CO_2 BLASTING

By Neal McManus, CIH, ROH, CSP

A previous article ("CO_2 Blasting: The Remediation Tool of the Future," *Cleaning & Restoration*, June 2007) reviewed the pros and cons of abrasive blasting using pellets of dry ice propelled by a stream of compressed air. Abrasive blasting minimizes the risk of musculoskeletal injury (compared to sanding and abrading in overhead and other awkward positions). A blasting medium that leaves no residue and can penetrate into inaccessible areas holds a lot of promise. Dry ice, the solid form of carbon dioxide (CO_2) gas, readily sublimes to the gaseous form at normally encountered temperatures. The fracturing of the pellets into small fragments during collision with surfaces in their path promotes sublimation. The compressed air used in the process pushes the pellet stream considerably away from the operator and at the same time supplies large quantities of air containing the normal level of oxygen. This supply of air near the breathing zone of the worker ensures that oxygen deficiency (defined in regulatory terms

Figure 1: Dry ice is not ice! Waste dry ice spread on the ground, as shown here, can generate a cloud of carbon dioxide having high concentrations. In this example, the concentration of CO_2 was 2500 ppm at chest height in the early morning in late spring.

as being less than 19.5 percent in most jurisdictions) is unlikely to occur.

Carbon Dioxide Exposure

While the disappearance of dry ice due to sublimation during abrasive blasting is its greatest strength, this property is also its greatest limitation. However, assessment of exposure to carbon dioxide during abrasive blasting is a difficult technical challenge.

Carbon dioxide is present in the normal atmosphere at an average concentration of 350 ppm (parts per million). This level can be elevated when cool air traps combustion gases from furnaces at low heights, or when combustion gases from engines of vehicles and mobile equipment, such as compressors, are present at ground level.

CO_2 has an unusual relationship with the body because it has a normal presence in the body at a high concentration. It is a product of human metabolism and is present in all cells, tissues and the blood. Transfer from the blood into the airspaces of the lung is the major route for the elimination of metabolic carbon dioxide from the body. The concentration of carbon dioxide in alveolar airspaces (or sockets within the jawbone in which the roots of a tooth rest) is normally 53,000 ppm at sea level. The corresponding concentration of oxygen in the alveolar airspaces is about 15.2 percent compared to 20.9 percent in the exterior atmosphere.

Carbon dioxide plays a vital role in regulation of respiration in the body. Elevated levels of carbon dioxide act as a respiratory stimulant in the neurological control of breathing. Response is virtually immediate. This happens because of the high permeability of membranes of the blood-brain and blood-cerebrospinal fluid barriers to carbon dioxide. Longer term adaptation also occurs. The reverse also readily occurs when the concentration of carbon dioxide decreases to normal levels. Much of this knowledge comes from studies of submariners, where elevated levels of carbon dioxide are present for prolonged periods. Typically, this situation occurs when exposure is above regulatory limits. Accompanying effects can include mild narcotic effects, respiratory arrest and asphyxiation. The occurrence of a particular effect depends on the concentration and duration of exposure.

Toxicology, the study of poisons, classifies substances that produce effects on the body as simple asphyxiants, chemical asphyxiants or toxics. Simple asphyxiants include nitrogen, steam and water vapor, and the chemically inert gases (helium, neon, argon, krypton and xenon). Simple asphyxiants exert their effect by reducing the concentration of oxygen available to the tissues of the body. They are the only substances permitted to depress the level of oxygen to 19.5 percent (the regulatory limit in confined spaces) without triggering concern about overexposure in their own right. Any other substance that depresses the level of oxygen requires identification, assessment and probably control.

Chemical asphyxiants, such as carbon monoxide, prevent transport of oxygen in the body or interrupt respiration at the molecular and cellular level. Carbon monoxide binds to hemoglobin in red blood cells, thereby preventing binding by oxygen. Toxic substances produce effects at the molecular level in individual cells, tissues and organs.

Carbon dioxide creates a dilemma for toxicologists. It is naturally present in the body at a high level compared to that in the atmosphere, and has an integral role in operation of regulatory systems. The body rapidly adapts to changing levels and can accommodate to levels considerably higher than those encountered in normal experience. Carbon dioxide does not fit into the normal system of classification. It is not a simple asphyxiant because it exerts mild narcotic effects at high levels of exposure.

