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Direct-Reading Monitoring Devices for Carbon Monoxide

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Reported by Mary Lynn Woebkenberg

Introduction

The class of monitoring devices discussed in this article is commercially available direct-reading monitoring methods for carbon monoxide in air. This will include instruments, detector tubes, badges, and diffusion tubes. The instruments are those intended for workplace monitoring and are not sold for in-home use or designed for ambient air monitoring.

Carbon monoxide is a highly poisonous, odorless, colorless, tasteless gas (vapor pressure >35 atmospheres at ambient temperatures).[1] Carbon monoxide combines with hemoglobin in the blood to form carboxyhemoglobin, which is useless as an oxygen carrier. The carbon monoxide–hemoglobin complex is actually more stable than the oxygen–hemoglobin complex, accounting for the toxicity of carbon monoxide. Health effects range from headaches and dizziness from minor exposures to unconsciousness and even death from high, acute exposures.[2]

Principle of Detection

Direct-reading instruments for carbon monoxide detection operate on one of the following principles: electrochemical (including potentiometric and coulometric), infrared spectrophotometry, photometry (including fluorescence), thermal conductivity, or heat of combustion.

1. Electrochemical instruments involve the measurement of electrical signals associated with chemical reactions of carbon monoxide and include instruments that operate on the basis of potentiometry and coulometry. Electrochemical cell detection represents the largest class of carbon monoxide monitors.

   Instruments using potentiometry as their operating principle measure the difference in potential between two electrodes in an electrochemical cell at zero current. Carbon monoxide is determined by measuring the current produced as a result of the electro-oxidation at a catalytically active electrode. A membrane can be used to regulate the concentration of carbon monoxide reaching the electrode. Careful membrane selection affords these devices increased selectivity.

   Carbon monoxide monitors using coulometry as their operating principle detect the quantity of electricity required to effect complete electrolysis of carbon monoxide.
2. Infrared spectrophotometers rely on the interaction of the infrared portion of the electromagnetic spectrum with the analyte, carbon monoxide. Absorption of infrared radiation causes vibration of molecular bonds, and the frequencies of these vibrations can be monitored. Carbon monoxide strongly absorbs infrared radiation at 4.7 μm, in the mid-infrared region. Selecting the infrared wavelength can be accomplished either by selecting the wavelength on an instrument dial or by using an appropriate filter supplied by the manufacturer.
3. Fluorescence analyzers and photometers, both of which fall in the photometric analyzer category, can be used for the detection of carbon monoxide. Fluorescence is the emission of photons from molecules in excited chemical states when the excited chemical states are the result of absorption of energy from some source of radiation and when the emission wavelength is longer than the wavelength of the excitation radiation. Fluorescence analyzers measure the amount of energy emitted at a selected wavelength.

   Photometers usually involve a color change of the sampling medium followed by measurement of the light reflected from the sampling medium. However, in one photometer designed specifically for the determination of carbon monoxide, mercury, via the reduction of solid-state mercury oxide by carbon monoxide, is measured using an ultraviolet filter photometer. The amount of mercury generated is equal to the quantity of carbon monoxide oxidized in the sample.[3]
4. Thermal conductivity detectors operate by measuring the change in resistance, as a surrogate for temperature, of the sensing device, which is a heated element. Carbon monoxide gas will conduct heat away from the heated element, causing a change in the temperature (resistance) of the element. Metal oxide sensors are the most common type in this class.
5. Heat of combustion detectors measure the heat released during the combustion of carbon monoxide. They do this either by measuring the change in resistance of a filament that is heated upon the combustion of carbon monoxide, or by measuring the resistance or temperature changes in catalytically heated filaments.

Detector tubes use a calibrated pump to pull a sample through a sorbent bed. The sorbent bed is impregnated with a chemical that will react with carbon monoxide. The reaction causes a color change and the resultant length of the stain is measured, or the stain is matched to a calibrated comparison chart. Typical detector tube reactions[4] for carbon monoxide include the reduction of iodine pentoxide to iodine with an accompanying color change from white to brown/green, and the reduction of ammonium molybdate plus palladium sulfate to molybdenum blue.

