Concentration	Symptom
250 – 350 ppm	Normal background concentration in outdoor ambient air
350 – 1,000 ppm	Concentrations typical of occupied indoor spaces with good air exchange
1,000 – 2,000 ppm	Complaints of drowsiness and poor air
2,000 – 5,000 ppm	Headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present
5,000 ppm	Workplace exposure limit (as 8-hour TWA) in most jurisdictions
> 40,000 ppm	Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma and even death

According to NIOSH concentrations of 40,000 ppm or higher should be regarded as immediately dangerous to life and health. Exposure to very high concentrations (e.g. exposure to 6% volume CO_2 for several minutes or 30% volume CO_2 for 20-30 seconds), has been linked to permanent heart damage, as evidenced by altered electrocardiograms. Concentrations greater than 10% are capable of causing loss of consciousness within 15 minutes or less.

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

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

Molecules can be conceptualised as balls (atoms) held together by flexible springs (bonds) that can vibrate (stretch, bend or rotate) in three dimensions. Each molecule has certain fixed modes in which this vibratory motion can occur. Vibrational modes are dictated by the nature of the specific bonds that hold the molecule together. The larger the molecule, the greater the number of modes of movement. Each mode represents vibrational motion at a specific frequency. The modes are always the same for a specific molecule. Chemical bonds absorb infrared radiation. The bond continues to vibrate at the same frequency but with greater amplitude after the transfer of energy. For infrared energy to be absorbed (that is, for vibrational energy to be transferred to the molecule), the frequency must match the frequency of the mode of vibration.

Specific molecules absorb infrared radiation at precise wavelengths. When infrared radiation passes through a sensing chamber containing a specific contaminant, only those wavelengths that match one of the vibration modes are absorbed. The rest of the light is transmitted through the chamber without hindrance. The presence of a particular chemical group within a molecule thus gives rise to characteristic absorption bands. Since most chemical compounds absorb at a number of different frequencies, IR absorbance can provide a "fingerprint" for use in identification of unknown contaminants. Alternatively, for some molecules it may be possible to find an absorbance peak at a specific wavelength that is not shared by other molecules likely to be present. In this case absorbance at a particular wavelength can be used to provide substance-specific measurement for a specific molecule. Carbon dioxide has such an absorbance peak at a wavelength of 4.26 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. The absorbance is not linear per concentration unit, but is mathematically predictable and easily calculated by micro-processor equipped portable gas detectors.

Miniaturised NDIR CO_2 sensors include an infrared light source (typically a tungsten filament lamp) capable of emitting light in the desired wavelengths. Optical filters are used to limit the light transmitted through the sensing chamber to a narrow range of wavelengths. Most NDIR CO_2 sensors are dual detector systems that provide both a reference and an active signal. Pyroelectric detectors capable of measuring absorbance at the specific wavelengths of interest are used to provide the measurement and reference signals. The active detector in a CO_2 sensor measures the amount of light in the 4.26 µm range that reaches the detector after passing through the sensing chamber. The reference detector measures the amount of light at another wavelength (or range of wavelengths) where there is no absorbance for the gas of interest. The greater the concentration of CO_2, the greater the reduction in the amount of light that reaches the active detector when compared to the reference signal.

Figure 3: Compact multi-sensor instruments are capable of providing direct CO_2 measurement during confined space and other atmospheric monitoring procedures

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 carbon dioxide, Freons®, ammonia, and methane, as well as generalised hydrocarbon combustible gas detection.

The regulations are already changing. Recent fatalities in the wine industry in California and Oregon have heightened concerns, and increased the obligation for direct CO_2 measurement during workplace procedures that may expose workers to this contaminant in the wine making industry. 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.

About the Author:

Robert Henderson is Vice President, Business Development for BW Technologies by Honeywell. Mr. Henderson has been a member of the American Industrial Hygiene Association since 1992. He is the 2006 Chairman of the AIHA Gas and Vapour Detection Systems Technical Committee as well as a current member and past chair of the AIHA Confined Spaces Committee. He is also a past chair of the Instrument Products Group of the International Safety Equipment Association.