Regulatory Limits

The regulatory limits used in many jurisdictions and as guidelines by industrial hygienists in many others are the Threshold Limit Values (TLVs). TLVs are recommended by the TLV Committee of the American Conference of Governmental Industrial Hygienists (ACGIH). These are guidelines, not fine lines, between safe and dangerous conditions. TLVs are believed to represent conditions under which nearly all workers may be repeatedly exposed day after day without adverse health effects.

TLV-TWA is the time-weighted concentration for a normal 8-hour workday and 40-hour workweek to which it is believed that nearly all workers may be repeatedly exposed, day after day, for a working lifetime without adverse effect. TLV-STEL is a 15-minute time-weighted average which should not be exceeded at any time during a workday, even if the 8-hour TWA is within the TLV-TWA. Up to four excursions at the TLV-STEL may occur per day provided

Figure 2 (a, b): Take advantage of natural ventilation. Positioning the storage bin adjacent to an opening to the outdoors that experiences outward flow can considerably reduce exposure to CO_2. Cool CO_2 is much heavier than air and descends rapidly to the lowest possible level. The concentration at chest height in a quiet area not subject to cross draft was 2800 ppm, whereas the concentration in the situation pictured was only 1400 ppm. The concentration increased to 2800 ppm during transfer by scoop into a 5-gallon plastic pail in this circumstance.

Table 1
Exposure Guidelines and Regulatory Limits for CO_2.

Limit	*Carbon Dioxide Concentration ppm*	*Oxygen Concentration percent*
TLV-TWA (8-hour time-weighted average)	5000	20.8
PEL (8-hour time-weighted average)	5000	20.8
TLV-STEL (15-minute time-weighted average)	30000	20.2
Immediately Dangerous to Life or Health	40000	19.9

that each is separated by at least one hour and that the TLV-TWA is not exceeded. The TWA intends to minimize the potential for asphyxiation and undue metabolic stress. The STEL is based on studies that examined increased pulmonary ventilation rates. The Documentation of the Threshold Limit Values published by ACGIH indicates that the TWA dates to 1947 and the STEL to 1984.

Permissible Exposure Limit (PEL) is the current regulatory limit in the U.S. enforced by the Occupational Safety and Health Administration (OSHA). The PEL predates the start of OSHA in 1970.

Immediately Dangerous to Life or Health (IDLH), was defined in the NIOSH Standards Completion Project for the purpose of selecting respiratory protection. IDLH represents the presumed maximum concentration from which a person could escape in 30 minutes in the event of respirator failure without experiencing any escape-impairing or irreversible health effects. Table 1 provides these values for carbon dioxide.

In relative terms, the guidelines and regulatory limit for carbon dioxide are generous compared to 10 ppm, which is more typical of exposure limits for airborne contaminants. Regulatory authorities demand that employers anticipate, recognize, evaluate and control exposures to airborne contaminants. Exceedence of workplace exposure limits requires control by ventilation, if possible, and if not, by respiratory protection. This burden ultimately could fall onto the restoration company in the event that it hires a much smaller subcontractor to perform this work.

Assessing CO_2 Exposure

The previous article ("CO_2 Blasting: The Remediation Tool of the Future, "*Cleaning & Restoration*, June 2007) highlighted the difficulty in assessing workplace exposure to CO_2. This article summarized work performed in 2004. At that time, the sensing technology and interpretive electronics focused on assessment of indoor environmental quality. Levels of CO_2 in excess of 2000 ppm would be considered extremely high in these situations. The smallest of the instruments relied on diffusion for entry of the atmosphere into the sensing chamber. These units lacked internal datalogging capability, alarms and built-in pumps. As a result, while in use, they risked damage or destruction from exposure to the blast and ultimately were unable to provide benefit in this application.

The other alternative of the day was the four-gas tester used for entry into confined spaces. Assessment of exposure to CO_2 uses oxygen depression as a surrogate for measuring carbon dioxide. This technique depends on very small decreases in oxygen level and very high alarm set-points relative to the ambient level of oxygen of 20.9 percent. An additional complication in the use of these instruments is baseline shift, which appears to be weather-dependent. Baseline shift can occur in the upward or downward

direction. Baseline shift upward to 21.5 percent and downward to 20.6 percent is observable with some types of oxygen sensors during prolonged operation. Upward baseline shift could completely miss overexposure to CO_2. (Downward shift appears to occur when rain is falling at start-up or on setting of the reference point, if different, and when sunny weather develops later in the day. The converse presumably is true when the weather is sunny at start-up or on setting of the reference point, if different, and when rain develops later in the day.)

