Worker Protection

Welding Safety

Assessing and controlling exposure to hexavalent chromium

By Jerome E. Spear

PURSUANT TO A COURT ORDER, OSHA issued a final rule on Feb. 28, 2006, that addresses occupational exposure to hexavalent chromium [Cr(VI)]. OSHA determined that the rule was necessary to reduce significant health risks due to Cr(VI) exposure. Certain Cr(VI) compounds have been found to cause lung cancer and nasal cancer in humans. Inhaling relatively high concentrations of Cr(VI) can also cause a wide range of other health effects (e.g., runny nose, sneezing, itching, nosebleeds, ulcers, holes in the nasal septum). Ingestion of very high doses of Cr(VI) can cause kidney and liver damage, nausea, irritation of the gastrointestinal tract, stomach ulcers, convulsions and death. Dermal exposures may cause skin ulcers or allergic reactions.

Activities with the potential for Cr(VI) exposure include:

- production and use of chromium metal and chromium metal alloys;
- chromium electroplating;
- welding of metals containing chromium such as stainless steel or other high chromium steels, or chromium coatings;
- production and use of Cr(VI)-containing compounds [such as Cr(VI) pigments, Cr(VI) catalysts and chromic acid];
- production of chromium-containing pesticides;
- painting activities involving the application of strontium chromate coatings to aerospace parts;
- removal of lead chromate.

According to OSHA, a total of 380,000 workers are exposed to Cr(VI). However, welders represent nearly half of the workers covered by OSHA's standard. This article summarizes major provisions of OSHA's Cr(VI) standards, the nature of Cr(VI) in welding fumes, common welding processes and fume generation rates (FGR), factors for Cr(VI) exposure from welding, exposure monitoring strategies and considerations for feasible engineering controls.

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Major Provisions of OSHA's Cr(VI) Standards

OSHA issued separate but similar standards for general industry, construction and shipyard sectors. Major provisions are summarized in Table 1 (p. 24).

Cr(VI) in Welding Fumes

Chromium has been used commercially in the U.S. for more than 100 years. It occurs mainly in three forms, described by its valence state. Metallic chromium [Cr(0)] is a steel-gray solid with a high melting point that is used to make steel and other alloys. Chromium metal does not occur naturally but is produced from chrome ore.

Trivalent chromium [Cr(III)] occurs naturally in rocks, soil, plants, animals and volcanic emissions. Cr(III) is used industrially as brick lining for high-temperature industrial furnaces and to make metals, metal alloys and chemical compounds.

Cr(VI) occurs through the oxidation of chromium compounds with lower valence states. It is considered the greatest occupational and environmental health concern as it is the most toxic. Other valence states are unstable so they are less common. They will most likely be quickly converted to either Cr(III) or Cr(VI) (OSHA, 2006).

Chromium metal is found in stainless steel and many low-alloy materials, electrodes and filler materials. The chromium present in electrodes, welding wires and base materials is in the form of Cr(0). Therefore, welders do not ordinarily work with materials containing Cr(VI). However, the high temperatures created by welding oxidize chromium in steel to the hexavalent state. The majority of the chromium found in welding fume is typically in the form of Cr_2O_3 and complex compounds of Cr(III). Some metal oxides in hexavalent form are also in the form of CrO_3. Pure CrO_3 is extremely unstable; however, other metal oxides, especially alkali metals, tend to stabilize Cr(VI) compounds (Fiore, 2006).

Welding fume is a complex mixture of metal oxides. Fumes from some processes may also include fluorides. The predominant metal fume generated from mild, low-alloy and stainless steel welding is iron oxide. Oxides of manganese are also typically present. Fumes from stainless steel and some low-alloy steel welding also typically contain chromium and nickel. Chromium is usually not intentionally added to mild steels or mild steel consumables, yet due to the use of scrap steel in the steel production process, some low levels of chromium metal may be present. However, in most mild steel welding, the exposure limits for fume constituents other than Cr(VI) (such as manganese) will be exceeded before the PEL for Cr(VI) is reached (Fiore, 2006).

Common Welding Processes & Fume Generation Rates

Different welding processes have different FGR. One must have a basic understanding of these processes and their relative FGR in order to assess the risk of exposures to welding fumes and gases. Following is an overview of common welding processes and their relative FGR (Spear, 2004).

Photo 1: Shielded metal arc welding, down-flat welding position.

•**Shielded metal arc welding** (SMAW or "stick welding") is commonly used for mild steel, low-alloy steel and stainless steel welding. In SMAW, the electrode is held manually, and the electric arc flows between the electrode and the base metal. The electrode is covered with a flux material, which provides a shielding gas for the weld to help minimize impurities. The electrode is consumed in the process, and the filler metal contributes to the weld. SMAW can produce high levels of metal fume and fluoride exposure; however, SMAW is considered to have little potential for generating ozone, nitric oxide and nitrogen dioxide gases.

Photo 2: Gas metal arc welding.

•**Gas metal arc welding** (GMAW) is also known as metal inert gas (MIG) welding. GMAW is typically used for most types of metal and is faster than SMAW. This process involves the flow of an electric arc between the base metal and a continuously spool-fed solid-core consumable electrode. Shielding gas is supplied externally, and the electrode has no flux coating or core. Although GMAW requires a higher electrical current than SMAW, it produces fewer fumes since the electrode has no fluxing agents. However, due to the intense current levels, GMAW produces significant levels of ozone, nitrogen oxide and nitrogen dioxide gases.

