Welding Fume Control: Regulations and Processes

ENVH 557
Workplace Exposure Controls
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Loren Kaehn, Jannette Kibogy, Danielle Parette, & Ben Wischmeier

Welding is a process that joins two work pieces together by heating them to their melting points and allowing them to cool together. Aside from heat, pressure or a filler material is sometimes used. Once the molten metal cools, the weld is the strongest method of joining metals (as opposed to nuts/bolts, screws, nails, etc.). For this reason, welding is widely used in industry. However, fumes given off from welding processes contain various components which are dangerous to human health, and cause a variety of illnesses. For this reason proper control of welding fume is necessary to maintain a safe and healthy work environment.

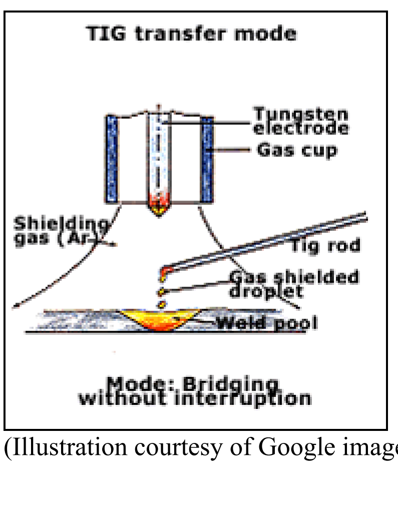
Welding overview

Arc Welding[1]:

Arc welding involves using two alligator clips that send a strong electrical current between them. One clip is attached to the work piece, while the other is attached to an electrode, which is sometimes covered in a flux material. When the two pieces are touched together by a worker, the rod and work piece complete the circuit and an electrical current is sent between them, producing enough heat to melt both pieces, bonding them together. This can also be done by machinery, where the two work pieces are positioned in between the clips, and a button is pushed to send the electricity through the electrodes.

Gas Tungsten Arc Welding (TIG) [1]:

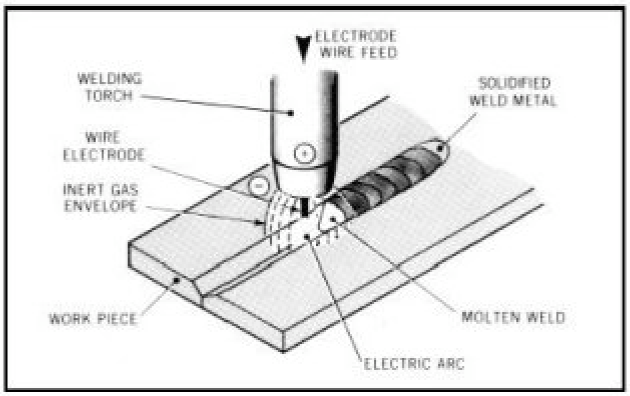
With TIG welding, an arc is formed between a non consumable tungsten electrode and the metal being welded. An inert gas, such as argon, is fed through the torch of the welding gun to create a shielded area around the welding pool and electrode. This is done to protect the weld from atmospheric gasses that can reduce the quality of the weld. If a filler metal is used, it is added separately to the weld area.



(Illustration courtesy of Google images)

Gas Metal Arc Welding (MIG)[1]:

MIG welding is very similar to TIG welding. However, a continuous and consumable wire electrode is also fed through the welding gun. This permits a shorter welding time because the welder doesn't have to stop to get a new filler rod.



(Illustration courtesy of Google images)

Raw Materials, possible exposures:

The raw materials used in welding vary from many different types of metals (i.e. stainless or mild steel), to thermoplastics. Filler material is also sometimes used to increase the strength of the weld. Filler is usually composed of a compatible metal. When the raw material and/or filler rod is melted, fumes are generated that contain gases/particles of the components of the material. For many steels, this includes nickel, manganese, and Chromium VI. The airborne particles are then available to be inhaled.