Colorimetric detector tubes provide an alternative to the use of instruments. Colorimetric detector tubes were among the first practical means to assess workplace conditions. These tubes use color change due to chemical reaction between the contaminant being measured and the solid material in the tube to indicate concentration. Some types contain a scale that enables direct read-out of concentration based on migration of the color change up the tube.

The critical issue with these tubes is absence of interferences with the chemistry. These products often use the same chemistry to measure different substances. This is analogous to using a sledgehammer to kill an ant. If interfering substances are not present, the readings are attributable only to the substance of interest. If interferences are present, the reliability of the readings is open to question. The solution to this problem and ultimately the way to optimize the utility of these tubes is to measure exposure simultaneously with an interference-free instrument and these tubes in the same environment. (This subject remains to be explored in a future article.)

There are two types of tubes available. The first uses a pump to pull the air through the tube. This is the original iteration of the product. The contaminant reacts with the color-forming chemical as air is drawn up the tube by suction from the pump. This product enables sampling during tasks and provides invaluable information about work activity. Results from these samples are analogous to individual frames from within a movie. If representative of the types of activity sampled, these samples can provide invaluable information about exposure during the overall task.

The other type of tube relies on passive diffusion of the contaminant up the tube. This type of product is a relatively recent innovation. The contaminant diffuses up the tube and reacts with the chemistry to create a color change. The tubes provide the readout in % • hours (1%=10000 ppm). The user divides the reading by the elapsed time in hours to determine the average concentration in parts per million. Obviously, this approach provides a blurred version of the

Figure 3: Dry ice delivery. A delivery rate of 3 lb/min (1.4 kg/min) of dry ice corresponds to production of 25 ft3/min of CO_2 gas by sublimation. This requires a minimum ventilation rate of 5040 ft3/min under ideal conditions to dilute the concentration to 5000 ppm. Displacement ventilation may require less air flow.

movie compared to the sharpness of the frames provided by the detector tube and pump.

To provide the greatest amount of information, the diffusion tubes require regular surveillance to determine the progress of the reading. The more frequent the surveillance vis-à-vis the activity, the more useful the accumulating reading as a tool for learning about the rate of exposure. This technique demands only a low level of surveillance when the accumulating average exposure is well below the exposure limit, and the greatest when the accumulating average exposure exceeds the exposure limit. This technique also smoothes out and therefore provides no information about the spikes that can occur.

Real-World Application

This example concerned a large, wood-framed apartment complex containing four floors and 64 units. A unit on the upper floor experienced a fire, and the entire building suffered extensive water damage during firefighting. The fire deposited soot on interior surfaces of sheathing in the roof space. Extensive mold infestation occurred on drywall and under sheet flooring, as well as carpet underpad throughout the building.

Abrasive blasting using pellets of dry ice was chosen for removal of soot from overhead surfaces on the uppermost floor and for removal of mold from surfaces of wood in other areas. An external contractor performed the abrasive blasting.

At the time of blasting, removal of drywall from walls and ceilings in most of the work area had already occurred, although drywall remained on some walls in some work areas. In open areas there is no hindrance to the flow of the blast jet. However, work in enclosed areas of existing rooms can considerably hinder movement of the blast jet.

The physical properties of gaseous carbon dioxide are important to consider in the context of the work reported here. The carbon atom and the two oxygen atoms in the molecule of CO_2 have a total weight of 44 units (12 + [2 x

Figure 4 (a, b): Work areas. Dry ice blasting in an open work area (shown following abrasive blasting and application of a sealant) offers greater opportunity for control of exposure than work occurring in enclosed geometries. The latter pose difficult ventilation challenges.

16]), whereas an 'average' molecule in air (78 percent nitrogen and 21 percent oxygen) has a molecular weight of 29 units. CO$_2$ gas is 1.5 times as heavy as air of the same temperature. Clouds of pure gas and mixtures of carbon dioxide and air are heavier than air and will sink. In addition, carbon dioxide gas that sublimes from the broken fragments of the pellets of dry ice is colder than the surrounding air. As anyone wearing shorts who opens the door of the refrigerator on a hot summer day quickly learns, cold air flows downward. Thus, cold carbon dioxide gas and the mixture created by the powerful jet of compressed air provided by the compressor generated during overhead abrasive blasting has a powerful incentive to flow downward on a hot day. While that downward flow of cool air may provide relief from the heat of the summer, it creates the potential for overexposure of the operator of the blasting equipment.

This situation is especially problematic where horizontal movement of the cold cloud of gas away from the breathing zone of the operator is hindered by the enclosing geometry created by walls, despite the open channels formed by the ceiling joists.

