Assessing and Controlling Hexavalent Chromium Exposure from Welding

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Introduction

Pursuant to a court order, OSHA issued a final rule on February 28, 2006 that addresses occupational exposure to hexavalent chromium (Cr[VI]). OSHA determined that the Cr(VI) rule is 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 (such as runny nose, sneezing, itching, nosebleeds, ulcers, and 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 that have the potential for Cr(VI) exposure include the following:

- 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, there are a total of 380,000 workers exposed to Cr(VI). However, welders represent nearly half of the workers covered by OSHA's hexavalent standard.

This paper 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.

Major Provisions of OSHA's Cr(VI) Standards

OSHA issued separate but similar standards for general industry, construction, and shipyard sectors. The major provisions of the final rule for controlling Cr(VI) exposure are summarized in Table 1.

Table 1
Summary of Major Provisions of OSHA's Final Rule for Hexavalent Chromium

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 $\mu g/m^3$	General Industry, Construction, Shipyards (including marine terminals and longshoring)
Permissible exposure limit (PEL)	5 $\mu g/m^3$	General Industry, Construction, and Shipyards
Action level (AL)	2.5 $\mu g/m^3$	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 if exposure is greater than the PEL. Must describe the corrective action being taken.	General Industry
	Results of the exposure determination must be posted (or each affected employee must be notified in writing) within 5 working days if exposure is greater than the PEL. Must describe the corrective action being taken.	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	General Industry, Construction, and

	reduce exposures to or below the PEL, must reduce to the lowest achievable levels and supplement with respiratory protection.	Shipyards
	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.	General Industry, Construction, and Shipyards
	Painting of aircraft or large aircraft parts, engineering controls must be used to reduce exposures below 25 $\mu g/m^3$ and supplement engineering controls with respiratory protection.	General Industry
	Job rotation is prohibited to achieve compliance with the PEL.	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.	General Industry, Construction, and Shipyards
	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
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	General Industry,

	controls) must be achieved by 11/27/06. Employers with 19 or fewer employees have until 5/30/07 to comply.	Construction, and Shipyards
	Compliance with engineering controls must be achieved by 5/31/10.	General Industry, Construction, and Shipyards

Cr(VI) in Welding Fumes

Chromium has been used commercially in the U.S. for more than 100 years. Chromium 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. Cr(VI) 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).

Chromium metal is found in stainless steel and many low-alloy materials, electrodes, and filler materials. The chromium that is 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). But rather, 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 of the metal oxides in its 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 40).

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 typically not intentionally added to mild steels or mild steel consumables but 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 39).

Common Welding Processes and Fume Generation Rates (FGR)

Different welding processes have different fume generation rates (FGR). Having a basic understanding of the welding processes and their relative fume generation rates is important in order to assess the risk of exposures to welding fumes and gases. An overview of common welding processes and their relative fume generation rates is provided below:

Shielded Metal Arc Welding (SMAW, “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.

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, GMAW 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.

Fluxed Core Arc Welding (FCAW) is commonly used for mild steel, low alloy steel, and stainless steel welding. This welding 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 welding process generates a substantial amount of fume due to the high electrical currents and the flux-cored electrode. However, FCAW generates little ozone, nitric oxide, and nitrogen dioxide gases.

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 non-consumable 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 little fumes.

Submerged Arc Welding (SAW) is another common welding process used to weld thick plates of mild steel and low alloy steels. In this welding 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. There are also little ozone, nitric oxide and nitrogen dioxide gases that are generated. The major potential airborne hazard with SAW is the fluoride compounds generated from the flux material.

Fume Generation Rates (FGR)

The primary sources of information when determining the components likely to be in the fume is the material safety data sheet and/or the manufacturer's technical data sheet of the consumable electrode/wire. About 90 to 95 percent of the fumes are generated from the filler metal and flux coating/core of consumable electrodes (Lyttle 45). 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 (such as chromate-containing coatings, lead-based paint, etc.).

In addition to the welding process, studies have shown that the FGR is also influenced by the following factors:

- **Electrical current:** In general, the fume generation rate is exponentially proportional to the current.
- **Arc voltage:** The fume generation rate generally increases when the arc voltage increases.
- **Electrode diameter:** The electrode diameter has a modest effect on the fume generation rate because of the differences in voltage and current. In general, a small diameter electrode has a higher FGR than a large diameter electrode.
- **Electrode angle:** The angle of the electrode to the workpiece has a slight (but unpredictable) affect on the fume generation rate.
- **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 fume generation rate obviously increases.
- **Steady/current pulsed current welding:** Technology has advanced to power sources that have pulsing capabilities. Studies have shown that utilizing a pulsing current during welding generates fewer fumes than under steady current welding process.