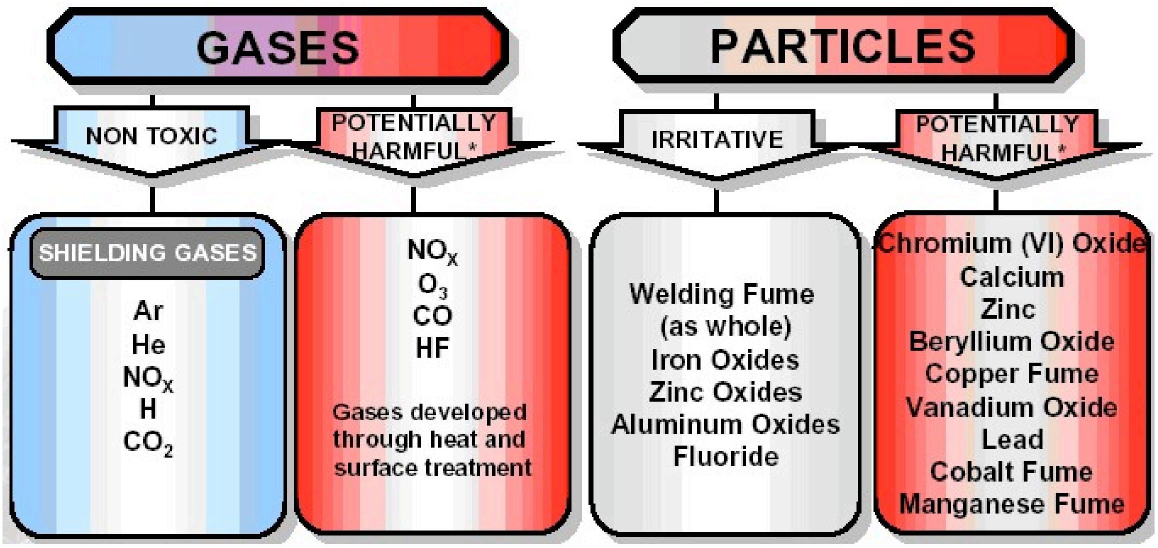
Ventilation concerns:

Finding a balance between ventilation to control human exposure, and not disturbing the inert area surrounding the weld during MIG and TIG welding is extremely important.

Illness associated with particular welding:

Most illnesses related to welding are due to inhalation of welding fumes and affect the respiratory system. The most dangerous exposures come from Chromium VI (Cr VI), Manganese, and Nickel, all of which are components in stainless steel. Cr VI has been shown to cause asthma, bronchitis, nasal perforation and lung cancer. It can also cause liver and kidney damage[17]. Nickel can also affect the liver and kidney, as well as cause allergic reactions, respiratory difficulties such as asthma, chronic bronchitis, and decreased lung function, and lung and nasal/sinal cancer.[16] Manganese has a more substantial effect on the neurological system. Over exposure to manganese can cause mood changes and reduced neurological responses. It also causes a disease known as Manganism, which is a disease that mimics Parkinson's disease, including shakes and tremors. Other symptoms of Manganism include impaired hand-eye coordination, weakness/lethargy, speech difficulty, psychological problems, and respiratory difficulties[2].

Hazardous exposures related to welding:



Graphic courtesy of www.etox.com

<u>Fume control methods</u>

As fume exposure is a major hazard created by welding operations, OSHA requires that either local exhaust ventilation (LEV) or general ventilating systems be provided and arranged to keep the fume, dust, particulate, and gas exposure levels below the permissible exposure limits[3]. Four typical control methods are used to maintain a safe level of exposure. These methods are: process enclosure, general mechanical ventilation, LEV, and personal protective equipment (PPE)

Process Enclosure (automatic welding):

As complex as welding is in the manufacturing process, some companies have spent millions of dollars to automate assembly of welding for frequent, repetitive welding operations. By using robotic devices to automate welding, the entire process can be enclosed within an area, limiting worker exposure to welding fumes.

Automatic welding consists of two categories: semi-automatic, and fully automatic. With semi-automatic, a machine operator loads parts into a welding fixture, and then a weld controller keeps the process, motion of the torch, and stillness of the parts to preset conditions. After the weld is complete, the operator removes the finished product, and the process starts all over[6].

For fully automatic welding, a machine, or series of machines load the workpeices, positions the torch, does the weld, checks the quality of the joint, and unloads the product. Depending on the type of operation, a machine operator may be necessary[6].

Automatic welding is used in the automobile industry, pipeline assembly, and other metal fabrication processes.

General Mechanical Ventilation:

Natural ventilation is considered sufficient for welding or cutting operations when the conditions do not meet those given under 29 CFR 1910.251-255.

LEV:

LEV is needed when employees are exposed to chemicals with a high toxicity, when large amounts of welding fume are generated, or if there is an increased cost from heating and ventilating in the winter.

LEV is created when a fan draws air through the ventilation system from an area of high pressure to an area of low pressure. The local exhaust is located as close to the source of contamination as possible to capture the contaminant before it is released into the work area.