Spot air samples were obtained using colorimetric detector tubes (Gastec 2LC, carbon dioxide) and the Gastec hand pump. Interference with the reading by other substances was unlikely, given the nature of the work and absence of chemical products. All samples were obtained at the height of the breathing zone. The breathing zone is an imaginary sphere that surrounds the head. Readings obtained in the breathing zone are considered representative of exposure at that moment during that activity. Outdoor temperature was about 16° C (61° F). Indoor temperature was about 25° C (77° F).

Table 2.
Spot Sampling for CO2

Location/Description	Concentration ppm
open air	400
open area on the lawn outside the building atop layer of discarded dry ice pellets spread on the ground, surface approx. 2 m by 3 m (6 ft by 9 ft)	2500
top of bin, open air, low level of dry ice inside	2800
top of bin full of dry ice, stored at the bottom of a stairway, no air motion	2800
top of bin full of dry ice, cross-flow of air (evident in mist trailing from the top of the bin) moving toward an open door	1400 1300
transferring dry ice by scoop into smaller container (20 L, 5 galllon) for transport to the auger unit, up wind position, cross-flow of air evident in mist trailing from the top of the bin	1900 2000
TLV-TWA (8-hour time-weighted average)	5000

Table 2 contains results from spot sampling for CO$_2$.

The concentration of 400 ppm is typical for carbon dioxide in late spring where free movement of the air is occurring. Note that the successive readings include ambient CO$_2$ Exposure due to work activity is normally not considered in isolation from exposure due to ambient CO$_2$ Exposure due to the activity alone is calculable by subtraction of the ambient level from the total.

The sample measured above the layer of discarded pellets of dry ice indicates that significant and needless exposure can occur in deceptive situations. Similarly, dramatic decrease in the concentration of CO$_2$ above a bin of dry ice occurs where horizontal air movement is occurring. The flow of cold gas from the top of the bin entrained in the horizontal flow of air is readily obvious as a moving mist descends to the floor. This simple innovation can dramatically reduce exposure of the blasting helper whose job is to ensure a ready supply of dry ice pellets to the hopper of the metering machine.

Long duration samples were obtained using passive colorimetric dosimeter tubes (Gastec 2D, carbon dioxide).

The readings reflect the sum of contributions from all sources of CO_2 in the environment of the sample. These include atmospheric CO_2, CO_2 in breath exhaled by workers gathered together during breaks and lunch, and CO_2 in exhaust gases emitted from vehicles and the mobile compressor operating in the vicinity of the sample location.

CO_2 Concentrations and Monitoring

Personnel performing and supervising these tests determined that reading the tubes every half hour and recording accumulating exposure provided an effective means for monitoring exposure. To illustrate, an accumulation of 0.25 % • h, which is easily read from the scale on the tube, accumulating in 30 minutes indicates exposure to 5000 ppm of CO_2 (1 % = 10000 ppm).

This approach proved highly beneficial early-on, as these individuals quickly learned about problems created by the enclosed nature of structures in the apartments, such as closets, bathrooms, laundry rooms, and so on in which blasting was occurring. This aggressive gathering of information led to intervention to create horizontal air flow at ceiling level, so as to force the gas mixture along the channels formed by the ceiling joists and away from the blaster. This approach led to some success, as measured by reduction in exposure of the blaster.

Frequent recording of accumulating exposure provides the basis for determining exposure during the actual work period, rather than the full work shift. This can provide valuable information consistent with the regulatory limits and guidelines contained in Table 1. The data obtained during this trial suggest that significant overexposure to carbon dioxide can occur during this work.

Safety Issues

As would be expected, the abrasive blaster experiences considerably greater exposure than the blasting helper. The exposure of the blasting helper is considerably greater than that predicted by spot samples. This suggests that the blasting helper experienced contact with an environment similar to the blaster. This is consistent with remaining nearby to ensure that blasting did not stop for lack of supply of pellets to the metering machine.

Results from this investigation indicate that significant exceedence of regulatory limits and guidelines for CO_2 can occur during abrasive blasting using dry ice pellets. This will necessitate the following actions:

- investigation to determine exposure more precisely
- investigation to determine situations in which exposure is controllable through ventilation and in which it is not
- use of respiratory protection in the event that ventilation is unable to control exposure

This situation is complicated by the existence of small subcontractors who specialize in this work and may operate as sole practitioners. These companies rely on assistance through labor provided by the restoration company or through a pick-up labor pool. Ultimately, the restoration company is responsible for the actions, conduct of work and protection of these workers. This means that the restoration company must take an active role in the ventilation of these worksites and the work areas where abrasive blasting will occur. This is especially the case when the contractor appears on the site with the blasting equipment and no ventilation equipment or respiratory protection.