•**Flux-cored arc welding** (FCAW) is commonly used for mild steel, low-alloy steel and stainless steel welding. This process has similarities to both SMAW and GMAW. The consumable electrode is continuously fed from a spool and an electric arc flows between the electrode and base metal. The electrode wire has a central core containing fluxing agents and additional shielding gas may be supplied externally. This process generates a substantial amount of fumes due to the high electrical currents and the flux-cored electrode. However, FCAW generates little ozone, nitric oxide and nitrogen dioxide gases.

Photo 3: Flux-cored arc welding, down-flat welding position.

•**Gas tungsten arc welding** (GTAW) is also known as tungsten inert gas (TIG) welding. GTAW is used on metals such as aluminum, magnesium, mild steel, stainless steel, brass, silver and copper-nickel alloys. This technique uses a nonconsumable tungsten electrode. The filler metal is fed manually and the shielding gas is supplied externally. High electrical currents are used, which causes this process to produce significant levels of ozone, nitric oxide and nitrogen dioxide gases. However, GTAW produces very few fumes.

Photo 4: Gas tungsten arc welding.

•**Submerged arc welding** (SAW) is a common welding process used to weld thick plates of mild steel and low-alloy steels. In this process, the electric arc flows between the base metal and a consumable wire electrode; however, the arc is not visible since it is submerged under flux material. This flux material keeps the fumes low since the arc is not visible. Little ozone, nitric oxide and nitrogen dioxide gases are generated. The major potential airborne hazard with SAW is the fluoride compounds generated from the flux material.

Photo 5: Submerged arc welding.

Fume Generation Rates

The primary sources of information when determining the components likely to be in the fume is the MSDS and/or the manufacturer's technical data sheet of the consumable electrode/wire. About 90% to 95% of the fumes are generated from the filler metal and flux coating/core of consumable electrodes (Lyttle, 2004).

Since the base metal weld pool is much cooler than the electrode tip, the base metal contributes only a minor amount of the total fumes. However, the base metal may be a significant factor of the fume exposure if the metal or surface residue contains a highly toxic substance (e.g., chromate-containing coatings, lead-based paint).

In addition to the welding process, studies have

Abstract: *This article summarizes major provisions of OSHA's Cr(VI) standards, the nature of Cr(VI) in welding fumes, common welding processes and fume generation rates, factors for Cr(VI) exposure from welding, exposure monitoring strategies and considerations for feasible engineering controls.*

Table 1

Summary of Major Provisions of OSHA's Final Rule for Hexavalent Chromium

Section	Provisions	Industry sector
Scope	All exposures to Cr(VI) in all forms and compounds. Excludes: •Pesticide application •Exposures to Portland cement •Objective data demonstrates exposures are below 0.5 µg/m^3	General industry, construction and shipyards (including marine terminals and longshoring)
Permissible exposure limit (PEL)	5 µg/m^3	General industry, construction and shipyards
Action level (AL)	2.5 µg/m^3	General industry, construction and shipyards
Exposure determination	May use exposure monitoring data and/or objective data.	General industry, construction and shipyards
Exposure monitoring	If the scheduled exposure monitoring option is used to determine exposure, exposure monitoring must be performed: •Initially •Every 3 months if ≥ PEL •Every 6 months if ≥ AL •Discontinue if < AL (and subsequent exposure monitoring taken at least 7 days later confirms exposure < AL) •Additional monitoring must be performed when there is a change that may result in new or additional exposures to Cr(VI)	General industry, construction and shipyards
Employee notification	Results of the exposure determination must be posted (or each affected employee must be notified in writing) within 15 working days. Must describe the corrective action being taken. Results of the exposure determination must be posted (or each affected employee must be notified in writing) within 5 working days. Must describe the corrective action being taken.	General industry Construction and shipyards
Regulated areas	Regulated areas must be demarcated when reasonably expected to be in excess of the PEL.	General industry
Methods of compliance	Must use feasible engineering controls to reduce exposure to or below the PEL. When infeasible to reduce exposures to or below the PEL, must reduce to the lowest achievable levels and supplement with respiratory protection. For a process or task where employees are not exposed to Cr(VI) for 30 or more days per 12 consecutive months, the requirement to implement engineering and work practice controls does not apply. Painting of aircraft or large aircraft parts, engineering controls must be used to reduce exposures below 25 µg/m^3 and supplement engineering controls with respiratory protection. Job rotation is prohibited to achieve compliance with the PEL.	General industry, construction and shipyards General industry, construction and shipyards General industry General industry, construction and shipyards
Protective work clothing and equipment	Must be provided to employees where skin or eye contact to Cr(VI) is present or likely. *(Note: According to OSHA, skin and eye hazards are minute for typical welding operations).*	General industry, construction and shipyards
Hygiene areas and practices	Change rooms and wash facilities are required when protective clothing and equipment is required. Certain activities (e.g., eating, drinking, smoking, chewing tobacco or gum, or applying cosmetics) are prohibited in areas where skin or eye contact with Cr(VI) occurs.	General industry, construction and shipyards General industry, construction and shipyards
Housekeeping	Keep surfaces free as practicable of accumulations of Cr(VI) and clean spills and releases of Cr(VI) materials promptly.	General industry only
Medical surveillance	Medical surveillance (initially and annually) for employees who: •Are exposed to Cr(VI) at or above the AL for 30 or more days a year. •Experience signs or symptoms of the adverse health effects associated with Cr(VI) exposure. •Are exposed in an emergency.	General industry, construction and shipyards
Communication of Cr(VI) hazards to employees	Employee training must be performed.	General industry, construction and shipyards
Recordkeeping	The following documents must be maintained: •Air monitoring data •Historical monitoring data •Objective data •Medical surveillance records	General industry, construction and shipyards
Dates	Compliance with all sections (except for engineering controls) must be achieved by Nov. 27, 2006. Employers with 19 or fewer employees have until May 30, 2007 to comply. Compliance with engineering controls must be achieved by May 31, 2010.	General industry, construction and shipyards General industry, construction and shipyards