In general, FCAW produces the greatest fume generation rate (for mild steel welding) and closely followed 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 may also be present in FCAW flux (Fiore 40), which may explain why Cr(VI) concentrations from SMAW operations are often higher than Cr(VI) concentrations from FCAW. GMAW tends to have a moderate relative fume generation rate. GTAW and SAW are inherently low fume generating processes.

Other ancillary process (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 these processes. Potential exposures to not only the operator but also 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. Options for exposure determinations include initial and periodic exposure monitoring and/or the use of objective data. If objective data is used, the data 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, exposure monitoring must be performed initially and periodically. For exposures that are determined to be at or above OSHA's PEL of 5 $\mu g/m^3$ (8-hour TWA), exposure monitoring must be performed at least every three months. For exposures that are determined to be at or above OSHA's Action Level of 2.5 $\mu g/m^3$ (8-hour TWA), exposure monitoring must be performed every six months. Additionally, exposure monitoring must be performed whenever there is a change in work processes or materials that may result in new or additional exposures to Cr(VI).

Exposure Factors

Welding fume exposure tends to be highly variable due to several exposure factors. These factors should be considered when assessing potential exposures to Cr(VI). The primary Cr(VI) exposure factors are described below.

1. **Welding process:** As discussed above, the welding process used has a significant affect on the fume generation rate.
2. **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 may also have some affect in stabilizing Cr(VI) resulting in higher Cr(VI) concentrations.
3. **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 the paint or coating does not contain chromates.
4. **Welding rate:** High welding rates obviously increases the fumes generated. However, information pertaining to an individual's welding or production rate is seldom accurately and consistently measured in exposure monitoring efforts. Consider utilizing an arc timer during exposure monitoring to accurately collect and document actual welding time, which may prove useful in explaining unusually high or low exposure monitoring results and/or in better categorizing similar exposure groups (SEGs).
5. **Relative welding position:** The welding position plays a significant role in welding fume 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 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 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.
6. **Local exhaust ventilation (LEV):** Studies have 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 further discussed later.
7. **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 not only to the welder but also other personnel inside the building or enclosed space.
8. **General/dilution ventilation and natural air currents:** Although general/dilution ventilation is 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.
9. **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 obviously affect potential exposures to welding fumes and Cr(VI) inside enclosed spaces, especially if the space is poorly ventilated.

<u>OSHA Method ID-215</u>

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 eight 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 seven days.

Significant amounts of Cr(VI) are often deposited on the interior walls of the 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 the sample location or position other than 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) described the results of simultaneously air sampling with collection sites at four locations – the welder’s body, the left front shoulder, the right front shoulder, the front chest, and inside the helmet. A total of 40 sets of four samples on each welder at each of these locations were collected. The welders monitored were using FCAW while building railroad locomotives. Goller and Paik concluded that fume concentrations inside the helmet were 36% to 71% of those measured outside the helmet (Goller and Paik 92), which supports the protocol of sampling inside the helmet recommended by the American Welding Society (AWS).

Liu et al. (1995) showed that the relationship between sample location and measured contaminant may not be as clear as earlier believed. A total of 20 volunteers performing SMAW in a controlled laboratory environment were monitored. A total of 23 sample sets was collected from both the breathing zones inside the helmets and at the shoulders of 20 volunteers who welded inside a 506 ft^3 test chamber. The results of this monitoring indicated that there was generally little difference between fume concentrations inside the helmet and those outside the helmet (Liu et al. 283).

More recently, Harris et al. (2005) supported 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. Harris et al. 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 (Harris et al. 380).

Based on the results of the studies described above, the fume concentrations inside the helmet has the potential of being higher than fume concentrations outside the helmet when welding outdoors or other non-enclosed work environments, whereas, the difference in fume concentrations appears to have little difference when welding in more restricted environments.

Sampling Variability

There are two types of variations that 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 a sampling method that is at least ±25% accurate must be used. 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 ±14%, which complies with OSHA's requirements of using a sampling method that is at least ±25% accurate. However, variations due to the workplace or environment are considerably larger than SAEs.

OSHA requires that if objective data is used, the conditions must closely resemble the workplace conditions that the data represents. 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 Similar Exposure Groups (SEGs). Consider the exposure factors previously 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 examples, 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 those 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 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 one hour (e.g., seven hours of an eight-hour work shift or nine hours of a 10-hour work shift).

