

Chapter 1

Introduction

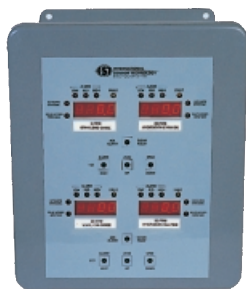
The detection of hazardous gases has always been a complex subject and makes choosing an appropriate gas monitoring instrument a difficult task. To address this problem, this book aims to provide the following essential tools:

- A simple guide to the various sensor technologies available
- Information to help you intelligently select the proper instruments for specific applications
- Information engineers can use to design a complete monitoring system
- Technical data and practical procedures that technicians can use to check and maintain a gas monitoring system

The main emphasis of the book is on gas detection technology that is used in the field of area air quality and safety. This field primarily involves the protection of personnel and property against toxic and combustible gases. The discussion includes the types of sensors used, the various instruments available, and the applications that incorporate these instruments.



An Analytical Instrument. The example shown above automates gas chromatography with the help of its built-in robotic technology. (Courtesy of CE Instruments)



A Gas Monitor. IST's MP-204 is a wall-mounted unit housed in weatherproof enclosure with four sensor channels.

Analytical Instruments and Monitoring Systems

To date, no gas sensors exist that are 100% selective to a single gas. Achieving such selectivity requires the use of instruments that employ analytical techniques to identify gases.

Examples of such instruments include *Fourier transform infrared* (FTIR) instruments that use the infrared spectral characteristics of gases, *gas chromatographs* that use analytical columns, and *mass spectrometers* that identify molecules through characteristic variable deflections from a magnetic field.

These instruments provide fairly accurate and selective gas readings. Some typical applications for these kinds of instruments include airport bomb detection, drug abuse screening, and analyzing air pollutants. However, these analytical instruments require skilled and knowledgeable operators, and are generally very expensive and designed for laboratory tabletops or specific on-line applications for in-plant installations.

In addition, many suffer from limitations such as high maintenance, slow response time, and large size, making them impractical monitors for area air quality and safety. Thus, they are typically used only as a last resort for applications in which a suitable sensor is not available.

For work area air quality and safety applications, monitoring systems must meet a number of practical criteria. These monitoring systems must be:

- rugged and corrosion-resistant
- weather- and dust-proof
- capable of being installed in hazardous areas
- durable and long-term
- operationally stable
- easy to maintain
- operated by a minimally skilled person

- suitable for multisensor systems that, for example, can be used for an entire chemical plant
- low cost

This book deals with gas monitors for work area air quality and safety applications. For practical purposes, we will not delve into the realm of the much more complex analytical instruments which, for the most part, do not meet these criteria.

Gas Sensors

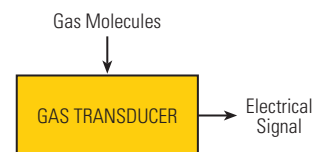
A gas sensor is a transducer¹ that detects gas molecules and which produces an electrical signal with a magnitude proportional to the concentration of the gas.

Unlike other types of measurement, types that are relatively straightforward and deal with voltage, temperature, and humidity, the measurement of gases is much more complicated. Because there are literally hundreds of different gases, and there is a wide array of diverse applications in which these gases are present, each application must implement a unique set of requirements. For example, some applications may require the detection of one specific gas, while eliminating readings from other background gases. Conversely, other applications may require a quantitative value of the concentration of every gas present in the area.

Types of Gas Sensors. There are many different technologies currently available for the detection of gases, each with certain advantages and disadvantages. The following sensing methods are the focus of our discussion and are the five types most suitable and widely used as gas monitors for area air quality and safety applications:

- electrochemical
- catalytic bead
- solid state
- infrared
- photoionization

¹ Any device that converts input energy of one form to output energy of another.



Some Examples of Gas Sensors

1. Catalytic Bead.
2. Infrared.
3. Solid State.
4. Electrochemical.
5. Photoionization.

All of these sensors are commonly used for detection of toxic and combustible gases in the work area for human and property protection, or for process control.

One common characteristic of these sensors, despite what is often claimed or implied, is that they are not specialized to detect any one specific gas. Each sensor is sensitive to a group or a family of gases. In other words, the sensor is non-specific and is subject to interference by other gases much like a smoke detector in a house cannot distinguish between the smoke caused by a furniture fire and the smoke caused by food burning in the stove or oven.

In limited cases, a chemical filter can be installed to filter out interference chemicals while permitting the target gas to pass through to the sensor. Alternatively, an analytical column can be installed to identify chemicals qualitatively and quantitatively.

For gas monitoring applications, a proper sensor is usually selected to match the specific application requirements and circumstances, with the user interpreting the readings based on an awareness of the sensor's limitations.

Terms, Definitions, and Abbreviations

Units of Measure for Gas Concentration

ppm: parts per million by volume (*see Table 1, opposite page*)

ppb: parts per billion by volume

mg/m³: milligrams per cubic meter

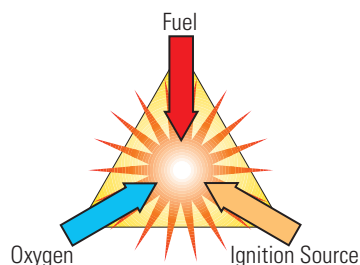
mg/cc: milligrams per cubic centimeter

g/m³: grams per cubic meter

g/cc: grams per cubic centimeter

For Combustible Gases

Flash Point (F.L.P): The temperature at which a combustible liquid gives off enough vapor to form



The Combustion Triangle

Table 1. Equations for Deriving Units of Gas Concentration

Gas concentration is commonly expressed as percent (%), ppm, or ppb. Mathematically, these are unitless expressions since they do not carry a unit for volume or weight but simply express the ratio of gases in relation to background air.