shown that FGR is influenced by the following factors (Spear, 2004):

•Electrical current. In general, FGR is exponentially proportional to the current.

•Arc voltage. FGR generally increases when the arc voltage increases.

•Electrode diameter. The electrode diameter has a modest effect on FGR because of the differences in voltage and current. In general, a small diameter electrode has a higher FGR than a large diameter electrode, all else remaining equal. However, there is usually a step up in electrical current when using larger diameter electrodes.

•Electrode angle. The angle of the electrode to the workpiece has a slight (but unpredictable) effect on FGR.

•Shielding gas. In gas-shielding arc welding, the FGR tends to be greater when 100% carbon dioxide (CO_2), as compared to argon, is used as the shielding gas.

•Speed of welding. As the welding rate increases, the FGR increases.

•Steady/current pulsed current welding. Technology has advanced to power sources that have pulsing capabilities. Studies have shown that using a pulsing current during welding generates fewer fumes than under a steady current welding process.

In general, FCAW produces the greatest FGR (for mild steel welding), followed closely by SMAW. However, when welding chromium-containing steel, Cr(VI) contained in the fumes generated from SMAW tends to be greater than Cr(VI) generated from FCAW. Alkali metals, such as sodium and potassium, stabilize Cr(VI) and are often SMAW electrode coatings and also may be present in FCAW flux (Fiore, 2006), which may explain why Cr(VI) concentrations from SMAW operations are often higher than those from FCAW. GMAW tends to have a moderate relative FGR. GTAW and SAW are inherently low fume-generating processes.

Other ancillary processes (such as air arc gouging and plasma arc cutting) can also generate a significant amount of fumes due to the high electrical current and arc voltage associated with them. Potential exposures to the operator and other personnel in the work area can be significant from such processes, especially in enclosed and confined spaces. Few research studies are available that examine potential Cr(VI) exposure associated with air arc gouging and plasma-cutting operations.

Exposure Monitoring

OSHA requires employers to determine Cr(VI) exposures to employees. This can be achieved using initial and periodic exposure monitoring and/or objective data. If objective data are used, they must reflect workplace conditions closely resembling the processes, types of material, control methods, work practices and environmental conditions.

If the scheduled monitoring option is used, monitoring must be performed initially and periodically. For exposures determined to be at or above OSHA's PEL of 5 $\mu g/m^3$ (8-hour TWA), monitoring must be performed at least every 3 months. For exposures determined to be at or above OSHA's action level of 2.5 $\mu g/m^3$ (8-hour TWA), monitoring must be performed every 6 months. Additionally, exposure monitoring must be performed whenever changes made to work processes or materials may result in new or additional exposures to Cr(VI).

Exposure Factors

Welding fume exposure tends to be highly variable due to several factors that should be considered when assessing potential exposures to Cr(VI). Based on the author's experience, the primary Cr(VI) exposure factors are as follows:

•**Welding process.** As noted, the welding process used has a significant effect on FGR.

•**Chromium content and flux ingredients in the consumable.** Stainless steel and chromium alloys typically contain between 11.5% and 30% chromium, by weight. Obviously, as the chromium content in the consumable increases, the amount of Cr(VI) emitted from the welding process will likely increase. Other ingredients in the electrode also may have some affect in stabilizing Cr(VI), resulting in higher Cr(VI) concentrations.

•**Chromate coatings on base material.** Chromates may be contained in pigments in coatings and paints to provide corrosion-resistant properties. When performing repair work on painted structures, be sure to analyze bulk samples of the coating to ensure that the paint or coating does not contain chromates.

•**Welding rate.** High welding rates increase the fumes generated. However, information pertaining to an individual's welding or production rate is seldom accurately and consistently measured when monitoring exposure. Consider using an arc timer to accurately collect and document actual welding time; this information may also prove useful in explaining unusually high or low exposure monitoring results and/or in better categorizing similar exposure groups (SEGs).

•**Relative welding position.** The welding position plays a significant role in exposure primarily due to the plume's path of travel. Welding in a down-flat position (such as a tank bottom or where the workpiece is positioned below the welder's waist) tends to present the highest potential fume exposures. Welding in a horizontal direction (such as when welding the girth seam of a tank) can also create relatively high fume exposures depending on the plume's path of travel in relation to the welder's breathing zone. Welding in a vertical direction (such as a vertical seam of a tank shell) tends to have the lowest potential fume exposure since the welder's breathing zone is typically not in the plume's travel path since the plume stays close to the heat-affected zone as it naturally rises.