OSHA does not include provisions for adjusting the Cr(VI) PEL for extended work shift; however, OSHA's provides two approaches for evaluating compliance for employees who work extended work shifts beyond eight hours. Federal OSHA compliance officers may choose one of the two following approaches:

1. The first approach is to sample what is believed to be the worst continuous 8-hour work period of the entire extended work shift.
2. The second approach is to collect multiple samples over the entire work shift. Sampling is done 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 upon the worst eight hours of exposure during the entire work shift. Using this method, the worst eight hours do not have to be contiguous. For example, for a 10-hour work shift, ten one-hour samples or five two-hour samples could be taken and the eight highest one-hour samples or the four highest two-hour samples could be used to calculate the employee's eight-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 instance, in California, Cal-OSHA requires the 8-hour TWA to be calculated using the following formula (in accordance with CCR, Title 8, Section 5155):

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

Where T is the duration in hours of the exposure to a substance at the concentration C. <u>Eight (8) is used as the denominator regardless of the total hours of the work shift.</u>

The American Conference for Governmental Industrial Hygienists (ACGIH) refers to the Brief and Scala model for adjusting its Threshold Limit Values (TLVs) for extended work shifts. The Brief and Scala model reduces the TLV according to a reduction factor calculated by the following formula:

$$\textit{Reduction Factor} = [8/(\textit{daily hours worked})] \times [(24 - \textit{daily hours worked})/16]$$

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

$$\textit{Reduction Factor} = [40/(\textit{hours worked per week})] \times [(168 - \textit{hours worked per week})/128]$$

Engineering Controls

OSHA's requires exposures above the PEL to be reduced using feasible engineering controls, which is consistent with other substance-specific standards and good industrial hygiene practice. If feasible engineering controls do not sufficiently reduce exposures to below the PEL, 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 utilizing feasible engineering controls becomes effective on 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. Possible options for substituting materials and processes to reduce potential Cr(VI) exposures are described below.

<u>Welding Processes</u>

As previously discussed, different welding processes have different fume generation rates. GTAW and SAW are inherently low in fume generation. GMAW also tends to be a relatively low fume process. Whereas, SMAW and FCAW operations tend to produce 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 welding heavy production welding. SMAW is a popular choice for repair welding due to its low cost, portability, and ease of use.

<u>Automatic and Mechanized Equipment</u>

Use of automatic and mechanized equipment may help reduce exposure in certain situations by increasing the operator's breathing zone from the welding zone. But again, mechanized equipment may not be practical in many situations due to the setup time and cost of equipment. The amount of welding and/or the size of a tank or job, the type of weld joint, and weld position are factors that need to be considered when determining the viability of using automatic or mechanized welding equipment. Also, be aware that use of mechanized equipment tends to increase the welding rate, thus, also tends to increase the fume generation rate.

Pulsed Power GMAW

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 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. This study also showed that average airborne concentrations of metal fume constituents from conventional GMAW were significantly higher than airborne concentrations during pulsed GMAW (Wallace et al. 95-96). 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 of 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 (such as corrosion resistance, durability, ductility, etc.) that adequate substitutes are not available. However, The Ohio State University has on-going research to develop a Cr-free consumable that is compatible with welding stainless steel material, including Types 304 and 316. The consumable composition is a Ni-Cu based system and may contain additions of Molybdenum and Paladium 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, and Lippold 704). Research is continuing to identify specific composition ranges for these consumables and to commercialize a shielded metal arc welding electrode. However, a chromium-free consumable for welding stainless steel is not commercially available at this time.

Finally, studies have shown differences in fume generation rates by type of wire. Metal concentrations and flux compositions of welding consumables can differ substantially between manufacturers. Also as mentioned previously, alkali materials, such as sodium and potassium, are often present in many flux coatings and stabilize Cr(VI). Therefore, the composition of the flux coating can be a factor in stabilizing Cr(VI) compounds. However, more field studies in this area are needed.

Local Exhaust Ventilation (LEV)

LEV Components

There are five basic components of a LEV system. 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 the failure 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 (such as flanged hoods, cone-shaped hoods, etc.).

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 (VP), 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 to be circulated, which is often the case when welding in 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 possibly creating too much airflow loss to be effective. There are a couple of options for air cleaning devices found in fume extraction systems: 1) electrostatic precipitators (ESPs) and 2) cartridge/fabric filtration. Both are capable of capturing sub-micron 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 sub-micron particles suitable for welding fumes. Maintenance of filtration systems is easier 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!

Please note that respirators and protective clothing may also be needed when changing or cleaning filters. Be sure to characterize the waste to determine if the filters and particulates need to be treated as hazardous waste. But recall, 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 (Wallace and Fischbach 150-151).

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 be factors in determining 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 re-enter 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. Examples of these systems/units and their advantages and limitations are described below.