Badges are typically color change devices. They do not require the use of sampling pumps, operating simply via diffusion. The chemistry can be similar to that of detector tubes, but the interpretation of the color change is usually not a length of stain reading. The badges can be of the "go/no go" variety (that is, a color change indicates the presence of a predetermined amount of carbon monoxide), or the badge can have a series of chemically impregnated spots that will

TABLE 1. Attributes and Limitations of Monitoring Devices for Carbon Monoxide

Instrument	Limit of Detection	Interferences	Power	Weight (kg)	Other Features
Electrochemical Potentiometry Coulometry	<1 ppm	H_2S, HCN, and HCl when present at concentrations >100 ppm, SO_2 and NO_2 at concentrations >10 ppm	Battery, some 110 VAC or optional 110 VAC	2.2 or less	Many have audio or visual alarms and datalogging capabilities
Infrared	<5 ppm	Gases that absorb at similar wavelengths (e.g., carbon dioxide, water vapor)	110/220 VAC, some battery	9–28	Few have alarms
Photometric	0.1 ppm	Various, depends on device	115 VAC	~15	Can be panel mounted and used as continuous monitors
Thermal conductivity	N/A	Universal detector	110 VAC	11	No alarms
Heat of combustion	1–10 ppm, 0.1–5% LEL	Universal detector	Battery and 110 VAC	0.5–4	Largest class available, many with alarms and dataloggers
Detector tubes	Depends on tube, as low as 1 ppm	Varies as function of chemistry used to detect carbon monoxide	Pumps can be hand operated or battery powered	Tubes are negligible, pumps 0.15–3	Pump size and operation vary greatly as function of manufacturer and use of tube
Diffusion tubes	50–600 ppm-hr, 10–200 ppm-hr	Varies as function of chemistry used to detect carbon monoxide	No power required	Negligible	No pump required
Badges	Some as low as trace ppb	Varies as function of chemistry used to detect carbon monoxide	No power required	Negligible	No pump required

progressively change color as the concentration of, or exposure to, carbon monoxide increases.

Diffusion tubes are basically detector tubes that have been manufactured and calibrated to operate on the principle of diffusion rather than using a sampling pump. Diffusion is controlled through the geometry of the tube according to

$$R \approx D(A/L)$$

where:

R = sampling rate
D = diffusion coefficient
A = cross-sectional area of the tube (diffusion path)
L = length of the diffusion path

Laboratory and field evaluations have been conducted on direct-reading carbon monoxide monitors,[5,6] and recommendations and performance criteria for detector tubes are available.[7,8]

Applications and Limitations

The devices presented for monitoring carbon monoxide have a variety of applications, including quantitative (definitive) analysis, semiquantitative (screening) analysis, or qualitative analysis (screening) analysis. The category to which a given device would be assigned depends on the manufactured design and capabilities of the device, as well as the measurement error associated with that device and the degree of error that is acceptable for a given application. That is, the applicability and suitability of a given carbon monoxide monitor depend on intrinsic properties of the device (see Table 1 and/or refer to *Air Sampling Instruments for Evaluation of Atmospheric Contaminants*[9,10]) and on your specific monitoring requirements. Table 1 gives an indication of some of the attributes and limitations of each monitoring technique discussed, including limits of detection (also referred to as sensitivity and limits of quantitation), interferences, weight, and power requirements. In this article these specifications are given in generalities. Information on a specific device or class of devices may be found in *Air Sampling Instruments for Evaluation of Atmospheric Contaminants*.[9,10]

Applicable Exposure Limits

Internationally there are a variety of legally promulgated as well as recommended limits for exposure to carbon monoxide. These include time-weighted average (TWA) exposures, ceiling values, peak values, and values for carbon monoxide, or surrogates thereof, in biological matrices. These exposure limits include:

permissible exposure limit [Occupational Safety and Health Administration (OSHA)]: 50 ppm (55 mg/m^3)
recommended exposure limit [National Institute for Occupational Safety and Health (NIOSH)]: 35 ppm (40 mg/m^3); ceiling—200 ppm (229 mg/m^3)
threshold limit value [American Conference of Governmental Industrial Hygienists (ACGIH)]: 25 ppm (29 mg/m^3)
maximum allowable concentration (MAK): 30 ml/m^3 (33 mg/m^3); peak value = 2 × MAK, 30-minute average
immediately dangerous to life or health (NIOSH): 1200 ppm
biological exposure index (ACGIH): carboxyhemoglobin in blood—3.5% of hemoglobin; carbon monoxide in end-exhaled breath—20 ppm
United Kingdom: 50 ml/m^3 (55 mg/m^3); short-term exposure limit—300 ml/m^3 (330 mg/m^3)
Environmental Protection Agency: domestic, all ages (TWA)—9 ppm, 8 hours
World Health Organization: domestic, all ages (TWA)—9 ppm, 8 hours

Methods

There are several published methods useful for the determination of carbon monoxide. Not all of these methods use direct-reading instruments or other field-readable techniques. These methods have been evaluated against accepted evaluation criteria.

