred after the space was tested and declared safe and the gas detector was removed

Gas detectors have been around for a long time, starting with that infamous methane sniffing canary, which sadly was a one-shot device, which when subjected to methane, tended to die rather quickly with no audio and visual alarm capabilities other than a slight cheep and a total lack of motion. Fortunately technology has advanced significantly and we find ourselves at this point in time with some very sophisticated electronic equipment.

But even the most sophisticated technology is useless if the sensors used are unable to detect the gases present.

The three main atmospheric hazards that you test for prior to and throughout a confined space entry are:

Combustibles (Flammables)

Eg: Methane
Propane
Gasoline
Various other site-specific hydrocarbons (specific to your industry)

Oxygen – Deficiency and enrichment

Toxics

Eg: Hydrogen Sulfide
Carbon Monoxide
Toxic Hydrocarbons
Various other site-specific toxics (specific to your industry)

Depending on its sensor configuration, proper gas detection equipment can help identify the hazard and protect your workers.

Selecting a gas detector should be based on the hazard faced. Unfortunately far too many purchasers make one of the largest and most crucial single equipment expenditures without really understanding what they are buying. Sensors and their capabilities are the single most important factor when choosing a gas detector, yet more often than not, decisions are based on size, price, bells and whistles and other such features that have nothing to do with the instrument's detecting abilities.

Gas detectors come in a variety of sizes, shapes, colours and sensor configurations. For confined space work, it is necessary to monitor for oxygen deficiency/enrichment, combustible gases and toxics. Therefore an instrument capable of dealing with these three hazards is necessary.

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COMB, H_2S, CO, O_2

SENSOR TECHNOLOGY

Combustible Gas Sensors

a) ***Catalytic Combustible Gas Sensors.***

These sensors look for explosive atmospheres. They detect combustible gases by causing an actual combustion of gases within the sensor chamber.

Catalytic sensors offer good linearity, and can react to most combustible gases. However, as resistance change to %LEL is quite small, they work better in concentrations between 1,000 and 50,000 PPM. They do not measure trace amounts of gas (under 200 PPM) and therefore are of no use in determining toxic levels. The disadvantages are:

- they must have a minimum of 14% oxygen content in the air to work accurately
- the sensor can be damaged by lead or silicone or other catalytic poisons
- the readings can be affected by humidity and water vapour condensation
- they respond poorly to low energy hydrocarbons such as oil vapours, kerosene, diesel fuel and commercial jet fuels
- they tend to loose their linearity after a year or so
- they are not recommended for use in an *acetylene* atmosphere

The flame arrestor will prevent ignition of most gases *except acetylene* outside the sensor. It is extremely important to check the approvals for which type of hazardous locations the detector can function in. Most portable gas detectors today will be certified for service is Class I, Div I, Group ABCD atmospheres.

b) ***Metallic Oxide Semiconductor (MOS) Combustible Gas Sensor***

MOS or “Solid State” Combustible Gas Sensors have been around for years. This sensor has a long operation life (3 to 5 years), is very rugged and will recover better from high concentrations of a gas that could damage other types of sensors.

There are also disadvantages:

- MOS sensors also require oxygen to work accurately, although not as much as the catalytic
- some sensor’s heating elements have a high demand for power which requires larger battery packs
- the readings can be affected by humidity and water vapour condensation
- the MOS sensor may respond to many VOCs, HFCs and solvents, but is not specific to any single compound.

c) ***Infra-Red Combustible Sensors***

Recently Infra-Red Sensors have begun appearing in some instruments. They work well in low oxygen levels or acetylene atmospheres; however, they are quite expensive. These sensors work by reflecting light off a mirror and measuring the amount of light adsorbed during refraction. Infrared sensors typically require a constant flow across the sensing assembly and may be slow to clear from alarm. They are unable to detect hydrogen. An Infra-Red sensor calibrated for a simple hydrocarbon such as Methane or Ethane will not be accurate for vapour of higher molecular weight hydrocarbons, solvents or fuels.

