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A Summary of Gas Detection

by

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Gas Detection - A Background

People have worked in hazardous atmospheres since before recorded history. The open flame light sources of pre-historic cave painters were sources of potentially deadly carbon monoxide and consumers of life giving oxygen, and in a poorly ventilated area could have eventually proved fatal. Often the potential toxicity of the environment was only poorly recognized, if it was recognized at all. Fatalities and injuries were accepted as a risk of doing the job, or the tasks were given to unwilling workers under armed guard.

Some of the first attempts to detect toxic atmospheres came in coal mines. Coal mines are notorious sources of combustible and toxic gases as well as low oxygen levels. Open flame lamps served as some of the first detection systems. A low oxygen environment would cause the flame to burn low, or become extinguished. An atmosphere rich in combustible gases would cause the flame to burn more brightly. However, too much combustible gas resulted in the very explosion that was trying to be avoided. A later improvement on this method was the flame lamp, which contained the flame inside a glass barrel and allowed the hot gases to escape through a flame arresting wire mesh. Graduating marks were placed on the glass to allow a rough calculation of the presence of combustible gas or the absence of oxygen. While this method greatly improved the intrinsic safety of this detection method, a dropped lamp could still prove fatal in the wrong environment.

Another attempt at an intrinsically safe detection method was also used in coal mining applications into the twentieth century. This was the use of small caged birds to detect toxic environments (the proverbial 'canary in a coal mine'). The concept was that these birds would exhibit the effects of the toxic environment before they became injurious to humans. As you can imagine, a healthy bird at the beginning of the work period was a vital requirement. While effective in certain applications, these birds were not capable of detecting all hazardous conditions.

In the 1920's a number of significant advancements in the field of gas detection came into play. In Japan Dr. Jiro Tsuji developed a method of detecting combustible gases using light-wave interference in 1925. Dr. Tsuji later went on to found Riken Keiki Co., Ltd, currently represented in North America by RKI Instruments. In 1927 Dr. Oliver Johnson of the Standard Oil Company developed a method of detecting combustible gases using a platinum catalyst in a Wheatstone bridge electronic circuit. Dr. Johnson later went on to found Johnson-Williams or J-W, one of the first gas detection companies in the United States.

Since the 1920's a number of advancements have been made in these two technologies. In addition, a number of other technologies have also come into use. We'll take a look at what some of these technologies are after we examine some of the applications that brought about their requirement.

Common Applications of Gas Detection

<u>Application</u>	<u>Common Gases Detected</u>
Water & Waste Water Treatment	chlorine, hydrogen sulfide, methane, oxygen
Petroleum Production & Refining	hydrogen sulfide, combustible gases
Natural Gas Production & Transport	natural gas, hydrogen sulfide, mercaptans
Mining	methane, oxygen, dust
Gold Extraction	hydrogen cyanide
Electroplating	hydrogen cyanide
Food Processing & Cold Storage	chlorine, ammonia, methane, dust
Grain Storage & Transportation	methane, oxygen, phosphine, dust
Breathing Air (Supplied Air Systems)	carbon monoxide, oxygen
Parking Garages	carbon monoxide
Semiconductor Manufacturing & Processing	arsine, phosphine, silane, hydrogen, hydrochloric acid, numerous other gases
Fuel Storage & Transportation	combustible gases, oxygen
Leaking Underground Storage Tanks	combustible gases, oxygen
Pulp & Paper Manufacturing	chlorine, chlorine dioxide, hydrogen sulfide, sulfur dioxide, oxygen
Beer & Wine Making	oxygen, carbon dioxide, sulfur dioxide
Fertilizer Manufacturing	ammonia
Indoor Air Quality	carbon dioxide, carbon monoxide, oxygen
Stack (Flue) Gas Emissions	oxygen, nitric oxide, nitrogen dioxide, carbon monoxide, sulfur dioxide
Chemical Manufacturing & Processing	various

Methods Of Detection

We will give here a brief overview of a few of the more common methods of gas detection currently in use. It is important to remember that this list is in no way comprehensive. Many varied methods of detection have been devised over the years and may be employed in very specific areas of detection. In addition, variants of the methods discussed here may also be in use.

Catalytic Combustible:

A heated catalytic bead (usually platinum or palladium) is used to burn less than combustible concentrations of combustible gases (this is the same concept as a catalytic converter in an automobile). As the gases burn the wire in the bead heats up. As the temperature increases so does the resistance in the wire. Using a wheatstone bridge, this temperature increase is compared against a reference (non-catalytic) bead to give a combustible gas reading.

Advantages: This method is extremely common in the detection of LEL (lower explosive limit) concentrations of combustible gas. It is also sometimes used for higher ppm (part per million) detection. It is relatively inexpensive and rugged, and has a long shelf life.