For instance, one ppm of CH₄ simply means one part of methane amongst 999,999 parts of background air. It is expressed as

$$\frac{V_g}{V_a + V_g} = \frac{V_g}{V_T}$$

V_g = volume of gas; V_a = volume of air; V_T = total volume of air and gas

Multiply the fraction derived from the formula above:

- by **10² %** to obtain the **percentage**
- by **10⁶ ppm** to obtain the **ppm**
- by **10⁹ ppb** to obtain the **ppb**

For example, if you mix 1 cc of gas with 99 cc of air, the calculation is as follows:

$$\frac{1 \text{ cc}}{1 \text{ cc} + 99 \text{ cc}} = 0.01$$

Thus, $0.01 \times 10^2\% = 1\%$
 $0.01 \times 10^6 \text{ ppm} = 10,000 \text{ ppm}$
 $0.01 \times 10^9 \text{ ppb} = 10,000,000 \text{ ppb} = 10^7 \text{ ppb}$

In cases like this, one would normally not clumsily express the units as ten million parts per billion. Instead, the simpler expression, 1%, is preferred.

This volumetric expression of concentration is straightforward. Additionally, the volume ratio is equal to the pressure ratio according to Dalton's law of partial pressures. It is expressed as

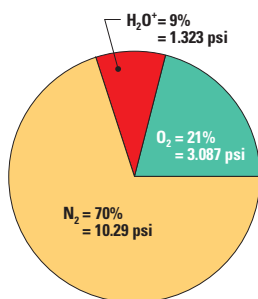
$$\frac{P_g}{P_a + P_g} = \frac{P_g}{P_T} = \frac{V_g}{V_T}$$

P_g is the partial pressure of the gas within the total pressure P_T and P_a is the partial pressure of air. As an example, 1 psi of gas within 99 psi of air with total pressure of 100 psi has a concentration of 1% as in the volume expression.

Another unit, commonly used in the medical and metallurgical industries, is mg/m³ or milligrams per cubic meter, in situations wherein the chemical is either in liquid or solid state at room temperature. To convert mg/m³ to percent or ppm, the ideal gas law must be used. Chemical conversion factors are included in the *Gas Data* section in *Appendix II, page 199*, and the conversion formula is discussed on page 173 in Chapter 11, *Gas Sensor Calibration*.

² The law of partial pressures, first formulated by James Dalton in 1802, states that the pressure of a mixture of gases, P, which do not react chemically, is the sum of the independent pressures (partial pressures) that each gas exerts:

$$P = P_1 + P_2 + \dots + P_n$$



$$\begin{aligned}
 P &= P_{O_2} + P_{N_2} + P_{H_2O^+} \\
 &= 3.087 \text{ psi} + 10.29 \text{ psi} + 1.323 \text{ psi} \\
 &= 14.7 \text{ psi}
 \end{aligned}$$

an ignitable and combustible mixture when air is present near the liquid’s surface.

That is, it is the temperature at which a combustible liquid chemical has sufficient partial pressure² in the air to be ignited. The partial pressure curves of chemicals are available from chemical libraries or manufacturers of the chemicals.

Lower Explosive Limit (LEL) or Lower Flammable Limit (LFL):

The minimum concentration of gas or vapor mixed with air (percent by volume, at room temperature) that will cause the propagation of flames when it comes in contact with a source of ignition. In common terminology, mixtures below the LEL or LFL are too lean to ignite.

Upper Explosive Limit (UEL) or Upper Flammable Limit (UFL):

The maximum concentration of gas or vapor mixed with air (percent by volume, at room temperature) that will cause the propagation of flames when it comes in contact with an ignition source. In common terminology, mixtures above the UEL or UFL are too rich to support combustion. The combustible range is, therefore, between the LEL and the UEL (see Figure 1 below).

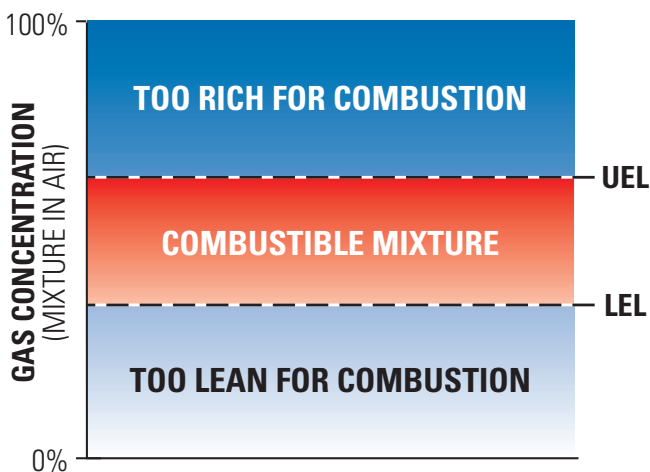


Fig. 1. A Window of Combustibility

Specific Gravity (Sp.Gr.): The ratio of the weight per unit volume or mass of a substance at 68°F (20°C) to the mass of an equal volume of distilled water at 39.2°F (4°C).³

Vapor Density: The weight per volume of gas or vapor compared to dry air; both components having the same temperature and pressure. For example, air has a vapor density of 1; carbon dioxide, 1.52; hydrogen, 0.07; methane, 0.55; and propane, 1.52.

³Water at 4°C has the *LOWEST* volume per gram. Ice expands when its temperature goes below 0°C and will crack a rigid encasement of it even if it was made of cement.

For Toxic Gases

The National Institute for Occupational Safety and Health (NIOSH) is a branch of the U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention. Acting under the authority of the Occupational Safety and Health Act of 1970 and the Federal Mine Safety and Health Act of 1977, it publishes *recommended exposure limits* (RELs) for hazardous substances or conditions in the work place.

