Welding Fume in the Workplace

Preventing potential health problems through proactive controls

By H. Shane Ashby

WELDING IS A COMMON industrial process—so common that up to two percent of the working population in industrialized countries has been engaged in some sort of welding (Liss 2). Welding is also a hazardous process. Burns to the skin, flash burns to the eyes and fire are some of the more immediate and acute hazards.

One hazard is less readily noticeable, but has both acute and more long-term chronic effects—welding fume. Fumes are solid particles that originate from welding consumables, the base metal and any coatings present on the base metal.

Despite advances in control technology, welders continue to be exposed to welding fume and gases (Wallace, et al 4). The chemicals contained in these fumes and gases depends on several factors: 1) type of welding being performed; 2) material the electrode is made of; 3) type of metal being welded; 4) presence of coatings on the metal; 5) time and severity of exposure; and 6) ventilation (ELCOSH "Hazard Alert" 1).

Although the types of welding are many, it has been estimated that shielded metal arc welding (SMAW), gas metal arc welding (GMAW) on mild steel, stainless steel and aluminum are performed by 70 percent of welders (Liss 2).

According to OSHA, possible elements of welding fume and related hazards include the following.

- **Zinc.** Used in large quantities in the manufacture of brass, galvanized metals and various other alloys. Exposure to these fumes is known to cause metal fume fever. Symptoms are similar to those of the common flu: fever (rarely exceeding 102ºF), chills, nausea, throat dryness, cough, fatigue, and general weakness and aching of the head and body. These symptoms rarely last more than 24 hours.
- **Cadmium.** Used frequently as a rust-preventive coating on steel and as an alloying element. Exposures to high levels of cadmium fumes can produce severe lung irritation, pulmonary edema and, in some cases, death. Long-term exposures to low levels can result in emphysema and can damage the kidneys. Cadmium is listed by OSHA, NIOSH and EPA as a potential human carcinogen.

Although welding fume is a less readily noticeable hazard, it has both acute and more long-term chronic effects.

- **Beryllium.** Used as an alloying element with copper and other base metals. Exposure to high levels of beryllium can result in chemical pneumonia. Long-term exposure can result in shortness of breath, chronic cough and significant weight loss, accompanied by fatigue and weakness.
- **Iron Oxide.** Iron is the

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Table 1

Exposure Limits

Substance	OSHA PEL-TWA ($\mu g/m^3$)	NIOSH REL-TWA ($\mu g/m^3$)	ACGIH TLV-TWA ($\mu g/m^3$)
Aluminum Fume	15,000 (Total) 5,000 (Respirable)	5,000	5,000
Arsenic	10	2 (Ceiling)	10
Barium	500	500	500
Beryllium	2	0.5 (Ceiling)	2
Calcium Oxide	--	2,000	2,000
Cadmium Fume	5	LFC (Ca)	10 (Total) 2 (Respirable)
Cobalt	100	50	20
Chromium, Hexavalent	--	1	50
Chromium, Metal	1,000	500	500
Copper Fume	100	100	200
Iron Oxide Fume	10,000 (as Fe)	5,000	5,000
Lithium	--	--	--
Magnesium Oxide	15,000	--	10,000
Manganese	5,000 (Ceiling)	1,000	200
Molybdenum	5,000 (Soluble) 15,000 (Insoluble)	--	5,000 (Soluble) 10,000 (Insoluble)
Nickel	1,000	15 (Ca)	1,000
Lead	50	100	50
Phosphorus	100	100	100
Platinum	2 (Soluble)	1,000 (Metal) 2 (Soluble)	1,000
Selenium	200	200	200
Silver	10	10	100
Sodium	--	--	--
Tellurium	100	100	100
Thallium	100	100 (Soluble)	100
Titanium Dioxide	15,000	LFC (Ca)	10,000
Vanadium Pentoxide	100 (Ceiling)	50 (Ceiling)	50
Yttrium	1,000	1,000	1,000
Zinc Oxide Fume	5,000	5,000	5,000
Zirconium	5,000	5,000	5,000
Welding Fumes	--	LFC (Ca)	5,000

LFC=lowest feasible concentration
Ca=NIOSH potential occupational carcinogen

Source: Wallace, et al 26-27

principal alloying element in steel manufacture. During welding, these fumes arise from both the base metal and the electrode. The primary acute effect of exposure is irritation of nasal passages, throat and lungs. Long-term exposure may cause iron pigmentation of the lungs, a condition known as siderosis. Most authorities agree that these iron deposits in the lungs are not dangerous.