•**Local exhaust ventilation (LEV).** It has been shown that the use of LEV can lower fume exposure. However, the effectiveness of LEV depends on several factors, including work practices and proper maintenance of the LEV units. (The use of LEV for fume control is discussed on p. 28.)

•**Welding environment** (inside or enclosed space). Welding inside buildings or an enclosed space presents the potential for an accumulation of fumes that may increase exposures to the welder as well as to other personnel inside the building or enclosed space.

•**General/dilution ventilation and natural air currents.** Although general/dilution ventilation is

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often used when welding indoors or inside enclosed spaces, local exhaust ventilation is preferred for fume control since it attempts to capture fumes at the source. The effect on the plume's travel path is unpredictable when using only general ventilation.

• **Other welding (or ancillary/allied processes) performed in the area.** The amount of welding or other related activities (such as air arc gouging and/or plasma cutting) may affect potential exposures to welding fumes and Cr(VI) inside enclosed spaces, especially if the space is poorly ventilated.

OSHA Method ID-215

OSHA requires that exposure monitoring be performed using a sampling method that is at least ±25% accurate. OSHA specifically references exposure monitoring to be performed using OSHA Method ID-215 (or equivalent). This method involves collecting an air sample onto a 5.0 micron polyvinyl chloride (PVC) membrane mounted in a 37-mm or 25-mm polystyrene cassette holder. The recommended flow rate is 2.0 liters per minute for 480 minutes (i.e., 960 liters). NIOSH Analytical Method 7605 is comparable to OSHA Method ID-215.

Cr(VI) samples collected on PVC from welding operations do not require field stabilization as with Cr(VI) samples collected from other operations (such as chromium plating samples). However, Cr(VI) samples collected from welding operations must be analyzed within 8 days of sampling in accordance with OSHA ID-215 to minimize the effects caused by the interaction of Fe(II) and Cr(VI) to form Cr(III). Storage stability tests showed that these samples were not stable for longer periods of time. Studies indicate that the loss exceeded 10% after 7 days.

Significant amounts of Cr(VI) are often deposited on the interior walls of sampling cassettes. Tests showed that Cr(VI) equivalent to 0% to 123% of the amounts found on the PVC filter were present on the interior walls of cassettes. Therefore, it is now routine analytical procedure for the lab analyst to wipe interior walls of sampling cassettes for all metal samples.

Sample Media Location

OSHA ID-215 does not address sample location or position other than to state that the cassette should be in a vertical position with the inlet facing down. The location of sample media during welding fume sampling has been a subject of discussion for several years.

Goller and Paik (1985) describe the results of simultaneously air sampling with collection sites at four locations: the welder's left front shoulder, right front shoulder, front chest and inside the helmet. A total of 40 sets of four samples was collected on each welder at each location. The welders monitored were using FCAW while building railroad locomotives. Goller and Paik conclude that fume concentrations inside the helmet were 36% to 71% of those measured outside the helmet, which supports the protocol of sampling inside the helmet recommended by the American Welding Society (AWS).

Liu, Wong, Quinlan, et al. (1995) showed that the relationship between sample location and measured contaminant may not be as clear as once believed. A total of 20 volunteers performing SMAW in a controlled laboratory environment were monitored. Twenty-three sample sets were collected from the breathing zones inside the helmets and at the shoulders of the participants, who welded inside a 506 ft^3 test chamber. Little difference was found between fume concentrations inside the helmet and those outside the helmet.

More recently, Harris, Longo, DePasquale, et al. (2005) support the findings of Liu, et al. (1995). As part of a larger study, Harris, et al. examined airborne concentrations of manganese and total fume during SMAW inside a 2,194.5 ft^3 test chamber for different electrodes and different ventilation rates. The researchers concluded that in more restricted work environments (such as fabricating structures that include enclosed or restricted spaces such as ships, tubs, barges, petroleum and chemical processing equipment, or offshore platforms), fume concentration distribution may be relatively uniform and with little difference between concentrations inside and outside the helmet.

Based on the results of the cited studies, the fume concentrations outside the helmet have the potential to be higher than fume concentrations inside the helmet when welding outdoors or in other nonenclosed work environments, whereas the difference in fume concentrations appears to have little difference when welding in more restricted environments.

Sampling Variability

Two types of variations should be considered when conducting exposure monitoring: 1) variations due to sampling and analytical errors (SAE) and 2) variations due to the workplace or environment. OSHA requires that the sampling method used be at least ±25% accurate.

The SAE for Cr(VI) collected on PVC membranes from welding operations and analyzed in accordance with a method based on OSHA ID-215 is ±12.9%, which complies with OSHA's requirement. However, variations due to the workplace or environment are considerably larger than SAEs.

If objective data are used, OSHA requires that the conditions closely resemble the workplace conditions that the data represent. This attempts to address the environmental variability to some degree. The primary strategy to control for environmental variation should be to define and categorize exposure determinations by SEGs.

Consider the exposure factors discussed when defining and categorizing SEGs. Next, use professional judgment and relevant sampling data (if available) to prioritize data collection needs based on potential exposure levels.