Toxic Sensors

a) ***Electrochemical (Wet Chem) Toxic Sensors***

These sensors react to a specific chemical (substance). Chemically specific sensors are available for up to 30 different gases including chlorine, ammonia, carbon monoxide, carbon dioxide, nitrogen dioxide, nitric oxide, hydrogen cyanide, hydrogen sulfide and sulfur dioxide. The manufacturer’s technical information will indicate what sensors are available for their unit.

These sensors have very good linearity, which makes them very accurate for the substance they will react to. They can measure either large or small quantities and these sensors have a typical life span of approximately 1 year for many toxic gases and up to two years for hydrogen sulfide and carbon monoxide.

As with all sensors, Wet Chem sensors have their limitations. The electrolytic fluid can freeze when left in environments having temperatures lower than 0 degrees C. Some chemical sensors may be adversely affected by altitude as they may be pressure sensitive.

Abnormal readings are another issue with regards to Wet Chem sensors. Abnormal readings are generally readings that don't make sense. For instance you are working in a sanitary sewer and your instrument is showing a CO reading of 300 PPM (current TWA in Ontario is 35 PPM) and a low reading (below the TWA of 10 PPM) of hydrogen sulfide. What you likely have is an interference from the hydrogen sulfide. Some electrochemical carbon monoxide sensors are subject to interference from low levels of hydrogen sulfide. The knowledge that carbon monoxide is not a common occurrence in sanitary sewer applications (whereas hydrogen sulfide is) would lead you to consider that you are probably having an interference problem. In some instances, oxidizers like chlorine, chlorine dioxide and ozone can cause opposite readings on such toxic sensors such as carbon monoxide and hydrogen sulfide.

Awareness of the hazards in your workplace, some basic understanding of chemistry, knowing what interfering gases adversely affect your unit and strict testing protocols will minimize this problem.

b) ***Metallic Oxide Semiconductor (MOS) Toxic Broad Range Gas Sensors***

There are a number of different MOS sensors on the market and one has been developed for detecting toxic gases. Its make-up and operation is similar to the one used for the detection of combustible gases. However, the MOS broad range toxic sensor is capable of reacting to low PPM levels of wide range of toxic gases including carbon monoxide, hydrogen sulfide, ammonia, styrene, toluene, gasoline and many other hydrocarbons and solvents. MOS sensors cannot detect carbon dioxide or sulfur dioxide. The sensor is incapable of telling you what gas you have encountered or the concentration, only that the atmosphere may be hazardous to your health.

C) ***Photo Ionization Detectors (PID's)***

Industrial Hygienists, Safety and Environmental professionals and others have used Photo ionization sensor technology for evaluating atmospheric hazards in the workplace since the 1960's. Life expectancy of these sensors is 1-3 years and costs range between $300 and $1400 for lamp replacement. They are usually too costly to use in a multi-sensor instrument.

Oxygen Sensors

Oxygen sensors are the only true chemically-specific sensors. They are similar to the electrochemical (Wet Chem) sensors described previously. They are also susceptible to freezing, are sometimes affected by altitude and have a nominal operational life of one to two years. *Never* use an oxygen sensor to detect toxic gases. It is true that a toxic gas will displace the oxygen in a confined space. However, it takes 60,000 PPM of *any* gas to lower the oxygen from 20.9% (normal) to 19.5% (alarm point). More importantly, 60,000 PPM of any toxic gas will *kill* you.

DESIGNING A GAS DETECTOR

Let's build a gas detector for confined space work. To start out it will require a combustible sensor. We previously described the three types of combustible sensors available and their features. However, for confined space work, any of the three technologies will provide adequate protection. Secondly, we need an oxygen sensor to detect both oxygen enrichment and deficiency. There are several manufacturers of oxygen sensors and while they may all look different, they are essentially the same technology and will work well.

To complete this instrument we will require a toxic sensor(s). The key to safe confined space gas detection lies in these toxic sensors. There are two main sensor types used in multi-sensor instrmuments electrochemical (Wet Chem) and Broad Range (Solid State MOS).