• **Mercury.** Compounds are used to coat metals in order to prevent rust or inhibit foliage growth. Exposure to these fumes may produce stomach pain, diarrhea, kidney damage or respiratory failure. Long-term exposure may produce tremors, emotional instability and hearing damage.

• **Lead.** Lead oxide fumes are generated by cutting and welding of lead-bearing alloys or metals that are coated with lead-based paint. Inhalation and ingestion of lead oxide fumes and other lead compounds will cause lead poisoning. Symptoms include metallic taste in mouth, loss of appetite, nausea, abdominal cramps and insomnia. Chronic effects are anemia and general weakness, mainly in the muscles of the wrists. Lead adversely affects the brain, central nervous system, circulatory system, reproductive system, kidneys and muscles.

• **Fluorides.** Found in the coatings of many types of fluxes used in welding. Exposure may irritate the eyes, nose and throat. Repeated exposure to high concentrations of fluorides in the air over a long period may cause pulmonary edema and bone damage. Fluorides are retained in bone and excessive intake may result in an osteosclerosis or a reduction of bone density, which is recognizable by X ray.

• **Chlorinated hydrocarbon solvents.** Used in degreasing operations. The heat and ultraviolet radiation from the arc will decompose the vapors and form highly toxic and irritating phosgene gas.

• **Phosgene.** Formed by the decomposition of chlorinated hydrocarbon solvents by ultraviolet radiation. It reacts with moisture in the lungs to produce hydrogen chloride, which in turn destroys lung tissue.

• **Carbon monoxide.** A gas usually formed by the incomplete combustion of various fuels. Welding and cutting may produce significant amounts of CO. In poorly ventilated areas, operations that use carbon dioxide as the inert gas shield may produce hazardous concentrations of CO. Carbon monoxide is odorless, colorless and tasteless, and cannot be detected by the senses. Symptoms of overexposure include pounding of the heart, a dull headache, flashes before the eyes, dizziness, ringing in the ears and nausea. However, because these are common symptoms, they are often explained away as "just not feeling good"—people rarely connect them to CO exposure.

• **Ozone.** Produced by ultraviolet light from the welding arc. Ozone is produced in greater quantities by GMAW, gas tungsten arc welding (GTAW) and plasma arc cutting. Ozone is a highly active form of oxygen and can irritate all mucous membranes. Symptoms of ozone exposure include headache, chest pain and dryness of the upper respiratory tract. Excessive exposure to ozone can cause fluid in the lungs and is thought to have long-term effects on the lungs.

• **Nitrogen oxides.** Produced by GMAW, GTAW and plasma arc cutting. Even greater quantities are formed if the shielding gas contains nitrogen. Nitrogen dioxide, one of the oxides formed, has the greatest health effect.

Although it is irritating to the eyes, nose and throat, dangerous concentrations can be inhaled without any immediate discomfort. High concentrations of nitrogen dioxide can cause shortness of breath, chest pain and fluid in the lungs. (OSHA "Welding Health" 1).

Exposure Limits

Each individual constituent of welding fume has exposure limits (Table 1). However, some debate has centered on what the actual exposure limit on total welding fume should be.

"In 1989, the OSHA PEL (permissible exposure limit) for total welding fume was set at 5 mg/m^3 (5000 μg/m^3) as an eight-hour TWA (time-weighted average); however, this limit was vacated and currently is not enforceable. Since 1989, OSHA has not reestablished a PEL for total welding fume.

"NIOSH indicates that it is not possible to establish an exposure limit for total welding emissions since the composition of welding fumes and gases varies greatly and the welding constituents may interact to produce adverse health effects.

"Therefore, NIOSH suggests that the exposure limits set for each welding fume constituent should be met and that welding fume emissions should be controlled with current exposure limits considered to be upper limits" (Wallace, et al 6).

The American Conference of Governmental Industrial Hygienists (ACGIH) has a TLV-TWA for welding fume-total particulate of 5mg/m^3. "The ACGIH TLV (threshold limit value) represents conditions under which it is believed that nearly all workers may be repeatedly exposed to day after day without adverse health effects" (Wallace, et al 6).