For example, all things being equal, down-flat welding is expected to result in higher exposures than vertical welding positions. Also, FCAW and SMAW operations are expected to result in higher exposures than GTAW and SAW operations.

For SEGs with minimal exposures, only a few samples may be needed to justify and document that exposures are below OSHA's action level. The primary focus should be on collecting sufficient data to properly characterize those SEGs with potentially high Cr(VI) exposures.

Sampling Protocols for Extended Work Shifts

OSHA's lead standards for construction and general industry are the only federal OSHA standards that require PEL adjustments with respect to extended work shifts. The PEL for Cr(VI) is based on an 8-hour time-weighted average (TWA). To minimize errors and assumptions associated with fluctuations in exposure, conduct representative full-shift sampling for air contaminants when determining compliance with an 8-hour TWA. OSHA's *Technical Manual* defines full-shift sampling as a minimum of the total time of the shift less 1 hour (e.g., 7 hours of an 8-hour work shift or 9 hours of a 10-hour work shift).

OSHA does not include provisions for adjusting the Cr(VI) PEL for an extended work shift; however, the agency has two approaches for evaluating compliance for employees who work shifts that last more than 8 hours:

1) Sample what is believed to be the worst continuous 8-hour work period of the entire extended work shift.

2) Collect multiple samples over the entire work shift. Sampling is conducted so that multiple personal samples are collected during the first 8-hour work period and additional samples are collected for the extended work shift. The employee's exposure (for OSHA compliance purposes) in this approach is based on the worst 8 hours of exposure during the entire work shift.

Using this method, the worst 8 hours need not be contiguous. For example, for a 10-hour work shift, 10 1-hour samples or five 2-hour samples could be taken and the eight highest 1-hour samples or the four highest 2-hour samples could be used to calculate an employee's 8-hour TWA, which would be compared to the 8-hour TWA-PEL.

Some organizations and standards suggest different protocols for addressing extended work shifts. For example, Cal/OSHA requires the 8-hour TWA be calculated using the following formula (in accordance with CCR, Title 8, Section 5155):

8-hour TWA = $[(C_1)(T_1) + (C_2)(T_2) + \ldots + (C_n)(T_n)]/8$

where T is the duration in hours of the exposure to a substance at the concentration C; 8 is used as the denominator regardless of the total hours of the work shift.

American Conference of Governmental Industrial Hygienists (ACGIH) refers to the Brief and Scala model for adjusting its threshold limit values (TLVs) for extended work shifts. This model reduces the TLV according to a reduction factor calculated by the following formula:

Reduction factor = [8/(daily hours worked)] x [(24 - daily hours worked)/16]

The reduction factor for a 10-hour work shift would be 0.7; for a 12-hour work shift, it would be 0.5. A contaminant with a TLV of 5µg/m^3 would be reduced to 3.5 µg/m^3 for a 10-hour work shift using this model and 2.5 µg/m^3 for a 12-hour work shift. The reduction factor for a 7-day-per-week work schedule is calculated by the following:

Reduction factor = [40/(hours worked per week)] x [(168 - hours worked per week)/128]

Engineering Controls

OSHA requires that exposures above PEL be reduced using feasible engineering controls, which is consistent with other substance-specific standards and good industrial hygiene practice. If such controls do not sufficiently reduce exposures, then exposures must be maintained as low as feasibly achievable via engineering controls and supplemented with respiratory protection. Job rotation is specifically prohibited to achieve compliance. Compliance with the feasible engineering controls provision took effect May 31, 2010. This provision does not apply where employees are not exposed to Cr(VI) for 30 or more days per 12 consecutive months.

Substitution

Eliminating or minimizing potential Cr(VI) exposures by substituting materials and processes that generate fewer Cr(VI) fumes should be the first consideration for feasible engineering controls. Following are several options for substituting materials and processes to reduce potential Cr(VI) exposures.

Eliminating or minimizing potential exposures by substituting materials and processes that generate fewer Cr(VI) fumes should be the first consideration for feasible engineering controls.

Welding Processes

As noted, different welding processes have different FGR. GTAW and SAW are inherently low in fume generation. GMAW also tends to be a relatively low fume process. SMAW and FCAW operations tend to produce the most fume.

However, not all welding processes can be used in all situations. SAW is limited to flat and horizontal positions. GTAW has a very low deposition rate and is not a good choice for production welding. Conversely, FCAW has a high deposition rate, which makes it a popular choice for heavy production welding. SMAW is a popular choice for repair welding due to its low cost, portability and ease of use.

Automatic & Mechanized Equipment

Use of automatic and mechanized equipment may help reduce exposure in certain situations by further distancing the operator's breathing zone from the welding zone. Again, however, mechanized equipment may not be practical in many situations due to setup time and cost. The amount of welding and/or the size of a tank or job, the type of weld joint and weld position are factors to consider when determining the viability of this option. Also, be aware that use of mechanized equipment tends to increase the welding rate and, thus, tends to increase FGR.

Photo 6: Local exhaust ventilation capture hood. These hoods come in various configurations and directly affect the capture efficiency.

Pulsed Power Welding

Pulsed power welding is a GMAW process in which the power is cyclically programmed to pulse so that effective, but short duration values of power can be utilized. Small metal droplets are transferred directly through the arc to the workpiece. The current alternates from a low background current, which begins to melt the wire while maintaining the arc, to a high peak current during which spray transfer occurs. One droplet is formed during each high peak current pulse. The average arc energy during this pulsed process is significantly lower during conventional GMAW spray transfer, thus reducing the amount of welding wire that is vaporized.