Even the latter situation is more complex than is the case with most other substances. Unlike the situation for many other workplace contaminants, the only type of respiratory protection approved for use against overexposure to carbon dioxide is an air supplying respirator. There is no cartridge capable of providing protection against overexposure to CO_2. PAPRs (powered air-purifying respirators), which are almost universal in their application for other types of restoration work, would be unsuitable in this application unless rated for use with a hose instead of cartridges. There is, an obligation to assess the quality of air provided through breathing air systems. As a result, there is a powerful incentive to determine the levels and modes of exposure and to learn how to control them through the use of ventilation.

Air-supplying respirators range from a simple, open-ended hose connected to the facepiece, to air supplied by a blower through a hose to the facepiece, to compressed air supplied to the facepiece from cylinders or the compressor that supplies the abrasive blasting feed unit.

The concern with the open-ended hose, blower supplied hose or compressor-supplied air line is the quality of air delivered. This could be contaminated with CO_2 or other

Figure 5: Monitoring exposure to CO_2 using passive dosimeter tubes. Passive dosimeter tubes provide an inexpensive way to monitor exposure to CO_2 during abrasive blasting using dry ice. The change in color indicates exposure in % • hours (1 % = 10000 ppm) on the scale printed on the tube. This method can provide considerable information when regular periodic observation of the tube and recordkeeping occur during the work.

contaminants. The source of air for these supplies must come from outside the containment and remote from the discharge of the negative airmovers. There is no real-time method to establish the quality of the air provided by these sources other than testing performed by a knowledgeable individual who is on site, and has appropriate equipment and training.

The intake of mobile compressors is located under the shroud. The air provided by these units is subject to contamination from exhaust leakage from the exhaust system of the engine, also located under the shroud, and less significantly, to exhaust gases in the area from this and other mobile equipment and vehicles trapped by confining geometry created by structures and aided by cool or cold weather.

Compressed air provided in cylinders is potentially the most reliable in composition. Even this product, unfortunately, is not fault-proof. A number of individuals have died through use of contaminated or mislabelled compressed air sold for breathing purposes.

The stakes in this situation are quite high, but hardly without hope. The abrasive blasting technique involves supplying large volumes of air at high velocity that expands six- to seven-fold in volume. Compressed air that continues to emit from the blasting gun when the flow of dry ice ceases greatly aids in controlling exposure to CO_2. Contained areas also have considerable volumetric flows produced by exhausting and recirculating negative air units. As a result, excess carbon dioxide clears quickly or is rapidly diluted.

Colorimetric detector and passive dosimeter tubes have an obvious place in establishing and controlling the exposure of individuals to carbon dioxide during abrasive blasting using dry ice. This technology, does however, demand the attention of supervisors committed to active intervention to obtain and act upon results through harnessing ventilation air flow. ■

Acknowledgement

Special thanks are due to Jim Short of On Side Restoration Services Ltd., Vancouver, British Columbia for for making available the opportunity described here. Special thanks are also due to On Side site personnel Donn Crawford and Bill Wright, and to Peter Beaupré of ProActive Personnel, who collected the samples in a highly efficient and effective manner.

Neil McManus, CIH, ROH, CSP, currently with NorthWest Occupational Health & Safety in North Vancouver, BC (www.nwohs.com), is a practicing industrial hygienist with over 25 years of broad-spectrum service “in the trenches”. . He is a Fellow of the American Industrial Hygiene Association, and one of the few members to have chaired the Confined Space Committee of AIHA twice. He also is the Chair of the ANSI Z9.9 Subcommittee on portable ventilation systems and created the first draft of the proposed standard. Mr. McManus also has an M.Sc. in radiation biology and an M.Eng. in occupational health and safety engineering, as well as a B.Sc. in chemistry and a B.Ed. specializing in chemistry and biology.

He has written numerous articles and short publications, and is the author of Safety and Health in Confined Spaces, Portable Ventilation Systems Handbook, The Confined Space Training Program, and coauthor of The Hazcom Training Program and The WHMIS Training Program.

Reprinted with permission from the November 2007
issue of *Cleaning & Restoration* magazine,
published by the Restoration Industry Association, © 2007