To formulate these recommendations, NIOSH collects and evaluates data from the fields of industrial hygiene, toxicology, occupational medicine, and analytical chemistry. These recommendations are then published and transmitted to the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) for use in promulgating legal standards.

OSHA published the *permissible exposure limits* (PELs) that are known as the General Industry Air Contaminants Standard.

The American Conference of Governmental Industrial Hygienists (ACGIH) is a professional society, not an official government agency. Membership is limited to professionals in governmental agencies or educational institutions engaged in occupational safety and health programs in the United States and around

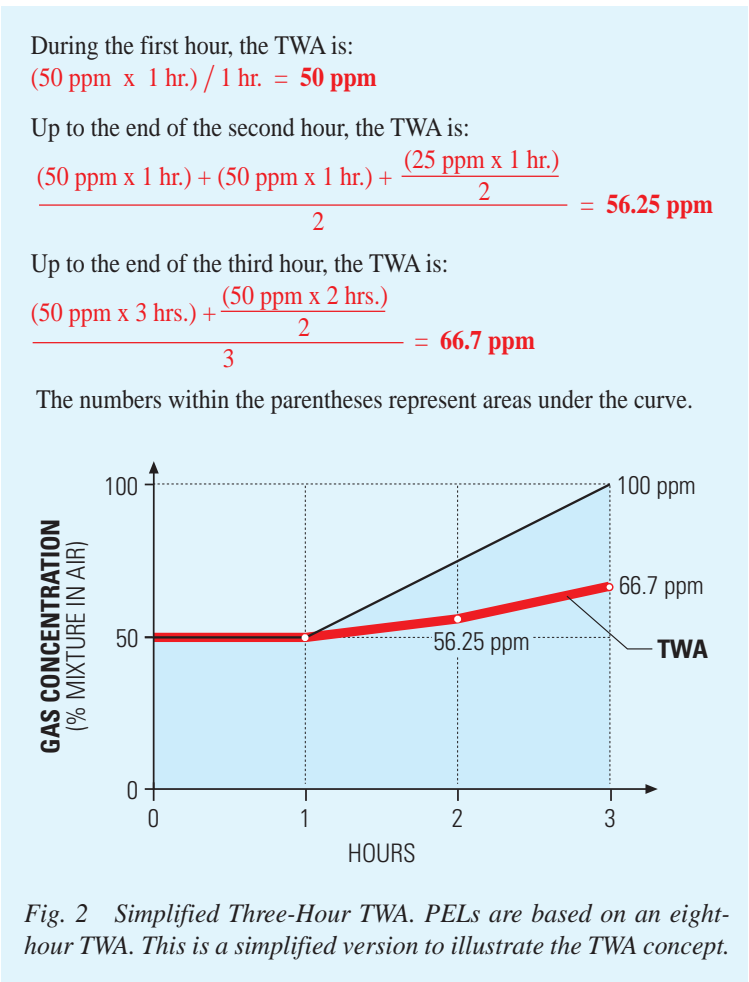
the world. ACGIH publishes the exposure standard, *threshold limit values* (TLV).

These three different standards—NIOSH’s RELs, OSHA’s PELs and ACGIH’s TLVs—are similar to each other, yet in some instances there are variations among them. All are based on *time-weighted-average* (TWA), *short-term exposure limit* (STEL), *ceiling* (C) and *immediately dangerous to life or health* (IDLH) concepts. The following definition of these terms are for informational purposes only. It is beyond the scope of this book to include detailed discussions of each.

Time-Weighted Average (TWA) is the average concentration of contaminants over a specified time

period. Mathematically, TWA is the integrated area under the concentration curve over time divided by time period. To illustrate the concept of TWA (Figure 2), let us assume that during a three-hour period, CO concentration is constant at 50 ppm during the first hour; then the CO concentration increases steadily to 100 ppm at the end of the third hour. The TWA at any given moment is represented by the red line.

Many microprocessor-based instruments and data logging programs are capable of performing the TWA calculation, and the time interval used by the instruments to calculate the TWA is much shorter than one hour.



Recommended Exposure Limit (REL) is TWA concentration permissible for up to ten-hour workdays during a forty-hour work week.

Permissible Exposure Limit (PEL) and **Threshold Limit Value (TLV)** are TWA permissible concentrations, to which workers may be exposed continuously, day after day, without adverse effects, for a normal eight-hour workday and a forty-hour work week.

Short-Term Exposure Limit (STEL) is defined as a fifteen-minute TWA exposure which should not be exceeded at any time during a work day even if the eight-hour TWA is within limits. Exposures at the STEL should not be longer than fifteen minutes and should not be repeated more than four times per day. There should be at least 60 minutes between successive exposures at the STEL. The concept of STEL is illustrated in Figure 3.

Ceiling Limit: The concentration which should not be exceeded at any time.

Immediately Dangerous to Life or Health (IDLH) concentration is the maximum concentration above which only a highly reliable breathing apparatus providing maximum protection for workers is permitted. The IDLH value is based on the ability of a worker to escape without loss of life, irreversible health effects, or other health effects such as disorientation or incoordination that could prevent escape.

The preceding information is a simplified version interpreted from the NIOSH *Pocket Guide to Chemical Hazards*. Appendix II at the end of this book lists data

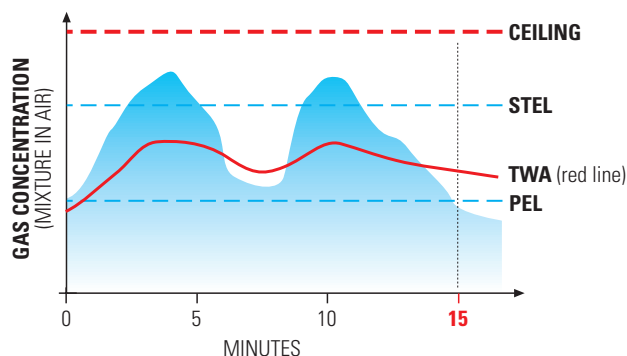


Fig. 3. A graphical example of permitted TWA excursions above STEL, provided the 15-minute TWA does not exceed the STEL.

