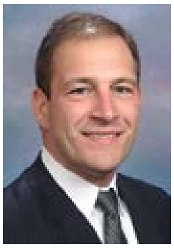
SAFETY SOLUTIONS

CARBON MONOXIDE



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Carbon monoxide is one of the more pervasive hazards in construction. It's nearly impossible to imagine a job site without a heater, generator, truck, or other piece of equipment using an internal combustion engine. Equally important as the work site, pedestrians can also be affected by carbon monoxide when working is being performed in occupied structures. Beyond the work site, our homes may contain a number of sources of the deadly gas that kills hundreds and injures thousands every year. If we apply some very simple "best practices" to our job sites and our homes, we can see that carbon monoxide is a very controllable hazard.

Carbon monoxide (CO) is a tasteless, odorless, and colorless gas which is created in any combustion reaction that introduces carbon (C) to oxygen (O). On the modern concrete restoration and repair project, CO originates from two primary sources: engines and heaters (Fig. 1). Any internal combustion engine (ICE) creates or has the potential to create CO. Gasoline engines produce the greatest exhaust concentration of CO compared to propane or diesel (the three most commonly used fuels for construction equipment). A common misconception is that diesel or propane engines do not produce CO; that couldn't be farther from the truth. Although they produce considerably less CO than gasoline, diesel and propane combustion reactions do create CO. Furthermore, the exhaust concentration of CO can vary depending on how well a piece of equipment is maintained. Something as simple as a clogged air filter will alter the exhaust concentration of CO. Additionally, a temporary heater caked with soot (carbon buildup) in the combustion chamber will create more CO than the same heater when new.

Fig. 1: A temporary heater is common on a construction site when working during cold weather

Ideally, a contractor should evaluate means and methods to eliminate the emission of CO into the work area. This may be accomplished by switching to tools and equipment that are powered by electricity. This is easily accomplished with smaller tools such as power saws, light-duty pressure washers, low-volume paint sprayers, and small concrete mixers. However, it is inevitable that an engine will at some point be used. After all, a contractor is often required to use a generator to supply electricity. Furthermore, concrete buggies, water blasters, motor vehicles, as well as a number of other engine power units are very common on repair projects. When this is the case, a contractor must initiate a CO control program.

The first step in controlling CO emissions is knowing the concentration of CO in the work area and the acceptable level of CO to which an employee may be exposed. For the purpose of simplicity, this article will focus on OSHA's Permissible Exposure Limit (PEL) to CO, which is 50 ppm (parts per million). There are a number of different organizations that regulate employee exposure to CO (Fig. 2). The acceptable level of exposure will vary based on location or regulation. OSHA's CO PEL of 50 ppm is an 8-hour time-weighted average (TWA) exposure limit, meaning that over the course of an 8-hour shift, an employee may be exposed to variable concentrations as long as the overall average exposure does not exceed 50 ppm.

Organization	Limit Definition	Abbreviation	Limit
Occupational Safety and Health Administration (OSHA)	Permissible exposure limit	PEL	50 ppm
National Institute for Occupational Safety and Health (NIOSH)	Recommended exposure limit	REL	35 ppm
National Institute for Occupational Safety and Health (NIOSH)	Ceiling	—	200 ppm
National Institute for Occupational Safety and Health (NIOSH)	Immediately dangerous to life and health	IDLH	1200 ppm
American Conference of Governmental Industrial Hygienists (ACGIH)	Threshold limit value	TLV	25 ppm
Centers for Disease Control and Prevention (CDC)	Lethal concentration low	Lclo	4000 ppm
Health & Safety Ontario	Time-weighted average (8 hours)	TWA	25 ppm
Health & Safety Ontario	Short-term exposure limit (15 minutes)	STEL	100 ppm

Fig. 2: CO exposure regulations and limits by various organizations

For example, if an employee is exposed to a constant level of CO of 100 ppm for 1 hour and no other exposure for the remainder of the 8-hour shift, the overall average exposure would be equal to 12.5 ppm (100 ppm/8 hours = 12.5 ppm TWA), which is below OSHA's PEL and thus allowable. However, an employer must keep in mind that the National Institute for Occupational Safety and Health (NIOSH) has set an employee exposure ceiling of 200 ppm. This is a maximum level to which an employee can be exposed regardless of the length of time. A 201 ppm exposure for 1 second would be in violation of this regulation.