Wallace, Landon, Song, et al. (2001) showed a 24% significant reduction in total weld fume personal air sampling results for pulsed power welding as compared to conventional GMAW welding when welding mild steel in production environments. The study also showed that average airborne concentrations of metal fume constituents from conventional GMAW were significantly higher than airborne concentrations during pulsed GMAW. As a result, studies conducted in both laboratories and production environments have shown that GMAW with a pulsing-power source produces fewer fumes than GMAW using a steady current power source. However, pulsed power welding is only a viable optional for GMAW operations; this technology is not suitable for flux-cored wire.

Substituting Consumable Materials

The amount of Cr(VI) produced is largely influenced by the composition of the welding consumable, including the flux ingredients. Substituting materials for stainless steel or other steels with a lower chromium is often not a viable option. Stainless steel and other Cr-alloy steels have certain desired properties (e.g., corrosion resistance, durability, ductility) that adequate substitutes are not available.

However, Ohio State University researchers are working to develop a Cr-free consumable that is compatible with welding stainless steel material, including Types 304 and 316. The consumable composition is a nickel-copper-based system and may contain additions of molybdenum and palladium to improve the corrosion resistance of the deposit.

Initial testing has shown that these consumable compositions have good weldability, strength and ductility comparable to welds made with Type 308L/304L filler metal. The corrosion resistance is also comparable (Kim, Frankel & Lippold, 2006). Research is continuing to identify specific composition ranges for these consumables and to commercialize a shielded metal arc welding electrode. However, a CR-free consumable for welding stainless steel is not commercially available at this time.

Finally, metal concentrations and flux compositions of welding consumables can differ substantially between manufacturers. In addition, as noted, alkali materials, such as sodium and potassium, are often present in many flux coatings and stabilize Cr(VI) (Fiore, 2006). Therefore, the composition of the flux coating can be a factor in stabilizing Cr(VI) compounds. However, more field studies are needed in this area.

Local Exhaust Ventilation

Local Exhaust Ventilation Components

A local exhaust ventilation (LEV) system consists of five basic components. All LEV systems have at least a fan that supplies static pressure and physically moves the air, ductwork and a hood. The hood (if present) comes in various configurations and directly affects the capture efficiency. A major mistake by LEV users, especially those using portable LEV units, is failing to use a hood type that minimizes hood entry losses. A system with merely a plain exhaust duct as its hood has the lowest capture efficiency as compared to other hood types (e.g., flanged hoods, cone-shaped hoods).

The duct is a significant contributor to airflow loss due to friction. Airflow loss also occurs from elbows and bends, expansions and contractions, branch entries and transition pieces to fans or air cleaners. Calculating the amount of airflow loss of a system can be cumbersome and complicated. Friction loss in a duct depends on the roughness of the material, diameter, velocity pressure and duct length. The key point regarding ducts is to avoid long runs of duct and minimize kinks, bends and elbows.

The LEV system may or may not be equipped with an air cleaner. Using LEV systems equipped with an air cleaner is particularly important when air is recirculated. This is often the case when welding inside large tanks or vessels where it is not practical to run several ducts to the outside or in locations where long lengths of duct would be necessary and may create too much airflow loss to be effective. Options for air cleaning devices found in fume extraction systems include: 1) electrostatic precipitators (ESPs); and 2) cartridge/fabric filtration. Both can capture submicron particles. ESPs are good for removing submicron-sized particles but they cannot handle heavy fume loadings and require frequent maintenance.

Depending on the filtration system, some cartridge/fabric filters may be able to collect submicron particles suitable for welding fumes. It is easier to maintain filtration systems than ESPs, but filters must be periodically replaced and/or cleaned. Depending on the fume loading, the filters may need to be changed frequently to avoid excessive static pressure drops. In some situations, filter changes and cleaning may need to occur daily. Regardless of the type of air cleaner utilized, poor maintenance results in poor fume collection.

Respirators and protective clothing also may be needed when changing or cleaning filters. Be sure to characterize the waste to determine whether the filters and particulates need to be treated as hazardous waste. Recall also that some Cr(VI) compounds may be converted to Cr(III), especially after several days.

Fume Control Considerations

Some studies have examined the effectiveness of LEV in controlling welding fume exposures. In general, the overall conclusions are that LEV may significantly reduce fume exposure. Wallace and Fischbach (2002) examined the effectiveness of two types of portable LEV units during SMAW inside a building and outside in a semi-enclosed tank at a boilermaker union training facility. The study indicated that LEV does not capture all the fumes and, thus, does not eliminate exposure. There are also situations where LEV will not reduce exposures below applicable occupational exposure limits.

Key fume control characteristics and considerations are summarized as follows:

1) Fumes are greatly influenced by air currents. Air currents created by either natural or mechanical ventilation can affect how well the fumes are captured. Using LEV outdoors (or even semi-enclosed spaces) has been shown to be less effective in capturing fumes due to opposing air currents.

2) Studies have shown that LEV significantly reduces fume exposure but does not eliminate exposures because not all the fumes will be captured. Using LEV systems also does not guarantee that exposures will be below applicable PELs.