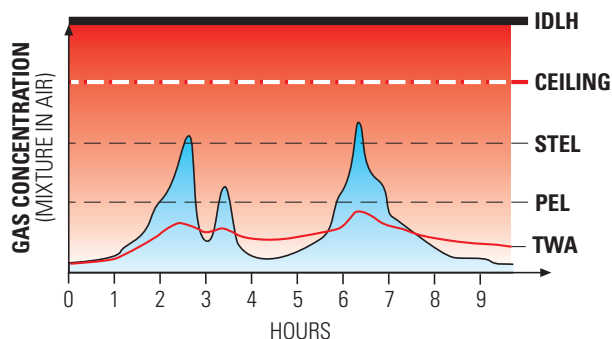


Fig. 4. Basic Rules for Compliance: TWA for eight working hours does not exceed PEL/TLV. Observe the definition of STEL and never exceed the ceiling limit.

extracted from the same pocket guide that includes REL, PEL and IDLH concentrations.

Figure 4 illustrates the overall summary of the toxic gas safety concept.

Combinations of Substances. When two or more hazardous substances are present in the area, the additive effects should be considered. That is, if the sum of the fractions of hazardous substance concentrations divided by the respective PEL exceeds

unity, then the threshold limit of the mixture must be considered excessive. This case is illustrated in the following formula:

$$\frac{C_1}{PEL_1} + \frac{C_2}{PEL_2} + \frac{C_3}{PEL_3} + \dots + \frac{C_n}{PEL_n} < 1$$

If it is greater than one, then the PEL is exceeded. C_1, C_2 and C_3 represent the TWA of various hazardous substances.

For example, if the ambient air contains 35 ppm of carbon monoxide (PEL 50 ppm) and 350 ppm of carbon dioxide (PEL 5000 ppm), the calculation is as follows:

$$\frac{35}{50} + \frac{350}{5000} = 0.77$$

The threshold limit is not exceeded.

This discussion is for conceptual purposes only. It does not take into account the effect of the combining of chemicals that can react with each other, resulting in a final mixture that can be more toxic to humans than the individual toxicities of each gas.

Performance Specifications

Accuracy: Webster’s dictionary defines accuracy as

“the quality or state of being accurate or exact; precision; exactness.” Accurate is defined as “free from mistake or error; precise; adhering closely to a standard.” Precise is defined as “strictly defined; minutely exact; low tolerance; etc.” Accordingly, a measurement can be precise but not necessarily accurate. The accuracy can only be determined when compared to a standard.

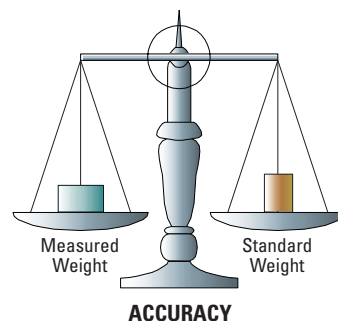
Accuracy is the most important definition of the quality of performance for most of the objects we deal with every day; for example, your watch, the weather thermometer, the bathroom scale, and the measuring tape, to name a few. The definition of these measurement standards are well-defined.

At the National Institute of Science and Technology (NIST; formerly National Bureau of Standards), standards for weight, length, temperature, etc. are kept. Internationally, there is a total agreement about the “absoluteness” of those standards.

In real life, the most accurate instrument may not necessarily be the best. For example, the measuring tape which is used by the tailor is not very accurate, but it is practical for the task. Calipers used in a machine shop are more accurate than the tailor’s tape but would not be suitable for use by the tailor. Thus, each instrument serves a different objective. The gas monitors serve more like a tailor’s tape than a machine shop’s caliper.

The Challenge of Accuracy. With gas monitoring systems, there is no standard by which to compare accuracy. There are hundreds of different chemicals, each having its own unique chemical and physical properties.

As an example, what is 100 ppm of carbon monoxide (CO) in air? Mathematically, this equates to 0.01% of CO and 99.99% air. After the mixture is made, its accuracy is difficult to determine since



The *International Vocabulary of Basic and General Terms in Metrology* defines the terms for result of the measurement as follows:

1. **Accuracy:** Closeness of the agreement between the result of a measurement and a true value of the measurand.*
2. **Repeatability:** Closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement.
3. **Reproducibility:** Closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement.
4. **Linear scale:** Scale in which each spacing is related to the corresponding scale interval by a coefficient of proportionality that is constant throughout the scale.

* *measurand*—a particular quantity subject to measurement; e.g., vapor pressure of a given sample of water at 20°C.

there is no standard 100 ppm of CO to compare with and there is no common agreement that defines a 100 ppm CO mixture.

Because calibration standards are difficult to define in practice, accuracy is the most misunderstood and abused term in gas monitoring. There are few agreements amongst manufacturers of instruments, and there is no common understanding in general.