Disadvantages: Catalytic sensors are non-specific, and give different responses to different combustible gases (i.e. 50% LEL methane gives approximately twice the response of 50% LEL gasoline mixtures. Thus an improperly calibrated unit could read only 50% LEL in a potentially explosive atmosphere). Also, the catalytic bead is very susceptible to a variety of poisoning compounds including silicone, lead, chloro-fluoro carbons (CFC's) and high concentrations of hydrogen sulfide.

Electrochemical:

Electrochemical sensors use two or more electrodes in an electrolyte to either oxidize or reduce a chemical. By varying the electrode materials and the electrolyte, it is possible to make sensors for a variety of different gases. Electrochemical sensors are commonly used in the detection of oxygen, and of toxic gases. They typically are not used for organic compounds.

Advantages: The small size, low power consumption and relative durability of this design lends itself well to portable detection instruments. It is also used in a variety of fixed applications as well.

Disadvantages: The electrolyte in the sensors is prone to leakage. Due to its often caustic or acidic nature, this can damage surrounding components and may cause a health or environmental hazard. Also, some electrochemical sensors are consumptive (oxygen sensors are a good example) and have limited lifetimes.

Photo Ionization Detectors:

PID's are becoming more common in usage. A beam of ultraviolet light is used to temporarily displace an electron from a chemical, creating an ion. The electrical current formed as this ion reforms with an electron is measured to give a concentration reading. This method works well on many low levels of chemical compounds. However, some chemicals such as methane have an ionization potential higher than UV lamps can provide, thus making these compounds undetectable by a PID.

Advantages: Good method for detection of low level (ppm) organic compounds. Newer designs are much smaller and less expensive than older units.

Disadvantages: PID's give a non-specific response (i.e. they don't specify what they are responding to). While good at low concentrations, they cannot practically detect LEL concentrations of combustibles. Also, as noted before, some chemicals with high ionization potentials cannot be detected.

Flame Ionization Detectors:

FID's utilize a flame (often fueled by hydrogen) to ionize chemical compounds. This flame allows them to reach a higher ionization potential than PID's. However, the need to carry around a fuel source, higher cost, and the potential (or perceived) danger of the flame in certain environments have made this method less popular than PID's. Note that FID's are available which use flame arresting methods to allow use in potentially combustible environments.

Advantages: Higher energy of the flame allows greater ionization than PID's.

Disadvantages: Higher cost, and the need to have a refillable fuel source. Also, their size makes them difficult to use in multi-gas portables as PID's are now being used.

Infrared or Ultraviolet Absorption:

Some chemical bonds will absorb certain wavelengths of light. By sending an infrared or ultraviolet beam of light through a gas sample, and determining the amount and wavelength of IR or UV absorption, a reading can be obtained for a variety of different gases. Typical applications have included carbon dioxide, CFC's and combustible gases. Gas detection using light absorption has also been used to make 'open path' gas detectors where the light source and the light receiver are up to hundreds of feet apart. These devices detect any gas that absorbs light in the range being detected that impacts the light beam.

Advantages: IR & UV detectors do not have a shelf life, and are not susceptible to the poisons that catalytic sensors are, making them a good choice where these poisons are present. Also, they can detect gases such as carbon dioxide and CFC's that are difficult to detect with other methods.

Disadvantages: IR & UV detectors tend to have higher energy requirements than many other methods. This has limited their use in portable technologies. Also, while resistant to some sensor poisons, the IR & UV chambers are susceptible to high humidity, dust environments and corrosive gases.

Metal Oxide Sensors:

The semiconductor properties of some metal oxides (such as tin) lends itself to gas detection. Common applications include combustible gases and hydrogen sulfide, but they will detect a wide variety of other chemicals. When these semiconductors are exposed to certain gases, their electrical resistance decreases. This decrease can then be measured and related to a gas concentration. Rugged and durable, these sensors are often used in environmentally hostile applications such as oil field production. However, the non-linear logarithmic response of the semi-conductor to a linear increase in gas concentration can make them difficult to use.

Advantages: Rugged, durable and resistant to many common sensor poisons, these sensors are often a good choice for environmentally hostile areas.

Disadvantages: MOS sensors are notoriously non-specific. False alarms can result from the sensors response to relatively innocuous chemicals such a cleaning solutions. This combined with their logarithmic response makes it difficult to get reliable, repeatable performance. Also, some sensors will lose sensitivity if not exposed periodically to gas.

Thermal Conductivity:

Different gases transport heat at different rates. Thus, a heated wire will lose heat at a different rate in air than it will in a gas such as helium. This difference can be used to make a gas detector. However, because the rate of heat loss is difficult to accurately detect at low levels, this method is typically only used where volume percentages of gases are being detected. Common applications include volume percent detection of combustible gases, helium and carbon dioxide.