Determining the level of CO exposure is simple. A number of gas meters are available to measure the level of CO. Some are diffusion models which require the device to be exposed to the atmosphere (Fig. 3). Some have pumps that allow a user to lower a tube into a confined space to sample the atmosphere remotely, and range in size from a small cell phone to a cinder-block-sized device. They can be purchased as a single gas meter or a multi gas meter that can sample a number of gases and contaminants. Higher-end models will log data which can be uploaded to a computer for analysis and, in some cases, do so wirelessly via infrared or Bluetooth technology. The simplest way to choose a CO gas meter is to speak with a vendor of such devices. Explain to them what you are trying to accomplish and they should be able to supply you with a device that suits your needs. A single gas diffusion model is the easiest to use. A multi-gas data logger with Bluetooth communication would be the most complicated. Under no circumstances should a contractor use a CO detector designed for household use. Household CO detectors calculate the exposure as a percentage of carboxyhemoglobin (COHb) saturation in blood, not real-time ppm.

Once an employer recognizes the exposure, understands the limits, and acquires an appropriate CO gas meter, it is time to sample. While in fresh air, turn the gas meter on. Most models self-calibrate but only do so in fresh air. When the meter is finished calibrating, you may introduce it into the environment that may contain CO. It is important to test inside *and* outside the work area. CO that seeps into an occupied area is not only dangerous to the occupants but also could trigger a response by the fire department if building CO detectors are triggered. On top of that, there could be associated fines and penalties, not to mention bad publicity. Most meters will have a screen which displays the actual level of CO. Most meters will begin to sound alarms of varying intensity as the exposure climbs. Usually the first level at which an alarm sounds is 25 ppm (NIOSH) or 35 ppm (ACGIH). A more intense alarm will sound at 50 ppm (OSHA). The most intense alarm will sound when levels are above 100 ppm the short-term exposure limit (STEL). Again, these alarm levels can vary from device to device and many of the devices on the market can be programmed to specific criteria.

Once an atmospheric sample confirms the presence of CO in the work area, the employer must initiate application of the Hierarchy of Hazard Control. In the Hierarchy of Hazard Control, the first acceptable step in controlling or eliminating the exposure is through Engineering Controls. As previously stated, the best Engineering Control available is to remove the process that creates CO. However, this isn't always possible. If removal of the CO source is not possible, a contractor could isolate and ventilate the source. This is accomplished by erecting a box of sorts in which a generator or pressure washer can be placed, and running a manifold from the exhaust to a safe location outside the work area or directly into the building ventilation system. The next best possible engineering control is general ventilation of the work area to displace or dilute the CO. It is often asked, "How much ventilation is required?" Unfortunately, there is no simple answer to that question. It is based on the amount of CO generated versus the volume of the work area. A single floor fan is almost never enough in an enclosed space. To be safe, the contractor needs to monitor the work area with CO meters to determine how much ventilation is necessary. The vapor density of CO is 0.97, which is slightly lighter than air. Pockets of CO will not dissipate quickly without force acting on them. They must be moved by airflow. Remember, for every fan pushing air into the work area, at least one fan is needed to pull air out of the work area. Without positive *and* negative pressure, air and CO will be exhausted from the work area. Once again, building occupants must be considered when general ventilation is used. The CO must be exhausted to a safe location.

After Engineering Controls have been exhausted, Administrative Controls are implemented. A simple Administrative