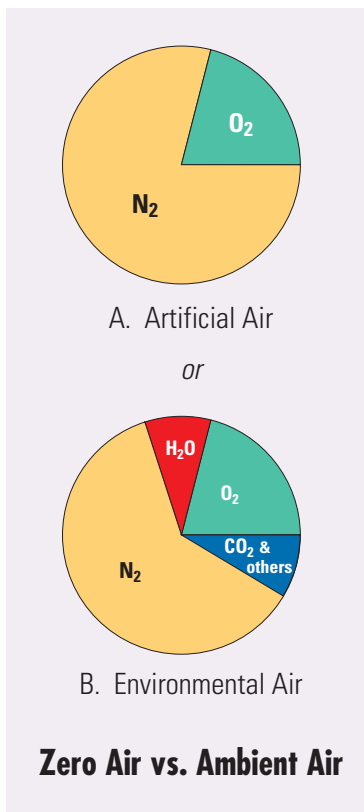
Realistically, it is best to establish a calibration method that can yield *consistent and precise* calibration data. The accuracy of this calibration method can be compared to an accepted standard when challenged.

As long as the calibrations are done with high *precision*, the *accuracy* of your calibration can be established when an accepted standard is available.

Repeatability: Repeatability is the ability of sensors to repeat the measurements of gas concentrations when the sensors are subjected to precisely calibrated gas samples.

Zero Air: “Zero air” is available on the market in the form of a mixture of oxygen and nitrogen in a high pressure tank. In normal applications, however, gas monitoring sensors are put to work in “non-ideal” environments and, consequently, there are many other components in the ambient air besides O₂ and N₂, such as water vapor, carbon dioxide, carbon monoxide, and other trace gases.

Therefore, it is not practical to zero a sensor to a simple mixture of oxygen and nitrogen. Some sensors can be zeroed with dry air or N₂ but some cannot. For instance, most infrared (IR) detectors can be zeroed with dry air or N₂ as long as the wavelength being detected has a minimum water vapor effect. However, with solid-state sensors or photoionization detectors (PIDs), very different



readings may result from dry air compared with wet air.

In many applications, sensors may be satisfactorily zeroed by exposing the sensor to a bag of air collected from a location where the air is “normal.” In fact, this is the easiest way to verify whether a sensor is giving a real alarm or a false alarm.

Linearity: Quantitatively, linearity refers to the output signal in relation to the gas concentration: If 1 volt equals 10 ppm and a full scale 5 volts represent 50 ppm, then the output will be linear. With most sensors, the initial output of the sensor is linear or close to it, but as the gas concentration increases, the output signal is gradually reduced. Figure 5 shows a typical sensor response curve.

Specificity or Selectivity: This is the ability of an instrument to detect a target gas without being affected by the presence of other interfering gases.

Most sensors are sensitive to a family of gases, and there are no sensors specific to only one gas. Among the more specific sensors is an electrochemical sensor for the detection of oxygen.

Different techniques are employed in order to achieve some degree of selectivity to suit practical applications. For example, a charcoal filter is used to filter out most hydrocarbons while letting only CO, H₂, and CH₄ pass through.

In solid-state sensors, the surface temperature of the sensor can be set differently in order to make it more sensitive to one gas and less sensitive to other gases.

The most common practice is to use an analytical column, in which the gas sample stream is introduced into the column and the chemical

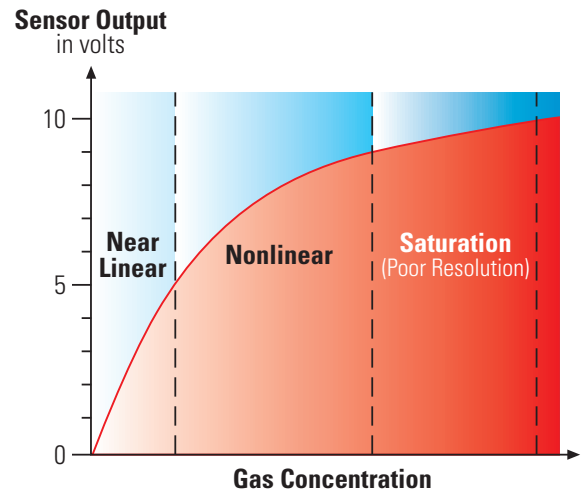


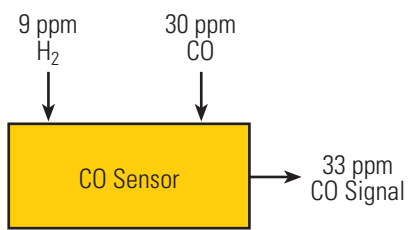
Fig. 5. Typical Sensor Output Curve. As the gas concentration increases, the output signal becomes smaller in relation to the increase in gas concentration, resulting in poor resolution. Most sensors provide better accuracy at lower concentrations than at very high concentrations. Thus, instruments on the market today commonly have output signals that are digitally linearized.

components are separated and come out at the end of the column at different times, where they are detected by a sensor.

This method works well for laboratory use but has proven to be impractical for gas monitoring because it requires a high degree of user knowledge and a high degree of maintenance. Additionally, since the sample must be drawn through the column, the time necessary to take readings can be relatively excessive. Sample times of 15 to 30 minutes are not unusual.

For ambient air monitoring, it is much more practical to use a sensor directly installed at the location being monitored and compensated for the different gases which may be present.

Interference Ratio: As mentioned earlier, sensors are not selective to a single gas and will read other gases as well. Thus, a common practice for manufacturers of gas monitoring equipment is to provide data indicating the ratios that different gases will read on the sensor. For instance, on a 100 ppm carbon monoxide sensor, hydrogen may read at a 3-to-1 ratio. This means that 3 ppm of H_2 will read the same as 1 ppm of CO.



9 ppm H_2 shows as 3 ppm CO

In many cases, even though it is stated that a certain gas will not interfere, if the concentration of this gas is high enough, it may in fact actually interfere. For example, while a CO sensor with a charcoal filter has little interference from certain solvents at 100 ppm, when the concentration is increased to 1,000 ppm, they may interfere drastically.