It should be noted that ACGIH is a private professional society. Its TLVs are updated frequently while PELs cannot be updated without an act of Congress or OSHA.

As a result, TLVs are often more current and usually more protective. However, industry is legally required to meet only those levels specified by OSHA PELs (Wallace, et al 6). The agency's welding fume PEL applies in those operations that involve the welding of iron, mild steel or aluminum unless a more-protective substance-specific standard may be applied (e.g., exposure to lead, cadmium, beryllium).

OSHA Requirements

29 CFR 1910.252 states:

(iii) Maximum allowable concentration.

Local exhaust or general ventilating systems shall be provided and arranged to keep the amount of toxic fumes, gases or dusts below the maximum allowable concentration below the maximum allowable concentration as specified in 1910.1000 of this part.

(2) Ventilation for general welding and cutting—(i) General ventilation shall be provided when welding or cutting is done on metals not covered in paragraphs (c)(5) through (c)(12) of this section.

(A) in a space of less than 10,000 cubic ft. per welder;

(B) in a room having a ceiling height of less than 16 ft.;

(C) in confined spaces or where the welding space contains partitions, balconies or other structural barriers to the extent that they significantly obstruct cross ventilation.

(ii) Minimum rate. Such ventilation shall be at the minimum rate of 2,000 cubic ft. per minute per welder, except where local exhaust hoods and booths as per paragraph (c)(3) of this section, or airline respirators approved by the Mine Safety and Health Administration and the National Institute for Occupational Safety and Health, pursuant to the provisions of 30 CFR Part 11 are provided. Natural ventilation is considered sufficient for welding or cutting operations where the restrictions in paragraph (c)(2)(i) are not present.

Although each individual constituent of welding fume has exposure limits, some debate has centered on what the actual exposure limit on total welding fume should be.

Some questions may arise as one reads this standard. For example, if a facility meets or exceeds the flow rate specified in the standard, yet exposure limits are exceeded, would OSHA issue a citation? If contaminants are below exposure limits yet the minimum flow rate has not been met, could the facility be cited? OSHA clarified this in a letter of interpretation dated Aug. 27, 1993.

OSHA is not issuing notices for failure to maintain specific flow rates for fixed enclosures or freely movable hoods. Instead, OSHA issues notices when "adequate" ventilation has not been provided. OSHA defines adequate ventilation as that ventilation required (natural or mechanical) such that personal exposures to hazardous concentrations of airborne contaminants are maintained below the allowable levels specified in 29 CFR 1910.1000. When permissible exposure limits are exceeded, notices may be issued for those specific exposure limits which have been exceeded and may also be issued for failure to provide adequate ventilation under the general duty provisions of the Act (OSHA "Enforcement of" 2).

According to OSHA, if the employee is wearing a welding helmet and either no respirator or a negative-pressure respirator, sampling should be performed inside the helmet and outside any respirator.

1910.252(c)(4)(iv)(B)(C) also requires specific control measures for welding materials that contain certain metals, such as precautionary labels on welding materials containing cadmium or fluorine compounds. The standard does not stop there, however. 1910.252 (c)(4)(iv)(A) requires "all filler metals and fusible granular material to carry the following notice, as a minimum on tags, boxes or other containers."

CAUTION
Welding may produce fumes and gases hazardous to health.
Avoid breathing these fumes and gases.
Use adequate ventilation.
See ANSI Z49.1-1967, Safety in Welding and Cutting, published by American Welding Society.

1910.252(c)(5), (7), (8), (9) and (10) contain requirements for welding and cutting with materials that contain zinc, lead, beryllium, cadmium and mercury. According to the standard, in all cases, work should only be performed "using local exhaust ventilation and airline respirators unless atmospheric tests under the most adverse conditions have established that the worker's exposure is within the acceptable concentrations defined by 1910.1000 of this part."

Air Sampling Methods

To determine a worker's exposure to welding fumes, a mixed cellulose ester (MCE) filter, 0.8 microns should be used. Multi-element analysis (up to 13 metals) can be achieved on a single filter (OSHA "Chemical Sampling" 2). To ensure proper sampling, the filter should be placed near the employee's breathing zone (in a hemisphere forward of the shoulders with a radius of six to nine in.). If the employee is wearing a welding helmet and either no respirator or a negative-pressure respirator, sampling should be performed inside the helmet and outside any respirator (OSHA "Correct Placement" 1, 2) (photo, above left).