To select the correct toxic sensor we need to evaluate our confined spaces. If your area of work is an industrial site, where the toxic gases are known or can be controlled, then a chemically specific toxic sensor can be chosen (providing a sensor exists for that gas hazard). Manufacturers produce gas detectors that are capable of supporting one or two of these chemically specific sensors. Some instruments are available with a range of plug-in sensors that can be changed in the field without fuss or calibration. Other instruments must be ordered with the specific toxic sensor(s) you require. However, there is a limit to the sensors available and, if toxic hydrocarbons or solvents are a concern (common to municipal water and waste water systems as well as industrial applications), then the broad range (MOS) type may be your best bet.

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O_2, COMB, H_2S, CO, MOS TOXIC

If you are in an area where the toxics are unknown or cannot be controlled, such as storm and sanitary sewers, pumping stations, waste treatment plants, industrial sites with toxic hydrocarbons and the like, then the broad range (MOS) type is your best solution. Unlike the chemically specific electrochemical sensors, these sensors cannot differentiate one toxic gas from another but they will tell you whether it is safe to enter or it is time to get out. The broad range sensors have their limitations as well and cannot detect any of the dioxides, i.e.: carbon dioxide, sulphur dioxide.

It must be noted that a gas detector with a combustible sensor will *not* protect you from toxic levels of hydrocarbons. A classic example is gasoline. Gasoline used to have a TWA of 900 PPM. It is now considered a carcinogen. A combustible gas detector, calibrated to methane, will not alarm on gasoline until around 50% of the LEL or 5000 to 7000 PPM. This is well in excess of the old TWA and is certainly an even bigger problem now that it is rated as a carcinogen. Regardless of its cancer causing issues, this level can cause a worker to be rendered unconscious, potentially causing death through drowning or falling. The only toxic sensors capable of detecting these low levels of hydrocarbons are the broad range.

SAMPLING METHODS

In confined space testing it is important that the operator know how the sensor comes in contact (operation) with the atmosphere. There are three primary means of exposing the sensor to the atmosphere- sample draw, diffusion and a detachable remote diffusion sensor assembly. There are strengths and weakness in all systems. Selection should be based upon need, not availability.

Sample Draw

The most common form of sampling a confined space is the sample draw method. The advantage of this method is that any monitoring is performed outside the space. With a sample draw system, a pump moves the sample from the atmosphere and draws it through a hollow tube to the sensor. The pump can either be a "*bulb*" hand aspirator which requires squeezing or an internal motorized sample pump.

Drawing the sample to the detector protects the tester by eliminating the need to enter the space and limits any movement of the door/cover to the space that may create a spark, which could ignite flammable gases that may collect around the entry point. For these reasons, the sample draw method is recommended when conducting your pre-entry test. The primary disadvantage of this method is sample dilution.

The tube leaking or using a tube over 12' in length may reduce the concentration of some contaminant to the point where the readings presented are inaccurate. Other problems may include leaking pumps, cumbersome sample lines, and in some environments, the sample line may plug due to sludge, dirt or condensate icing.

A disadvantage of the manual sample draw methods is the effort involved moving the air sample along the tube to the sensor. A general rule of thumb is that it takes 3 pump strokes to move the sample 1 foot. If your line is 12', it will take 36 pump strokes to get the sample to the sensor, then the sampling must continue for up to 3 minutes to ensure a proper undiluted sample. If you are using a *bulb* hand aspirator strong wrists are both a requirement and the end result of a lot of entries.

Sensor Operation

Most gas detector sensors operate by diffusion. Diffusion works by air being absorbed into the sensor cell. Electronic gas detectors rely heavily on diffusion sampling. The atmosphere must be brought to the gas sensors by the aforementioned sample draw (aspiration) or by lowering the gas detector into atmosphere.

Some manufacturers offer a detachable remote sensor assembly as a means of remote sampling. Advantages of this technology include the lack of pumps and moving parts, much faster response time than aspiration and wires can carry the information with no potential of diluted readings. The sample method is still diffusion but the sensors are lowered into the atmosphere to be tested. Once the atmosphere has been tested by aspiration and/or remote sensors, the gas detector can be worn by the worker for the duration.