Because there are so many gases, it is not possible for manufacturers to present data on cross sensitivity ratios for all gases. Therefore, if interference data is not provided for a gas that is of interest to you, you should inquire with the manufacturer if the sensor is selective to a spe-

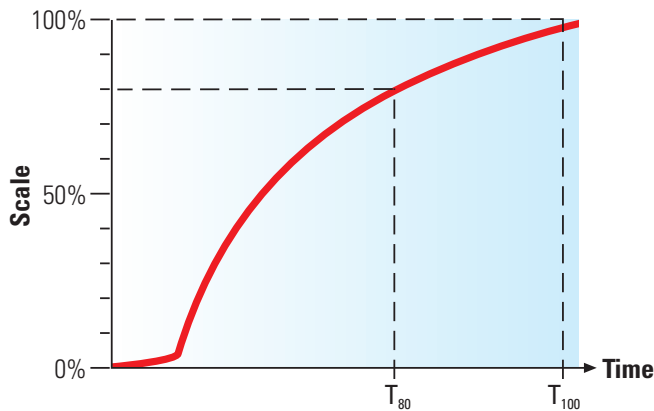


Fig.6. A Typical Sensor Response

cific gas being targeted; in which case, the manufacturer could provide the data needed.

Response/Recovery Time: This is typically defined as the time it takes for a sensor to read a certain percentage of full-scale reading after being exposed to a full-scale concentration of a given gas. For example, $T_{80} = 30$ seconds means that the sensor takes 30 seconds to reach 80% of the full-scale reading after being exposed to a full-scale gas concentration.

Temperature and Humidity: Specifications for these parameters are easy to understand, but beware of the humidity specification. Relative humidity is an indication of the amount of water vapor in air as a percentage of the total amount possible at a given temperature.

Quantitatively, the amount of actual water vapor in air is a function of temperature. For instance, at 80% relative humidity and a temperature of 25°C, water vapor is present at a level of 3%. However, the same 80% relative humidity at a temperature of 48°C produces a water vapor level of 10%. In the presence of chemicals, combined with the changing of temperature between day and night, the possible water condensation and resultant corrosive mixtures can compromise the life expectancy of a sensor.

Hysteresis: The difference in response of the sensor when calibrating from a zero level to mid-scale compared to the response when calibrating from full scale to mid-scale, is known as hysteresis. This quantity is normally expressed as a percentage of full scale. For example, a 100 ppm instrument, when calibrated from 0 to 50 ppm and exposed to a 50 ppm calibration gas, will indicate 50 ppm. However, when the sensor is calibrated to 100 ppm gas but is exposed to 50 ppm the sensor may indicate 55 ppm. This variation of 5 ppm is 5% full-scale hysteresis. Most infrared and photoionization instruments do not exhibit hysteresis, but many other sensors, including electrochemical, solid state, and catalytic sensors do exhibit hysteresis.

In alarm setting, the difference between the *on* point and *off* point alarm is also referred to as *hysteresis*. For instance, if the alarm comes on at 100 ppm, the alarm will not turn off until the gas is below 90 ppm. This hysteresis is needed; otherwise, an alarm can be chattering at the set point of 100 ppm.

Zero and Span Drift: While there is no specific definition for these two terms, common understanding holds that this drift is the percentage change of the zero or span calibration over a specified period of time, typically 30 days or more.

Hazardous Locations

Gas monitoring instruments are often installed in industrial process and production areas. These areas are often classified as hazardous locations. Industrial facilities in which potentially explosive gas atmospheres exist or may exist must utilize proper explosion proof protection methods when using these types of instruments. It is beyond the scope of this book to provide full details; however, the following information may be helpful. The reader is advised to consult with the manufacturer for specific needs.

North America and other parts of the world that

have been influenced by North American practices have traditionally used the National Electric Code (NEC[®]) articles 500-503. They employ a class and division system: *Classes* identify the type of hazard present as gases or vapors, combustible dusts, and flammable fibers. *Divisions* define the condition under which the hazardous material may be present. The devices designed and manufactured for these hazardous locations should be tested and approved for use by a nationally recognized laboratory such as Underwriter's Laboratories (UL[®]), Factory Mutual (FM), or the Canadian Standards Association (CSA[®]). The NEC 500 hazard classifications are as follows:

North American Certification Agencies

Underwriters Laboratories



Factory Mutual



Canadian Standards Association



Class I: Flammable gases or vapors.

Class II: Combustible dusts

Class III: Easily ignitable fibers and flyings

Groups are based on flame propagation characteristics, ignition temperature, and pressure generated during explosion of various gases and vapors. There are four different groups in Class I. These groups are as follows:

Group A: Acetylene

Group B: Acrolein, butadiene, ethylene oxide, formaldehyde, hydrogen, propylene oxide, and propyl nitrate

Groups C and D: All other combustible gases belong to Groups C and D

Division 1: Where ignitable concentrations of gases, vapors, dusts, and fibers can exist all the time or some of the time under normal operating conditions.

Division 2: Where ignitable concentrations of gases, vapors, dusts, and fibers do not exist under normal operating conditions. Hazardous conditions only exist in the event of abnormal conditions, such as acci-

dental rupture or breakdown of a container, storage tank, etc.

Gas monitoring instruments are typically designed and certified for use in Class I, Division 1, Group B, C and D hazardous locations for use in North American markets.

Zones. European countries, as well as a majority of other nations of the world, have been influenced by the International Electrotechnical Commission’s (IEC) three-tiered zone approach. The IEC separates the potentially explosive atmosphere into Zones 0, 1, and 2 based on the probability of occurrence and length of time a potential explosive mixture may be present. Apparatuses designed for use in these areas are usually tested and approved for use by the European Committee for Electrotechnical Standardization (CENELEC) test authorities using Euronorm (EN) standards. The division of these three zones are:

Zone 0: An area in which an explosive gas atmosphere is continuously present for long periods.