Advantages: Relatively simple design has very little in the way of sensor poisons. Sensors also have very long shelf life.

Disadvantages: Their lack of ability to detect low concentrations of gases make these sensors practical for a limited amount of applications.

Colorimetric:

Some chemicals will change color in a chemical reaction when exposed to other chemicals. This concept is used to make a 'stain' which is then detected either visually or electronically. This method is used in relatively low technology detector tubes as well as in detection systems specifically designed for the semiconductor (arsine, phosphine, etc.) gas detection market.

Advantages: Colorimetric use in portable detector tubes provides a low cost, lower accuracy method of detecting for a variety of different gases. This is virtually the only method that does not require calibration (critical to all the other detection methods). It also lends itself to very low level detection of gases in the semiconductor manufacturing industry.

Disadvantages: Colorimetric tubes have a limited shelf life, and have a low level of accuracy (although newer electronically read portable units are coming onto the market). In semiconductor applications the 'paper tape' used in detection can be very costly to purchase. Also, most paper tape calibration methods do not use an actual gas, limiting their gas detection verification.

Light Scattering:

Light scattering is used to detect dusts. While dusts are not technically part of gas detection, dust explosions are extremely powerful. In addition, explosive dusts can be found in many applications where gas detection is also in use. Examples would be coal dust or grain dust. This method involves detecting light scattered off of small dust particles. When you 'see' dust floating in the air in a beam of sunlight, you are actually seeing the light scattered off of these particles. This concept was first noticed by Gustav Mie in 1906, and since been incorporated into a number of dust detection designs.

Advantages: Light scattering provides one of the best methods of real time detection of dust concentrations. Sampling methods may provide more ultimate accuracy, but require laboratory analysis that does not give real time protection from dust explosions.

Disadvantages: Light scattering devices cannot easily distinguish between different types of dust. Therefore they can prove difficult to give accurate readings if more than one type of dust is present.

Using Gas Detection Technology

The gas detection methods discussed above are used in a variety of fashions depending on the specific need or application. Understanding how or where these technologies are used can be a vital part of choosing or designing a gas detection system.

Fixed Versus Portable:

If gases are routinely expected to be found in a certain area, it may be possible to use a 'fixed' or permanently mounted detection system. An example of this application might be in a chlorine storage room at a water treatment plant. The room is typically not occupied, but notification is required in the event of a leak. A fixed chlorine detection system can be installed which will provide notification of the leak event as well as warning personnel not to enter the room.

Other applications do not lend themselves as well to fixed instruments. An example of this application is sewer tunnels. It is not uncommon for sewers to develop toxic or combustible gases or a low oxygen situation. However, the sheer scope of the detection area might involve miles of tunnel. It would be cost prohibitive to install fixed detection systems at all entry locations. In addition, the presence of toxic environments is only of concern if personnel are entering these sites. In these applications the use of portable detectors is usually preferred.

Area Of Coverage:

Many people want to know how much of an area a gas detector is capable of covering for detection. Remember that for any of the gas detection methods discussed, gas is only being measured at the actual detector itself. A sensor cannot detect gas that it is not exposed to. While this concept seems simple, it can provide a variety of problems in application. In our example of the fixed chlorine detection system at the water treatment plant, where should the chlorine sensor actually be located? The best answer is as close to the leak source as possible. However, we often don't know where the leak will occur, so we would probably have to place the sensor in the best position to be as close to all the leak points as possible. Remember that gases will diffuse through air. You don't have to have your nose on the skunk to smell him, but the farther away you are, the more the scent dissipates until you can no longer smell anything.

Another thing to take into account are the physical properties of the gas that is being detected. Since hydrogen is lighter than air, a hydrogen leak will result in gas rising over the leak point. However, simply placing a detector in the ceiling may be ineffective due to the dilution the gas will experience during diffusion. You would effectively have to begin filling the whole ceiling with gas to get a reaction from the sensor. In contrast, gasoline vapors are heavier than air and would be expected to be found near the ground under normal conditions.

Temperature, wind and moisture can also play an important role. A high temperature may result in gases rising that would normally be expected to be found near the ground. A stiff breeze may blow the gas away from the detector. Fixed sensors in windy areas will typically only respond if the entire area is diffused with the gas being detected (i.e. a catastrophic level of gas is present). If the chemical being detected is water soluble then moisture may remove the gas before it is able to get to the detector. This is especially important to keep in mind when we talk about taking samples from remote locations through the use of pumps and tubing.

Sample Draw Versus Diffusion:

As mentioned above, the gas detector responds to the gas it is exposed to. However, it is not always practical to get the sensor to the area being detected. An example of this might be the need to check the gas concentration in a confined space before entry. While it is possible to actually lower the detector into the environment, this will expose the instrument to any adverse conditions that are present. It would also make reading any gas concentrations difficult. Some portable instruments have the ability to lower the sensors only, which solves the problem of reading the concentration but still exposes the heart of the detector (the sensor itself) to a potentially adverse environment.