According to OSHA, samples should be collected at a maximum flow rate of 2.0 liters / minute until a maximum collection volume of 960 liters is reached (OSHA "Chemical Sampling" 2). An American Industrial Hygiene Assn.-accredited laboratory should analyze the samples. Common analytical methods include NIOSH Method No. 7300, which provides a 26 metal scan, and NIOSH Method No. 0500M, which can determine exposure to total welding fume (OSHA "Occupational Safety" 6).

Having filters analyzed for total welding fume costs $15 to $20; analyzing for 10 metals common to welding fume costs $110 to $120. For both total welding fume and constituent metals, the cost is $125 to $135. Although this may sound expensive, the information gained is very valuable.

Control Methods

Once sampling results are returned, facility management must determine what (if any) corrective action is needed. For example, if results show that exposure limits are being exceeded, a respiratory protection program should be implemented until a permanent control can be developed.

In its "Occupational Safety and Health Guideline for Welding Fumes," OSHA notes several methods to control exposure to welding fume and its individual constituents.

- process enclosure;
- local exhaust ventilation (LEV);
- general dilution ventilation;
- PPE.

Other controls include using welding rods or wire that produce a low fume (since some 90 percent of the fume can come from the consumable). In addition, some welding guns can extract 95 percent of the fume (ELCOSH "Hazard Alert" 2).

When purchasing an LEV system, remember that it must be easy to move and adjust; otherwise, employees may not use it. A NIOSH study of two portable units found that the unit which performed best was the cheapest and lightest of the two (ELCOSH "Cheap Lightweight" 2).

Employees must also be aware of other protective measures.

- Remove all paint and solvents before welding or torch cutting.
- Use the safest welding method for the job. For example, stick welding creates much less fume than flux core welding.

CASE STUDY: Tennessee Plant

A study performed in a Tennessee plant demonstrated the importance of proper LEV systems. The facility had approximately 235 employees, 20 of whom were welders. They primarily performed MIG welding on small parts composed of mild steel. The company took initial area air samples, which showed total welding fume to be 2.4 mg/m^3 and personal samples of 2.6 mg/m^3.

While both results were well below the exposure limit, the company anticipated an increase in welding during the next year. In a proactive effort, it added a new general ventilation system. This system decreased area samples by 47 percent, yet had little effect on personal samples. Research revealed why: Although the negative pressure created by the new ventilation system caused

•Keep local exhaust hoods four to six in. from the fume source.

•Use air blowers to move fumes away from welders when outdoors in windy conditions.

•Keep the face far from the welding plume.

•If ventilation is not good, use a respirator (ELCOSH "Hazard Alert" 3).

Not every control method will be effective in a given setting. Therefore, a safety professional should assess conditions to determine which method or combination of methods will best suit a situation. A regular monitoring program should also be implemented.

Research Studies

According to Korczynski, "numerous studies have been conducted in the welding industry" (936); "the majority of the articles published on the welding industry cited inadequate / lack of any form of ventilation in the workplace" (943).

For example, a study conducted by the Workplace Safety and Health Branch in Manitoba, Canada, found similar results. Eight welding companies with a total of 44 welders participated in the study (Korczynski 936). "Welding activities ranged from large workpieces such as agricultural pens, grain handling equipment and transformers, to custom work on smaller pieces for the food industry. . . . The type of welding identified in all companies was electric arc welding and 90 percent was MIG on mild steel. . . . The remainder was either MIG stainless steel or tungsten inert gas on aluminum" (Korczynski 939, 940). A total of 42 welders were monitored for personal exposure to welding fumes. Nearly 60 percent were overexposed to manganese and 19 percent were overexposed to iron (Korczynski 940). "Two welders from two different companies had the two highest manganese exposures. Both had worked in isolated welding stations. One welder worked in a small confined space with no ventilation but was later relocated. The other worked in a curtained off welding station with only general ventilation. The company later purchased a fume extracting welding gun to reduce welding fume" (Korczynski 940).