Because each sampling method has its own strengths and weaknesses, all techniques are used to monitor the atmosphere. The sample draw is used for the *pre-entry* test that occurs just inside the space at the doorway. (suggestion: use a 6' or shorter tube). Diffusion sampling occurs at all other times. Regardless of sampling techniques, spaces two to three meters deep should be tested top and bottom before entering. Spaces four to five meters deep should be tested top, middle and bottom before entering.

Calibration/Bump Test

All portable gas detectors should be calibrated according to the manufacturers recommendations. Not calibrating or bump testing a gas detector on a regular basis is an invitation to disaster. Sensors and/or electronics can, and do fail and it is only prudent to check your instrument on a regular basis.

a) **Bump Test**

A bump or field test is the application of a known gas concentration in excess of the calibrated alarm point of the instrument. When this gas is applied to the gas detector it should trip the alarm point ensuring that the instrument is functioning correctly. If it does not then it indicates that a re-calibration is necessary. Multiple gas mixtures are available that allow you to do a simultaneous Bump test with one canister of gas. It is a good policy to bump test at least once a week.

b) **Calibration**

Calibration should be performed as per the manufacturers recommendations. Calibration is done with a known gas concentration that can be at the exact alarm point or at a higher concentration where the set point can be adjusted. This varies between manufacturers. If you are Bump/Field testing on a regular basis you can wait until that tests indicates a re-calibration is required. If Bump/Field test are not performed then the unit should be re-calibrated on a regular basis. Manufacturer's recommendations vary from daily to never. Daily may not be practical and never, while time saving can be an invitation to disaster. Somewhere in between is the answer. Every three to six months is common.

DESIGN CHARACTERISTICS

The third component to consider in gas detector selection is design characteristics. Many gas detectors are sold solely upon these characteristics. The reason for this is that many gas detector manufacturers do not make their own sensors. They design and make the electronic box of the gas detector.

The following characteristics should be considered after selecting the appropriate sensors:

- Construction
- Electronics
- Approvals
- Ease of use

a) ***Construction***

Monitoring devices *must* be very rugged and easily carried by the workers. Even with training and the best intentions of the workers, field use does abuse the units. Drops, jolts, exposure to the elements, misuse, etc., all can shorten the life of the instrument. The case and its components must be constructed to withstand rough handling.

The unit's alarm systems, which should be both audio and visual, must be loud enough to be heard in your environment by either the attendant outside the space or the entrant(s) inside. In a perfect world, both attendant and entrant would hear the alarm. Some manufacturers have remote alarms that could enable both the attendant and entrant to simultaneously hear the alarm. The option is only worth the money spent if the remote wiring is long enough for all your spaces.

Batteries are another consideration. Batteries can be either disposable or rechargeable but either type should supply enough power to last 10 to 12 hours. If the batteries cannot last the entire work period, a back up or stand by power source must be present. Batteries have all sorts of limitations. Many units have no way to determine the charge in them; cold and age decrease battery life; lead acid batteries can leak and damage your electronics; NiCad (rechargeable batteries) can develop memories and so on. Battery maintenance costs and efforts should be evaluated very carefully to ensure your system will work when required. The new nickel metal hydride rechargeable batteries appear to have cut down the memory problems found in the older NiCad rechargeable batteries.

4 SENSOR PORTABLE COMB, O2 AND ANY 2 OF 13 FIELD INTERCHANGEABLE TOXIC SENSORS

For confined space work, gas detectors need to be portable (hand held). If the unit is designed to be worn by the worker, it should rest on their belt, not weigh it down. In many tight spots, the worker should not wear the device as it may create a catch point. It may be advisable to have the ability to hang up the unit inside the space.