1. NIOSH, Method 6604–Portable, Direct-Reading CO Monitor[11]
2. OSHA, Method ID-209
   Method ID-210, Bag Sample, analysis[12]
3. ISO 4224, Carbon Monoxide by NDIR (in preparation)[13]
4. ASTM, D3162-94, Carbon Monoxide by NDIR[14]
5. EPA[15]
   Carbon Monoxide AIR
   Carbon Monoxide CEM at Petroleum Refineries 0010A
   Carbon Monoxide CEM—Stationary Sources 0010
   Carbon Monoxide Emission—Stationary Sources 0010B

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Disclaimer

Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

References

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12. Occupational Safety and Health Administration: Carbon Monoxide in Workplace Atmospheres. USDOL/OSHA-SLTL ID-210. OSHA, Salt Lake City, UT (1991).
13. International Organization for Standardization: ISO 4224: Ambient Air—Determination of Carbon Monoxide—Non-Dispersive Infrared Spectrometry Method. (in preparation).
14. American Society for Testing and Materials: D3162-94, Annual Book of ASTM Standards, Vol.11.03. ASTM, West Conshohocken, PA (1997).
15. U.S. Environmental Protection Agency: National Primary and Secondary Air Quality Standards. Federal Register 36: 8186–8201 (1971).

List of Manufacturers for Instruments, Detector Tubes, Badges, and Diffusion Tubes

AIM USA
P.O. Box 1930
Tempe, AZ 85280

Applied Automation
Compur Monitors Group
7101 Hollister Road
Houston, TX 77040

Beckman Instruments, Inc.
Process Instruments Division
2500 North Harbor Boulevard
Fullerton, CA 92634

Burlington Safety Laboratory, Inc.
2009 Route 130 S
Burlington, NJ 08016

COSMOS Gas Detection Systems
P.O. Box 70498
Seattle, WA 98107

Deutsh Engineering & Testing Services
P.O. Box 389
Monsey, NY 10952

Devco Engineering, Inc.
Control Systems Division
36 Pier Lane West
Fairfield, NY 07006

Enmet Corp.
2308 South Industrial Way
P.O. Box 979
Ann Arbor, MI 48103-0979

Foxboro Company
Foxboro, MA 02035

Gas Tech, Inc
8407 Central Ave
Newark, CA 94560

Gilian Instrument Corp.
35 Fairfield Place
West Caldwell, NJ 07006

Industrial Scientific Corp.
1001 Oakdale Road
Oakdale, PA 15071

Lumidor Safety Products
11221 Interchange Circle
Miramar, FL 33025-6001

Macurco, Inc.
3946 South Mariposa Street
Englewood, CO 80110

American Gas and Chemical Co.
220 Pegasus Avenue
Northvale, NJ 07647

Bacharach, Inc.
625 Alpha Drive
Pittsburgh, PA 15238

Biosystems, Incorporated
Box 158
Rockfall, CT 06481

CEA Instruments, Inc.
16 Chestnut Street, Box 303
Emerson, NJ 07630-0303

Crowcon Detection Instruments
2001 Ford Circle, Suite F
Park 50 Technecenter
Milford, OH 45150

Dynamation, Inc
3784 Plaza Drive
Ann Arbor, MI 48108

Environmental Sensors
4801 North Dixie Hwy
Boca Raton, FL 33431

Envirometrics Products Company,
1019 Bankton Drive
Charleston, SC 29406

GfG Gas Electronics, Inc.
6617 Clayton Road, Suite 209
St. Louis, MO 63117

GMD Systems, Inc.
Old Route 519
Hendersonville, PA 15339

Interscan Corp.
P.O. Box 2496
Chatsworth, CA 91313

MDA Scientific, Inc.
405 Barclay Boulevard
Lincolnshire, IL 60069

Metrosonics, Inc.
General Products Division
P.O. Box 23075
Rochester, NY 14692

Mine Safety Appliances Co.
P.O. Box 427
Pittsburgh, PA 15230

Matheson Gas Products
30 Seaview Drive
P.O. Box 1587
Secaucus, NJ 07096

Neotronics
P.O. Box 370
2144 Hilton Drive, S.W.
Gainesville, GA 30503

Quest Technologies
510 Worthington Street
Oconomowoc, WI 53006

Rosemount Analytical Inc.
600 South Harbor Boulevard
La Habra, CA 90631

Scott Aviation
225 Eirie Street
Lancaster, NY 14086

Sensidyne, Inc.
16333 Bay Vista Drive
Clearwater, FL 34620

Zellweger Analytics
P.O. Box 2100
4331 Thurmond Tanner Road
Flowery Branch, GA 30542

MST Measurement Systems, Inc.
327 Messner Drive
Wheeling, IL 60090

National Draeger, Inc.
101 Technology Drive
P.O. Box 120
Pittsburgh, PA 15230

Phillips Electronics Instruments
85 McKee Drive
Mahwah, NJ 07430

Roxan Inc.
5425 Lockhurst Drive
Woodland Hills, CA 91367-5735

RKI Instruments, Inc.
1855 Whipple Road
Hayward, CA 94544

SAF-CO Mfg., Inc.
P.O. Box 28885
Kansas City, MO 64118

Teledyne Analytic Inst
16830 Chestnut Street
City of Industry, CA 91749-1580