One solution is the use of a sample draw system. Typically these are either powered by a pump, or by a hand squeezed bulb. A sample is pulled through tubing to pass it over the detector. Filters can sometimes be installed to prevent water or other adverse elements from contacting the sensor. While this method has many advantages, it also has some disadvantages. Reactive chemicals will require the use of a chemically inert tubing material. Even with such use, water in the tubing can eliminate water soluble chemicals from reaching the detector. A water trap or filter in such an application will also work as a filter for any water soluble chemicals. It is also important to be sure that the sample system does not have any leaks in it, or the sample will be diluted. Also, too long of a sampling system will result in long (potentially impractical) delays in obtaining a reading.

Detection Levels

Different applications will require gases to be detected at different concentrations. Listed below are a few of the terms used to describe these levels. This list is by no means comprehensive. You should always consult local regulations to be sure that appropriate detection levels are being used as these can vary by state.

% Volume:

Volume percentage is used where a large concentration of gas is being detected. Typically these applications involve a gas that is not toxic in smaller concentrations, or are in areas where no personnel will be involved. Typical gases that are often measured in volume percent include oxygen and carbon dioxide.

% LEL or % LFL:

The Lower Explosive Limit (sometimes called the Lower Flammable Limit) of a gas is the minimum concentration of a combustible gas or vapor which will burn or explode in normal conditions if a source of ignition is present. Combustible gases are often measured in % LEL. A concentration which has reached 100% LEL is at the minimum concentration required for ignition. However, most detectors are designed to alarm at much lower concentrations. The Federal regulation for confined space entry (CFR 1910.146) requires that concentrations at 10% of the LEL or higher are considered to be unsafe for entry.

Permissible Exposure Limits:

PEL's are established by the National Institute for Occupational Safety & Health (NIOSH) and are enforced by Occupational Safety & Health Administration (OSHA). PEL's give the concentrations of a toxic chemical which create an unsafe work environment for an unprotected worker. Workers who are wearing protective devices (ex. Air purifying respirators, etc.) may exceed these PEL's within established guidelines (CFR 1910.134). Remember that these numbers are based on healthy individuals. Individual workers may find their susceptibility to a certain chemical has been increased due to illness, smoking or pregnancy for example.

Because toxic chemicals can cause harm in low levels over a long period of time (chronic exposure) or in higher concentrations over a short period of time (acute exposure), different PEL's are used:

Time Weighted Average: A Time Weighted Average (TWA) is the concentration which a worker can be exposed to on average over an eight hour work period. At no time can any of the other PEL's be exceeded. A TWA concentration is based on the assumption that the individual may be exposed to this concentration not only over an eight hour day, but over the entire working life of the individual.

Short Term Exposure Limit: A STEL is a shorter time weighted average, typically 15 minutes. STEL's are used where a chemical can have an adverse effect in slightly higher concentration over a short period of time.

Ceiling Limit: A Ceiling limit is the amount of toxic substance which should never be exceeded, even for an instant. Exposures over the ceiling limit can cause immediate hazards to the health of an unprotected worker.

Immediately Dangerous to Life & Health:

IDLH concentrations are defined by their very name. They are concentrations which are extremely hazardous. IDLH is not considered a permissible exposure limit as it is the concentration which is never permissible for an unprotected worker. CFR 1910.134 notes that the only allowable entry into IDLH atmospheres is through the use of positive pressure self contained breathing apparatus (SCBA) or positive pressure supplied air respirators (SAR) with an emergency egress bottle.

Threshold Limit Values:

TLV's are established by the American Conference of Governmental Industrial Hygienists (ACGIH). TLV's are typically non-mandatory, unless adopted by a particular state. However, they are widely used as guidelines where PEL's have not been established by NIOSH. In addition, some TLV's have been adopted where they are lower than the PEL's. For example California uses the TLV value for exposure to carbon monoxide which is lower than the Federal PEL.

Summary

Accurate knowledge of the application is always required in order to design an effective gas detection system. The information contained in this paper can be used as a basis for beginning such a study, but is not intended to be a complete guide. Many sources of information are available to the individual wishing to determine an appropriate detection strategy. These range from agencies such as OSHA's consultative services to the gas detection companies themselves and their representatives.

It is also important to remember that none of these systems can be relied upon if they are not checked on a regular basis, and their response to gas verified. Some gas sensors can be poisoned by exposure to adverse chemicals or conditions. Many of these failures are impossible to detect electronically. The only safe way to verify that a system is actually working is to calibrate it with a known and reliable calibration gas.