Fig. 3: Diffusion-type CO detector worn on employee vest

CARBON MONOXIDE LEVELS AND RISKS

CO Level	Action
1-4ppm	Normal levels in human tissues produced by body.
3-7ppm	6% increase in the rate of admission in hospitals of non-elderly for asthma. (Sheppard-1999)
5-6ppm	Significant risk of low birth rate if exposed during last trimester (Ritz & Yu-1999)
5ppm	1st visual display on NSI 3000 Low Level CO Monitor
9ppm	ASHRAE standard for allowable spillage from vented appliances, indoors, for 8 hours exposure daily. EPA standard for outdoors for 8 hours and a maximum 3 times per year. (Clean Air Act)
10ppm	Outdoor level of CO found associated with a significant increase in heart disease deaths and hospital admissions for congestive heart failure. (JAMA, Penny) Ist ambient level occupants should be notified-NCI Protocol
15-20ppm	First level World Health Organization lists as causing impaired performance, decrease in exercise time and vigilance 1st Alarm level for NSI 3000 Low Level CO Monitor-5 minutes
25ppm	Maximum allowable in a Parking Garage (International Mechanical Code)
27ppm	21% increase in cardio respiratory complaints (Kurt-1978)
30ppm	Earliest onset of exercise induced angina (World Health Organization) 1st visual display on UL2034 approved CO Alarm-Must not alarm before 30 days
35ppm	US NIOSH recommended 8 hour maximum workplace exposure EPA standard for outdoors for 1 hour and a maximum of 1 time per year Level many fire departments wear breathing apparatus before entering 2nd ambient level occupants should be notified and space ventilated 2nd Alarm level for NSI 3000 Low Level Monitor-5 minutes

CO Level	Action
50ppm	US OSHA recommended 8 hour maximum workplace exposure Maximum NCI level for Unvented appliances
70ppm	1st Alarm level of UL2034 approved CO Alarms- 2-4 hours 3rd Alarm level for NSI 3000 - 30 seconds NSI 3000 Low Level Monitor cannot be silenced by reset button
100ppm	Maximum NCI CO level during run cycle in all vented appliances(stable) Maximum NCI CO for all oil appliances
200ppm	First listed level(established in 1930) healthy adults will have symptoms-headaches, nausea NIOSH & OSHA recommend evacuation of workplace Maximum "Air Free" CO for vented water heater and unvented heaters (ANSI Z21) UL approved alarms must sound between 30 – 60 minutes(NSI 3000 – 30 seconds)
400ppm	Healthy adults will have headaches within 1-2 hours. Life threatening after 3 hours Maximum "Air Free" CO in all vented heating appliances (ANSI Z21) Maximum EPA levels for industrial flue exhaust UL Alarms must alarm within 15 minutes (NSI 3000 – 30 seconds) Maximum recommended light-off CO for all appliances – NCI (except oil)
800ppm	Healthy adults will have nausea, dizziness, convulsions within 45 minutes. Unconscious within 2 hours then Death(established in 1930) Maximum "Air Free" CO for unvented gas ovens (ANSI Z21)
800ppm+	Death in less than one hour
2000ppm	EPA standard for new vehicle emissions
3000ppm+	Typical emissions from propane lift trucks, gasoline powered tools etc. Death in less than 30 minutes.

NCI™ National Comfort Institute, Inc.

Fig. 4: Carbon monoxide levels and risks (reprinted with permission from the National Comfort Institute, Inc.)

Control is relocation of CO-generating equipment. Does the pressure washer or generator need to be in the work area? Can you place the equipment outside of the work area? When working in enclosed areas, is there a ventilation system that the building owner turns off at night when nobody is parking in the garage? Can that system be left on during the construction shift? While waiting to dump a load of concrete from a concrete buggy, the engine can be idled down to drastically reduce the amount of CO created. By limiting the number of buggies (or any type of equipment) running in the work area at any given time, an employer will find that the CO exposure is greatly reduced. When experimenting with Engineering and Administrative Controls, the possibilities are endless; be creative. The bottom-line solution is to limit the introduction of CO into the work area and get it out as soon as possible when it does appear.

The final step in the Hierarchy of Hazard Control applied to CO exposure is Personal Protective Equipment (PPE). Typically, respiratory protection from CO exposure is not feasible but not impossible. It requires the use of a supplied air respirator, as a negative-pressure filtering face piece such as a dust mask or half-mask respirator cannot be effectively used. A supplied air respirator can cost upwards of $2000 per worker, if not more. Multiply that by the number of workers and factor in maintenance and training, not to mention the effect of having multiple workers tethered to air lines, all trying to work in a small area. You can see how it is possible but perhaps not feasible.

As with all safety practices, employees must be trained how to protect themselves from a hazard; in this case, CO. Training should instruct an employee how to apply the Hierarchy of Hazard Control, how to use and understand CO meter readings, the health effects of CO poisoning (Fig. 4), and emergency procedures to follow should an employee be overexposed to CO. Of course, training should be documented and retained for *at least* the duration of that employee's tenure.

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