LEV operates with five basic elements* [5]:

1. A "hood" or opening that captures the contaminant at the source,
2. Ducts that transport the airborne contaminants through the system,
3. An air cleaning device (not always required) which removes the contaminant from the moving air in the system
4. A fan that moves the air through the system and blows it outdoors,
5. An exhaust stack through which the contaminated air is discharged.

**In order for the system to operate properly, makeup air must be provided to replace the exhausted air.*

Hoods can be broken down into three basic types[9]:

1. *Receiving Hood:* This hood is designed to receive the emissions of a source.
2. *Capture Hood:* This is a hood with one to three sides. A welding snorkel-type of hood is normal, but others include side-draft and down-draft.
3. *Enclosing Hood:* This is a hood with four or more sides and some form of vacuum. These hoods are designed to enclose the contaminant and limit its emission into the workplace.

Vacuums for LEV contaminant source extraction are divided into two types, both dependant on factors, such as air velocity, CFM, welder position, and ambient air movement[8]:

1. **Low Vacuum:** Low vacuum = high volume of air displaced
   - Operates 6"+ from weld source
2. **High Vacuum:** High vacuum = low volume of air displaced
   - Operates 2"-4" from weld source

PPE:

Protective clothing and equipment must be worn during all welding operations. Helmets and shields must be used to protect the eyes and face from ultraviolet light and infrared rays and hot metal particles. Helmets include lens holders which hold dark lenses designed to prevent flash burns and eye damage. These lenses absorb the infrared and ultraviolet rays produced by the arc during welding.

The appropriate personal protective clothing required for a welding operation varies with the size, location and nature of the work being performed. Clothing free of openings or gaps should be worn to prevent skin contact with hot metal particles or arc rays. Wool is preferred over cotton since wool is not easily burned. Personnel who work close to arc welding should always wear flameproof leather gloves and other protective clothing, such as leather aprons, a cape and bib, a coat, leg apron, and/or sleeves (see photo below).

(Photo courtesy of www.stsosha.com)

If working in confined spaces or where a hazard to sharp or falling objects exists, hard hats or head protectors should be used, as well as steel-toed boots and ear protection.

Screens should be provided in any area to protect nearby workers or passers-by from the welding glare. The screens should be positioned so that they are about 2 ft above the floor, but do not restrict ventilation. The screens are also painted with special paints that absorb ultraviolet radiation – usually light pastel colors of a zinc or titanium dioxide base[4].

Respiratory protection should also be provided, and is dependent on the type of welding job being performed and the ventilation being supplied. Air purifying respirators, such as disposable half-mask respirators can be worn in some conditions. In other conditions, such as confined spaces, supplied air respirators which provide clean, breathable air from an uncontaminated source may have to be used.

Research Review

Welding is a widely used process in industrial activities and it is therefore important to ensure that welders are well protected from any hazard associated with the process. The health effects of welding fumes have been studied for a long time and great effort has been made to mitigate exposure to welding fumes. However, even with the current technology levels, proper control of welding fumes is difficult to achieve and welders are still exposed to these hazardous fumes[10].

Various studies done on welding industries shows that most of the workplaces either lack or have inadequate general ventilation systems. In addition, these workplaces also have inadequate LEV systems; do not use them properly or as often as required[10]. The poor use of the LEV system occurs mainly due to the cumbersome nature and weight of the system. Employers are encouraged to invest in a slightly expensive but easily adjustable LEV system, than cheaper, cumbersome ones that will be underutilized. Another factor that contributes to increased exposure to welding fumes is the poor set up and maintenance of the LEV systems. The air velocities are usually set at levels that may not be adequate to capture all the generated fumes thus allowing it to enter the workers breathing zone.

Although ventilation is generally considered the most effective control method during welding[12], research shows that various factors such as: 1) fume generation rate; 2) welders head position; 3) position of LEV; all affect the ability of the LEV to control the fumes and should incorporated into the control strategies[10,11,14]. The fume generation rate is dependant on the type of welding being performed and the type of metal being welded. The table below shows weld fumes generation ratios for the various welding methods. This information can be used to determine the amount of fume being generated and consequently, the air velocity needed to adequately capture those fumes[15].

