Understanding Carbon Dioxide Sensors and their Applications

Safety professionals sometimes forget that carbon dioxide is a toxic gas with a strictly defined Occupational Exposure Limit. The safest approach is to measure CO_2 directly when the gas is present in potentially dangerous concentrations.

Liquid and solid carbon dioxide (dry ice) are widely used as refrigerants, especially in the food industry. Carbon dioxide (CO_2) is also used in many industrial and chemical industry processes. CO_2 is particularly associated with the beer and wine making industries, where it is produced by yeast during the fermentation process. CO_2 in the headspace of fermentation vessels can easily reach 50% by volume or even higher concentrations. CO_2 is also widely used in the oil industry, where it is commonly injected into oil wells to decrease viscosity. It is also one of the most common atmospheric hazards encountered in confined spaces.

Compact multi-sensor instruments are capable of providing direct CO_2 measurement during confined space and other atmospheric monitoring procedure

Carbon dioxide (CO_2) is a byproduct of living organisms, and is naturally present in the earth's atmosphere with an average concentration of about 350 ppm in fresh air. CO_2 is a primary byproduct of bacterial decomposition, and in many confined spaces there is a direct relationship between low concentrations of oxygen and elevated concentrations of CO_2. If the low oxygen is due to bacterial action, a concentration of 19.5% oxygen would be associated with an equivalent concentration of at least 1.4%, or 14,000 ppm CO_2, which is almost three times higher than the occupational exposure limit.

The true concentration of CO_2 can be substantially higher if the oxygen deficiency is due to displacement. Fresh air contains only 20.9% oxygen by volume. The balance consists mostly of nitrogen, with minor or trace concentrations of a wide variety of other gases including CO_2. Because oxygen represents only about one-fifth of the total volume of fresh air, every 5% of a displacing gas that is introduced into a confined space reduces the oxygen concentration by only 1%. In the case of an oxygen deficiency due to the introduction of dry ice into an enclosed space, a reading of 19.5% O_2 would not be indicative of 1.4% CO_2, it would be indicative of 7% CO_2, a concentration fourteen times higher than the toxic exposure limit!

CO_2 is also heavier than air, with a density of 1.5 times that of fresh air. When carbon dioxide is released into an enclosed or confined space it tends to settle to the bottom of the space, reaching the highest concentration in the lowest parts of the space. Because of this tendency to settle, as CO_2 is produced it can reach higher and higher concentrations in localised regions of the space (such as the head space immediately above the liquid in fermentation vats).

In spite of these considerations, in the past it was seen as adequate to simply measure the oxygen concentration. This attitude is changing as it becomes more feasible (and affordable) to directly measure CO_2 by means of compact, portable multi-sensor gas detectors.

Carbon dioxide is a toxic contaminant with strictly defined workplace exposure limits

CO_2 is listed as a toxic contaminant with strictly defined occupational exposure limits in almost every country. The most widely recognised exposure limits for CO_2 reference an 8-hour Time Weighted Average (TWA) of 5,000 ppm, with a 15-minute Short Term Exposure Limit (STEL) of either 15,000 ppm or 30,000 ppm.

While present as a natural component in fresh air, at higher concentrations exposure symptoms include headaches, dizziness, shortness of breath, nausea, rapid or irregular pulse and depression of the central nervous system. Besides displacing the oxygen in fresh air, high concentrations of CO_2 can worsen the symptoms related to oxygen deficiency, and interfere with successful resuscitation. Even moderately elevated concentrations associated with poorly ventilated indoor spaces can produce physiological symptoms. Concentrations of 40,000 ppm or higher should be regarded as immediately dangerous to life and health. Exposure to very high concentrations has been linked to permanent heart damage, as evidenced by altered electro-cardiograms. Concentrations greater than 10% are capable of causing loss of consciousness within 15 minutes or less.

Multi-sensor instruments are able to use wide range of sensors and detection technologies including O_2, standard pellistor LEL, NDIR combustible gas and CO_2, PID and over 20 different substance-specific electrochemical sensors for toxic gas measurement

How NDIR (non-dispersive infrared) CO_2 sensors detect gas

The most widely used technique for real-time CO_2 measurement is by means of non-dispersive infrared (NDIR) sensors that measure gas as a function of the absorbance of infrared light.

Specific molecules absorb infrared radiation at precise wavelengths. When infrared radiation passes through a sensing chamber containing a specific contaminant, only the light that matches these wavelengths is absorbed. The rest of the light is transmitted through the chamber without hindrance.

Carbon dioxide has an absorbance peak at a wavelength of 4.3 microns (µm). Absorbance of infrared light at this wavelength is proportional to the concentration of CO_2 present in the sensing chamber of the sensor.

Miniaturised NDIR CO_2 sensors include an infrared lamp that emits light in the desired wavelengths. Most NDIR CO_2 sensors are dual detector systems that provide both a reference and an active signal. The active detector measures the amount of light in the 4.3 µm range that reaches the detector after passing through the sensing chamber. The reference detector measures the amount of light at another wavelength where there is no absorbance for the gas of interest. The greater the concentration of CO_2, the greater the difference between the two signals.

In the past, infrared based instruments have tended to be bulky, expensive, and required a high level of operator expertise to obtain accurate readings. A new generation of miniaturised NDIR sensors has permitted the development of infrared based instruments for an ever widening variety of atmospheric hazards including combustible gas as well as CO_2 detection.

The regulations are already changing. Recent accidents have heightened concerns, and increased the obligation for direct CO_2 measurement during workplace procedures that may expose workers to this contaminant. In Germany and Austria regulations already require direct measurement of CO_2 during most confined space entry procedures. It is clear that with the increased availability, and increasingly affordable cost of miniaturised NDIR CO_2 sensors, more and more atmospheric monitoring programs will include the direct measurement of this dangerous atmospheric contaminant.

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