Zone 1: An area in which an explosive gas atmosphere is likely to occur in normal operation.

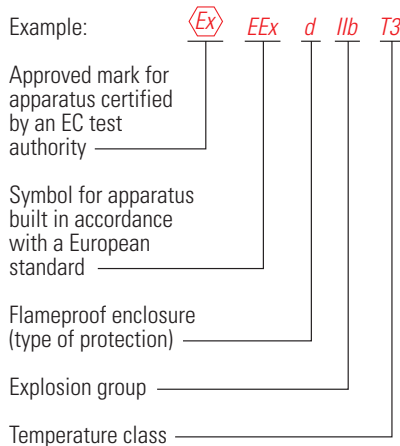
Zone 2: An area in which an explosive gas atmosphere is not likely to occur in normal operation, and if it does, it will exist for a short period only.

Zones 20, 21, and 22 are a subset of Codes 0, 1, and 2 that refer to ignitable dust clouds.

Definition Comparisons. In accordance with their explosive properties, the combustible gases and vapors are divided into temperature classes and explosion protection subgroups. There are no direct comparisons between the current NEC and IEC standards. National Fire Protection Agency (NFPA) in America adopted article NEC 505 which is comparable to IEC standards. A brief comparison of IEC (world), CENELEC (Europe) and NEC (USA) are as follows:

1. *Condition:* Hazardous conditions exist continuously

CENELEC Marking



or for long periods of time.

NEC 505: Class 1, Zone 0

NEC 500: Class 1, Division 1

IEC: Zone 0.

CENELEC: Zone 0

2. *Condition:* Hazardous condition is likely to occur in normal operation.

NEC 505: Class 1, Zone 1

NEC 500: Class 1, Division 1

IEC: Zone 1

CENELEC: Zone 1

3. *Condition:* Hazardous condition is not likely to occur in normal operation and if it does, only infrequently and for a short period.

NEC 505: Class 1, Zone 2

NEC 500: Class 1, Division 2.

IEC: Zone 2

CENELEC: Zone 2

Types of Protection

There are several acceptable types of protection for electrical equipment in hazardous locations. The more common types are the following:

- A. **Flameproof Enclosure (d)**⁴: The enclosure, such as the one shown in Figure 6, will withstand an internal explosion, without causing ignition of an external explosive atmosphere. The enclosure joints and structure covers are designed and manufactured for such purposes. This type of protection is most commonly used for gas monitoring applications and can meet the requirements of:

NEC 500 - Class 1, Division 1 & 2.

NEC 505-Class 1, Zone 1 & 2, AExd.

IEC-Exd.

CENELEC-EEExd.

⁴ The lower case letter in a CENELEC-approved marking designates the type of protection offered by an enclosure.

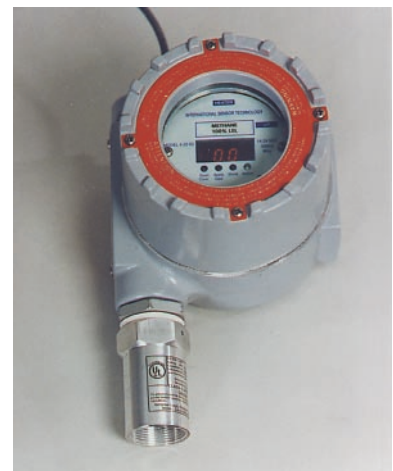
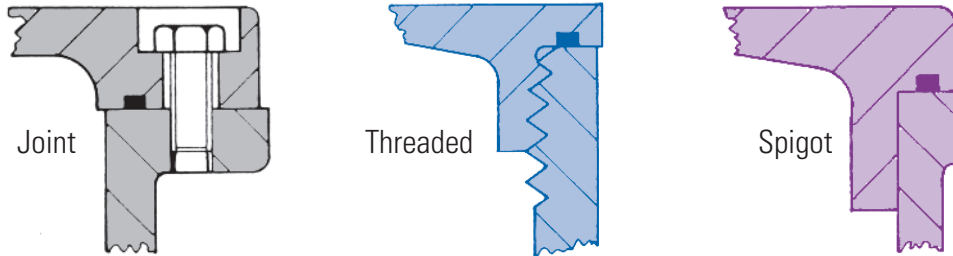


Fig. 6. An Explosion-Proof Enclosure

Types of Flamepaths in Flameproof Enclosures

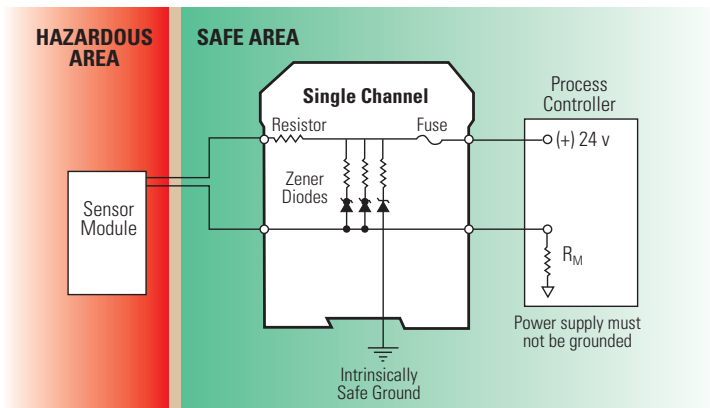


Materials used: Aluminum, Iron

(Courtesy of Cullen Associates)

B. Intrinsic Safety (i): The electrical energy in an intrinsically safe circuit which enters into the enclosure is not sufficient to generate a spark and ignite a combustible mixture in the hazardous area, in any worst case scenario. To meet this requirement, safety barriers or other devices

limiting the electrical energy are placed on the wires to limit the electrical energy allowed to flow through the circuit before the wire enters into the hazardous location. Safety barriers are a combination of zener diodes, power resistors, and fuses which are designed to limit the amount of electrical energy allowed to



(Courtesy of Cullen Associates)

flow through the wires. Various approved and certified safety barriers are available as standard electrical components. These are limited to low power device applications only. This method of protection can meet the requirements of:

NEC 500 - Class 1, Division 1 & 2.