3) The amount of fumes captured and the resulting exposures depend on the configuration of the LEV unit, the capture velocity, the welder's work practices and maintenance of the LEV units.

4) For fume extraction systems without an air cleaner (such as a filtration system or ESP), consider where the fumes are being exhausted. Are fumes exhausted to a different area in the work environment? Does it create a potential exposure problem for other workers? For fixed systems with a stack, where is the stack exhaust located? Is it near any air intakes that may cause the exhausted fumes to reenter the building or structure?

Types of Fume Extraction Systems

Fume extraction systems can generally be categorized as 1) fixed and flexible systems; 2) portable LEV units; and 3) fume extraction guns. The following discussion provides examples of these systems/units and their advantages and limitations.

Fixed/Flexible Fume Extraction Systems

An example of a fixed fume extraction system is a welding booth that contains a backdraft or downdraft ventilation system. Some systems even have a canopy hood; however, such systems are not an effective option since the fumes will likely pass through the welder's breathing zone before being captured by the hood and exhausted.

Fixed systems also can have movable extraction arms, which provide more flexibility than backdraft welding booths. Free-hanging air cleaners are found in some shops and facilities, but these systems are not an LEV option since fumes are not captured at the source; therefore, fumes are likely to pass through the breathing zone before being captured by the air cleaner.

Photo 7: Portable fume extraction unit with movable extraction arms. Such a system provides more flexibility than backdraft welding booths.

Advantages of fixed fume extraction systems include the following:

- Airflow losses can be more easily controlled.
- The system is more readily available for use once the initial setup is complete.
- The system can be designed with higher capacity fan to increase airflow, if needed. Therefore, longer runs of duct (as compared to portable units) can be used.

Disadvantages of these systems include the following:

- Initial setup cost is relatively high.
- The object being welded may partially block the airflow, thereby obstructing the capture efficiency. Backdraft welding booths are limited to welding small parts for this reason.
- Fixed systems with flexible fume extraction arms must be properly positioned and/or adjusted before and during welding.

Portable Fume Extraction Units

The two most common types of portable units are high-volume, low-vacuum systems and high-vacuum, low-volume systems. High-volume, low-vacuum systems use large diameter ducts or hoses that provide for larger capture distances. High-vacuum, low-volume systems tend to be more portable but they use smaller hoses; as a consequence, the capture distance is generally smaller. Also, if equipped with a filtering system, the smaller units tend to have lower fume loading capacities. A welder using portable fume extractors must frequently adjust the hood placement. Also, long runs of flexible ducts may be needed (causing more airflow loss) unless the unit is equipped with an air cleaner.

Advantages of portable fume extraction units include the following:

- Portable units are available in different sizes. Mobility is increased with smaller units.
- Setup cost is relatively low compared to fixed systems.

Disadvantages of these units include the following:

- The welder must adjust the hood placement frequently.

Photo 8: A fume extraction gun is one solution to the problems assocated with frequently repositioning exhaust hoses.

•The fan size is restricted due to size limitations of the unit, therefore, limiting the airflow and maximum duct length of the system.

•Air cleaners, if equipped, tend to have less fume loading capacities (as compared to fixed units). Thus, more frequent maintenance is required.

Fume Extraction Guns

One solution to the problems associated with frequently repositioning exhaust hoses is to use a fume extraction gun (FEG).

FEGs are available in two basic designs. One incorporates the ventilation direction into the gun design. Lines for the shielding gas and welding wire are encased in a large, single line leading from the gun. The other type is a conventional type in which the lines for the shielding gas, welding wire and air exhaust remain separate from welding gun.

Wallace, Shulman and Sheehy (2001) examined the effectiveness of FEGs during mild steel FCAW operations. The study concluded that FEGs appear to help reduce exposures but do not effectively control all welding fume emissions. The study further showed that even when using FEGs, the breathing zone airborne concentrations of welding fume and its components were still above recognized occupational exposure limits.

FEG advantages include the following:

•The devices allow for high welder mobility.

•FEGs eliminate the need for welders to frequently reposition the exhaust hood as welding progresses.

Disadvantages include the following:

•Use of FEGs is limited to GMAW and FCAW processes.

•The added weight of the welding gun can create ergonomic issues, especially for those who spend a considerable amount of time welding.

•Welding in positions other than flat or horizontal positions may reduce the capture efficiency.

•FEGs do not remove residual fumes. A welder tends to move the gun away from the welding zone when s/he breaks the arc, which causes residual fumes to be uncaptured.

Capture Velocity

Capture velocity is the key measure in evaluating the effectiveness of an LEV system. It is defined as the velocity necessary to overcome opposing air currents to allow welding fumes to be captured. In its *Industrial Ventilation Manual,* ACGIH (1998) recommends that the capture velocity be between 100 to 200 ft per minute (fpm) for contaminants released at low velocity into moderately still air, such as typical welding operations. For welding involving toxic metals [e.g., Cr(VI)], the capture velocity should be near the upper end of this recommended range. Generally, hoods need to be within 12 in. to maintain this velocity. However, in many cases, the hood may need to be just a few inches from the welding zone.