According to Korczynski, 50 percent of the participating companies had only a general / dilution ventilation system, while 40 percent had no ventilation system at all (941). In addition, some LEV systems were inadequate and / or not used by the welders, who complained that the units were heavy and cumbersome to move around (Korczynski 942). Again, this highlights the need to ensure that portable ventilation equipment is easy to move and adjust. Based on the findings of this study, the participants were advised to improve ventilation systems, train welders to properly maintain the ventilation equipment and implement a regular monitoring program (Korczynski 944).

A study in New Zealand noted similar results. "Only 16.1 percent of the current welders welded with functioning local exhaust ventilation and 65 percent did not normally use respiratory protection of any form" (Korczynski 943).

Companies in the U.S. are not immune to

the fume to move more quickly to the filters, it was still passing through the welder's breathing zone.

To solve this problem, the company purchased portable exhaust ventilation units (photos at right). These units moved 740 cubic ft. of air per minute and were positioned to pull the fume out of the welder's breathing zone. The units are lightweight and are easily manipulated by employees. The combination of local exhaust and general ventilation reduced the amount of welding fume exposure by 51 percent.

This study was performed over a six-month period at a final cost, including improvements implemented, of $46,000. Although less-expensive methods were available, this approach best fit the firm's current and future needs.

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such problems. Studies performed in five plants in the Midwest (three in Illinois, one each in Iowa and Michigan) found overexposures to iron oxide (Korczynski 943). A study in an Arkansas plant determined that air velocities of the existing LEV system were generally inadequate to capture fumes emitted during the various operations. The researchers recommended that the local exhaust system be upgraded and that welding operations in the plant be conducted inside appropriate booths (Korczynski 943).

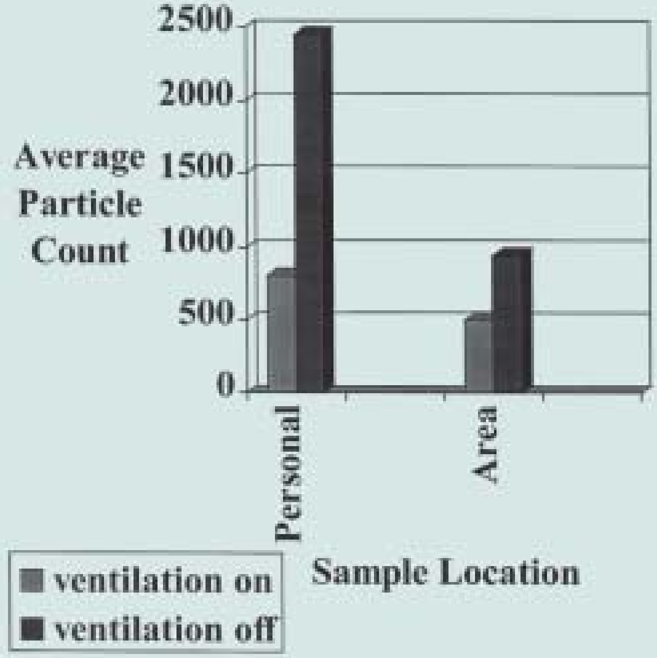
A safety professional should assess conditions to determine which control method or combination of methods will best suit a situation.

The Engineering Control Technology Branch of NIOSH conducted a study of welding operations and exposures to welding fume at the Boilermaker's Apprenticeship Training School. Data from this study support the use of LEV in controlling exposure to welding fume. During the study, personal and area samples were both significantly lower with ventilation on than with it off (Wallace, et al 21). "In 1996, NIOSH engineers looked at two portable LEV units in a controlled setting. Without LEV, total welding fume concentrations ranged from 2 to 60mg/m^3. Ventilation reduced the fumes to 3 to 13mg/m^3. . . . Although the measurements were not always below the exposure limits the equipment cut fumes and, thus, the risk of illness" (ELCOSH "Cheap Lightweight" 1, 2). Figure 1 provides a graphic representation of the results.

Figure 1

Figure 1

Effect of Ventilation on Particle Count Data (>3µ) Inside the Building



Conclusion

As a NIOSH literature review on welding and lung cancer revealed, welders have a 40 percent increased risk of developing occupationally induced lung cancer (Korczynski 937). This fact is compounded by the continued introduction of new welding processes, techniques and materials (Wallace, et al 4). As a result, welding will likely be a high priority for regulators—and, thus, for industry—in the coming years. ■

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