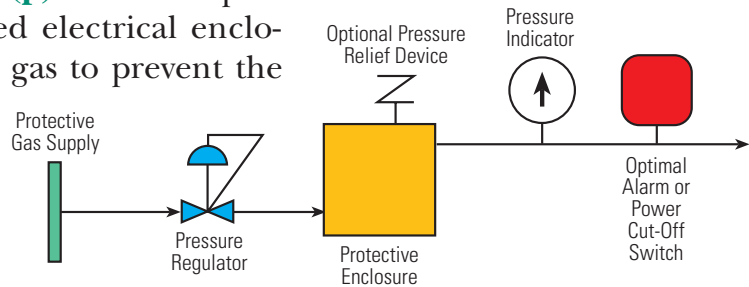
NEC-505 - Class 1, Zones 0, 1 & 2.

AExi(a).

IEC - Exi(a).

CENELEC - EExi(a).

C. Purged and Pressurized (p): This is the process of supplying sealed electrical enclosures with a protective gas to prevent the entrance of flammable gases while maintaining a positive enclosure pressure. This type of protection can meet the requirements of:



NEC 500 - Type X, Y & Z.

NEC 505 - Type X, Y & Z.

IEC - Exp.

CENELEC - EExp.

Type X pressurizing: Reduces the classification within the protected enclosure from Class 1, Division 1 or Class 1, Zone 1 to unclassified.

Type Y pressurizing: Reduces the classification within the protected enclosure from Division 1 to Division 2 or Zone 1 to Zone 2.

Type Z pressurizing: Reduces the classification within the protected enclosure from Class 1, Division 2 or Class 1, Zone 2 to unclassified.

D. Increased Safety (e): This is a type of explosion protection applied to electrical apparatus that does not produce arcs or sparks in normal service, in which additional measures are applied so as to give increased security against the possibility of excessive temperature and of the occurrence of arcs and sparks. This method of protection can meet the requirements of:

NEC 500 - No Standard.

NEC 505 - Class 1, Zone 1 & 2, AExe.

IEC - Exe.

CENELEC - EExe.

E. Other Protection Methods: Oil immersion(o), powder filling(q) and moulding(m).

Enclosure Classifications For Nonhazardous Areas

In North America, the National Electrical Manufacturer's Association (NEMA), as a way of standardizing enclosure performance, classified the enclosures in different ratings which are intended to provide information for users to make proper product choices. This rating system identifies the ability of the enclosure to resist various possible conditions. The classifications are as follows:

NEMA Type 1: For general-purpose indoor use, provides protection against incidental contact with the enclosed equipment.

NEMA Type 2: In addition to NEMA Type 1, provides protection against a limited amount of falling water and dirt.

NEMA Type 3: For outdoor use. Provides protection against windblown dust, rain and sleet, as well as formation of ice on the enclosure. Provides rust resistance.

NEMA Type 3R: Same as NEMA Type 3, but does not provide dust protection.

NEMA Type 4: Same as NEMA Type 3, except, it is for indoors or outdoors, provides protection against direct water hose down.

NEMA Type 4X: Same as NEMA Type 4, but it also provides corrosion resistance for indoor use.

NEMA Type 6: Same as NEMA Type 4X, but provides protection against water during temporary submersion at a limited depth.

NEMA Type 7: For indoor use in hazardous locations, Class 1, Groups A, B, C, and D.

NEMA Type 9: For indoor use in dust applications, Class II, Groups E, F, and G.

NEMA Type 12: For indoor use, provides protection against dust, falling dirt, and dripping non-corrosive liquids.

NEMA Type 13: For indoor use, provides protection against dust, spraying water, oil, and non-corrosive coolant.

Internationally, the protections for electrical apparatuses are designated with *ingress protection* (IP) followed by a two-digit number which defines the degree of protection. The first digit (0-6) defines the protection against contact and entry of foreign objects while the second digit (0-8) defines the protection against water.

Protection	First Digit	Second Digit
0	No protection	No protection
1	Large objects of more than 50 mm diameter	Vertically falling water
2	Medium-sized objects of more than 12 mm diameter	Falling water at up to 15 degrees from vertical
3	Small objects of more than 2.5 mm	Falling water up to 60 degrees from vertical
4	Granular objects of more than 1 mm diameter	Water splashes from any direction
5	Dust protected, not completely tight	Water from a nozzle from any direction
6	Dust tight	Powerful water jet
7		Short-term immersion
8		Continuous immersion

The IP classification is set by the International Electrotechnical Commission. The definitions for protections are different from that of NEMA. Therefore, the IEC enclosure classification designations cannot

be exactly equated with NEMA enclosures.

As examples, IP 66 is approximately equivalent to NEMA 4 or 4X, IP 67 is equivalent to NEMA 6, and IP 55 is equivalent to NEMA 12.

Summary

There is no clear definition delineating a gas monitor from an analytical analyzer. The distinction between the two is based largely upon their usage in the actual application. A gas monitor is most frequently used to monitor gases in toxic and combustible ranges for area air quality and safety applications. For this type of safety application, the concept of the units used in the measurements and the definition of terminologies is somewhat unique. It is important to understand the terms used. However, the examples of chemical toxicity presented in this book do not consider the complexity of actual toxicology and interreactions between contaminant chemicals. In critical applications, a specialist on the subject needs to be consulted.