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, systems with a canopy hood is not an effective option since the fumes will likely pass through the welder's breathing zone before being captured by the hood and exhausted out of the room or work area. Fixed systems can also 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 a 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.

Advantages of fixed fume extraction systems include:

- 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 fixed fume extraction systems include:

- The 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, and 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. Using portable fume extractors require the welder to make frequent adjustments to 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 <u>portable fume extraction units</u> include:

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

Disadvantages of <u>portable fume extraction units</u> include:

- The welder must make frequent adjustments to the hood placement.
- The fan size is limited 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 (FEGs): One solution to the problems associated with frequently repositioning exhaust hoses is to use a FEG. There are a couple of basic FEG 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 did not effectively control all of the 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 (Wallace, Shulman, and Sheehy 778).

Advantages of <u>fume extraction guns</u> include:

- FEGs allow for high welder mobility.
- FEGs eliminate the need for welders to frequently reposition the exhaust hood as welding progresses.

Disadvantages of <u>fume extraction guns</u> include:

- The 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 perform 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. Welders have a tendency to remove the gun away from the welding zone when he/she breaks the arc, which causes residual fumes to be uncaptured.

<u>Capture Velocity</u>

The capture velocity is the key measure in evaluating the effectiveness of a LEV system. The capture velocity is defined as the velocity necessary to overcome opposing air currents to allow welding fumes to be captured. The American Conference for Governmental Industrial Hygienists (ACGIH), in its *Industrial Ventilation Manual*, recommends the capture velocity to be between 100 to 200 feet per minute (fpm) for contaminants released at low velocity into moderately still air, such as typical welding operations (ACGIH 3-6). 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 inches to maintain this capture 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:

- **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 the capture distance should be within 1 ½ times the diameter of the duct. For instance, a two-inch duct usually requires the exhaust inlet to be just within 3 inches from the welding zone to have some effect in capturing the fumes.
- **Airflow through the duct/hood:** As the 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. Hood entry loss coefficients are published in ACGIH's *Industrial Ventilation Manual* for a number of different types of hoods (ACGIH 3-17).
- **The magnitude and direction of other air currents:** The magnitude and direction of other air currents also play a role in the capture distance. If there are strong opposing currents, the hood will need to 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 has limited effectiveness to control 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.
- **The 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 provides typical airflow rates and capture distances for LEV equipment (Fiore 42):

High Vacuum, Low Volume LEV Systems

- For an airflow rate of 50 to 110 ft^3/minute with a duct diameter of 1 ½ to 2 inches, the typical capture distance is 2 to 3 inches. The weld length before repositioning the hood is 4 to 6 inches (for a plain duct inlet) and 8 to 12 inches (for a flanged hood).
- For an airflow rate of 160 ft^3/minute with a duct diameter of 3 inches, the typical capture distance is 5 to 6 inches. The weld length before repositioning the hood is 9 to 12 inches.

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 inches, the typical capture distance is 6 to 9 inches. The weld length before repositioning the hood is 12 to 18 inches.

- For an airflow rate of 800 to 1000 ft^3/minute with a duct diameter of 6 to 8 inches, the typical capture distance is 9 to 12 inches. The weld length before repositioning the hood is 18 to 24 inches.

Please note that the required capture distance, typically ranges from 2 to 12 inches 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

In summary, guidelines and considerations for using LEV for welding fume control are provided below.

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 of these portable fume extraction units limit the extraction arm to about 10 to 15 feet for this reason. Also, periodically inspect flexible ducts for holes as this may also be another source of air loss.
2. **Avoid using plain ducts as capture hoods.** Exhaust inlets without a flange requires 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, the filters need to be changed frequently. The frequency depends on the fume loading. On the low volume, high vacuum (i.e., smaller more portable units), the filters may need to be cleaned and/or changed daily.
4. **Assess/control opposing air currents.** The effectiveness of LEV for welding has limited effectiveness outdoors or even semi-enclosed areas because fumes are greatly affected by air currents. Assessing opposing air currents can be done by simply observing how the plume behaves. If the plume dissipates rapidly before it reaches the hood, this may be an indication 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. A certain amount of administrative controls is needed for LEVs to be effective. This may include establishing LEV policies and procedures that outline requirements for using LEV when engaging in certain types of welding activities and/or in enclosed spaces, measuring the 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 other safety and health requirements on the job.

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 local exhaust ventilation, be aware of the air currents that the general/dilution ventilation is creating as this may impact the effectiveness of the local exhaust ventilation. Also, please 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 it causes the plume's tendency to travel through the welder's breathing zone.

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