The maximum acceptable distance to maintain the minimum capture velocity depends on several factors. These include (Spear, 2007):

•Duct size. The smaller the duct or hood, the closer the hood needs to be to the welding arc to effectively capture the fumes. As a rule of thumb, capture distance should be within 1.5 times the duct's diameter. For instance, a 2-in. duct usually requires the exhaust inlet to be just within 3 in. from the welding zone to have some effect in capturing the fumes.

•Airflow through the duct/hood. As airflow decreases, a shorter capture distance may be needed.

•Presence and type of hood. Different hood configurations have different capture efficiencies. A simple hood with no flange has the lowest capturing efficiency. A square hood also tends to have a lower capture efficiency than a round hood. ACGIH (1998) publishes hood entry loss coefficients for several different types of hoods.

•The magnitude and direction of other air currents. These factors also play a role in capture distance. If strong opposing currents are present, the hood must be positioned just a few inches to have some effectiveness, if any, depending on the magnitude of the opposing air currents. For this reason, using LEV outdoors is of limited effectiveness for controlling welding fumes. LEV is also not a viable option for some activities (e.g., air arc gouging operations) due to the large opposing air currents generated by the process.

•Hood location in relation to the natural plume travel. When welding a vertical seam inside a tank with little or no opposing air current, the plume tends to rise straight up. In this situation, the hood can be positioned further away providing it is reasonably in line with the plume's natural path of travel.

For flexible and portable systems, the nozzle or hood should be repositioned regularly during the course of welding. Adding a flange to the nozzle increases the capture distance, which also increases the length of weld that can be made before the exhaust nozzle (or hood) needs to be repositioned. The following discussion provides typical airflow rates and capture distances for LEV equipment (Fiore, 2006).

High-Vacuum, Low-Volume LEV Systems

•For an airflow rate of 50 to 110 ft^3/minute with a duct diameter of 1.5 to 2 in., the typical capture distance is 2 to 3 in. The weld length before repositioning the hood is 4 to 6 in. (for a plain duct inlet) and 8 to 12 in. (for a flanged hood).

•For an airflow rate of 160 ft^3/minute with a duct diameter of 3 in., the typical capture distance is 5 to 6 in. The weld length before repositioning the hood is 9 to 12 in.

High-Volume, Low-Vacuum LEV Systems

•For an airflow rate of 500 to 600 ft^3/minute with a duct diameter of 4 to 6 in., the typical capture distance is 6 to 9 in. The weld length before repositioning the hood is 12 to 18 in.

•For an airflow rate of 800 to 1,000 ft^3/minute with a duct diameter of 6 to 8 in., the typical capture distance is 9 to 12 in. The weld length before repositioning the hood is 18 to 24 in.

Note that the required capture distance typically ranges from 2 to 12 in. depending on the type of system used. The high-volume, low-vacuum systems generally allow for greater capture distances and a greater weld distance before the hood needs to be repositioned.

LEV Guidelines

The following discussion summarizes guidelines and considerations for using LEV for welding fume control.

1) Minimize airflow losses. The duct is a major source of airflow loss due to friction. Smooth, short ducts with no bends are ideal but usually not practical. So, keep duct runs as short as possible. Most portable fume extraction units limit the extraction arm to 10 to 15 ft for this reason. Also, periodically inspect flexible ducts for holes as this may be another source of air loss.

2) Avoid using plain ducts as capture hoods. Exhaust inlets without a flange require about 25% more airflow.

3) Perform frequent maintenance of LEV units. For units with a filtration system, the airflow will decrease as the filter or air cleaner becomes loaded. This static pressure drop can be significant. Therefore, filters must be changed frequently. This frequency depends on fume loading. On low-volume, high-vacuum units (i.e., smaller more portable units), the filters may need to be cleaned and/or changed daily.

4) Assess/control opposing air currents. LEV has limited effectiveness outdoors or in semi-enclosed areas because fumes are greatly affected by air currents. Opposing air currents can be assessed by simply observing how the plume behaves. If it dissipates rapidly before it reaches the hood, this may indicate that the opposing air currents are too great for the LEV unit to be effective.

To minimize the effects of opposing air currents, increase the airflow of the LEV system, shield the welding area from natural drafts or other opposing air currents, and/or if possible, locate the capture hood in the plume's natural path of travel.

5) Implement administrative procedures to increase LEV effectiveness. Providing LEV units to welders is not enough. Some administrative controls are needed as well. These may include establishing policies and procedures that outline requirements for using LEV when engaging in certain types of welding activities and/or in enclosed spaces; measuring capture velocities frequently; establishing a maintenance schedule for fume extraction systems (such as cleaning and/or changing the filtering system); and establishing PPE requirements to supplement engineering controls (when needed). These policies and procedures should be enforced as are other safety and health requirements.

General/Dilution Ventilation

Although general/dilution ventilation is often used when welding indoors or inside enclosed spaces, LEV is preferred for fume control since it attempts to capture fumes at the source. The effect on the plume's travel path is unpredictable when using only general/dilution ventilation. When using both general/dilution ventilation and LEV, be aware of the air currents that the general/dilution ventilation is creating as they may affect LEV effectiveness.

Also, note that welding outdoors does not guarantee that welding fume and Cr(VI) exposure levels will be below occupational exposure limits. General/dilution ventilation and natural ventilation have limited effectiveness if they cause the plume to travel through the welder's breathing zone. ■

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