Switches, buttons and knobs should be positioned or designed so that they cannot be knocked out of position, but one can still operate them with gloves on. The unit should be tamper resistant and default to an alarm mode in the event of battery or sensor failure. Gauges and/or displays should be large and easily read and understood. This means you must be able to not only see the displayed data, but also understand it. In confined spaces there are all types of lighting. Does the information show in all lighting situations? And finally, do the abbreviations make sense or do you need an explanation card on the detector? If the information cannot be understood, it may not be performing the job that it is intended to do.

b) ***Electronics***

Information provided must be reliable and useful as life and death decisions can be made based on the data provided. The electronics' response time, accuracy, precision, radio frequency (RF) interference, reading drift and sensitivity are all factors that can differentiate a poor purchase from a good investment.

c) **Approvals***

Once a manufacturer has developed an instrument for use in a hazardous atmosphere, it should be approved by an independent laboratory for intrinsic safety. Ie: UL, FM, CSA, TUV, MET etc.

** Federal OSHA in the USA identifies such approval laboratories as "NRTL" (**N**ationally **R**ecognized **T**esting **L**aboratories) and lists four pages of them on its website.*

d) **Ease of Use**

One of the most important considerations after sensor evaluation and selection is the ease of use of the instrument. Is it simple to operate? Is it simple to understand? Are the buttons/switches easy to use with gloves on? Do you have to use switches or buttons to get alarm information? Will it alarm when battery/sensors fail? Most importantly, is it one switch operation?

TECHNICAL CONSIDERATIONS

RF Protection

Radio Frequency Interference (RFI) protection is the unit's ability to protect the readings from interference caused by radio waves, pulsed power lines, transformers, and generators. RF protection is expressed in *immunity to x watts of radio transmission at a specific distance.* A prudent consumer should test a gas detector in and around cell phones, radios and walkie talkies before purchasing, especially if the gas detector is packaged in anything other than metal.

Response Time

This is the time period between obtaining data from the sensors and displaying it. This time period depends on what information is collected, the sensor response, how the unit of measurement being used (e.g. % LEL or PPM). Response time can range from several seconds for catalytic elements to minutes for some toxic sensors.

Accuracy and Precision

Accuracy is the relationship between the readout and the true concentration. This relationship is indicated by an error factor (indicated by “+/-“,e.g. +/- 0.5%). The lower the number, the greater the instrument’s accuracy. Precision is the number of times the accuracy would be right in any given number of tests (correct 19 times out of 20). In this case the higher the number, the greater the precision.

Sensitivity

This is the unit’s ability to accurately measure changes in concentrations. The hazards presented by the substance being measured would determine the need for sensitivity. For instance, at present in Ontario, chlorine has a time weighted average exposure value of 1 PPM and if is IDLH at 10 PPM; therefore, any change must be noted at once. On the other hand, carbon dioxide’s TWAEV is 5000 PPM, and is IDLH at 40,000 PPM; therefore the sensitivity need not be that great.

Selectivity/Specificity

This is the ability of the sensor/circuitry to respond to the desired target gas to the exclusion of other interfering gas species.

Reading Drifts

This is the movement in the instrument’s electronic readout when the atmospheric value remains the same. Moving the instrument from one angle to another, shaking it, ambient vibrations or no apparent reason may cause the readout to change. Poor electronic circuit board design and/or age of the machine or the sensor will cause the readings to drift. Sensor or component aging causing this problem is acceptable and can be compensated for as part of the unit’s ongoing maintenance program; however, poor construction is not acceptable. Poor construction cannot be repaired and creates mistrust of the unit with those who work with it. If they do not trust the readings, they will not use it and a tragedy could easily occur. Your best protection is to contact current users of the instrument and ask about their experiences.

Well we have now arrived at close to 4100 words on selecting a gas detector. If you are still awake, congratulations, because to get to this point you must have some interest in this topic not to have been bored to death.

In closing I would like you to please keep in mind that portable gas detectors are available from a variety of manufacturers. They range from single electrochemical sensor instruments to very precise multiple sensor units. Do not be swayed by sophisticated technology and fancy packaging. Choose a device that meets your needs (both short term and for the next 3 to 5 years if possible). Look at all the variables from sensors to design, but always keep sensors as your number one criteria. Your employees also have to be considered in the equation. If not, a perfectly good gas detector will collect dust because they feel *the damn thing isn’t any good!* A well thought out purchase can save lives and prevent injuries.