Table 1 - Weld Fume Ratios

Welding Process	**Metal Type**	**Range Weight of Fumes/Weight of Deposited Material**
FCAW	Carbon Steel	0.9-2.4 %
	Stainless Steel	0.9-2.4 %
SMAW	Carbon Steel	1.1-5.4 %
	Stainless, High Alloy	0.3-1.4 %
GMAW	Carbon Steel	0.3-0.9 %
	Stainless Steel	0.6-7 %
	Copper/Aluminum	0.5-1.6 %

The welders' position relative the fume source is also important in keeping exposure levels down. An assessment done by NIOSH on outdoor welding found that the position of the welder significantly affected the LEV's ability to control welding fumes[13]. The same effect can be expected for indoor welding as well and welders should be aware of their body position relative to the LEV system. It is also very critical to ensure that the adjustable LEVs are well positioned or moved to appropriate positions during the course of the welding for maximum capture of the fumes.

In summary, exposure to welding fumes in the workplace will vary depending on length of welding, methods and materials used for welding, and more importantly, the control strategies in place. Every workplace is unique, and a full exposure assessment should be made in order to determine adequate control measures.

Regulations and Standards – Welding Applications

The regulations and standards that relate to welding in the workplace include acceptable exposure limits, specific requirements for ventilation, and appropriate types of personal protection equipment (PPE). Regulations are mandated by federal and state laws, while industry standards are recommended best practices.

Exposure Limits:

Exposure limits include both regulatory and non-regulatory limits on allowable concentrations in the workplace. A comprehensive summary off applicable Occupational Exposure Limits (OELs) is provided in the appendices. Identifying potential contaminants in welding applications can be complex, due to the varied nature of the contaminants. Gases, vapors, metal fumes and particulates can all pose respiratory hazards. OSHA, WISHA and ACGIH set the following OELs:

- ACGIH Threshold Limit Values
- 1910.1000 Permissible Exposure Limits[19]
    - State Limits
- 1910.1026 Chromium (VI)
    - Standard lowered to .005 mg/m3 2/2007
    - Action level of .0025 mg/m3
        - E.g. monitor every 6 months, medical surveillance

Assessment of concentrations of contaminants in the workplace is conducted via the following methods[21]:

- Metals analysis – 26 or 13 metals
- Hexavalent Chromium – separate analysis
- Welding Fume
- Gases (CO, Ozone, NOx)

Ventilation Regulations:

A number of specific ventilation requirements are provided for in state and federal OSHA standards, primarily 29 CFR 1910.251-255. Substance specific standards, such as the Hexavalent Chromium standard, also call for engineering controls to be implemented.

1910.251-255 Welding

- Mechanical ventilation is required if:
  - Ceiling is <16 feet or room volume is <10,000 cf^3
  - General exhaust must be 2000 CFM per welder
  - Working in confined space
- Local exhaust is required if:
  - Lead, Cadmium, Beryllium or Mercury is welded on
  - Minimum 100 fpm at welding source

1910.1026 Chromium

- Engineering controls when exposures greater than the PEL
  - Unless “not feasible”
- Set up regulated areas
  - Mark off areas
  - Prohibit access to unauthorized employees
  - HEPA vacuum preferred vs. dry sweeping
  - Properly dispose of wastes
- Worker rotation not permitted
- Provide PPE
  - Clean and launder
  - Provide change rooms

Ventilation Industry Standards

A number of industry standards also apply to providing appropriate ventilation in welding processes. For design of new systems, the ACGIH lays out recommended designs (see appendices). ANSI and the American Welding Society also have standards for welding.

- 10.90 Welding and Cutting, ACGIH Ventilation Manual[18]

  - ACGIH Order of effectiveness of controls: enclosing hoods, vacuum nozzles, fixed hood on a worktable or rectangular hood fixed above a worktable, moveable hood above a worktable, moveable hood hanging freely or overhead canopy, dilution ventilation

- ANSI/AWS Z 49.1 Safety in Welding and Cutting[20]

Respiratory Protection Equipment

OSHA mandates regulations and industry groups provide guidance for the appropriate PPE to wear during welding work. When exposures require protection, equipment with the appropriate assigned protection factor should be provided[22]. Half face respirators and PAPR are commonly used in welding shops.

Respiratory Protection	**Assigned Protection Factor**

P100 Filtering Facepiece	10 x OEL
Half face respirator	10 x OEL
Powered Air Purifying Respirator – loose fitting	25 x OEL
Full face respirator	50 x OEL
Powered Air Purifying Respirator – tight fitting	1000 x OEL
SCBA	1000 x OEL

For example, full shift exposures to Hexavalent Chromium greater than 5 ug/m3 would require a P100 filtering facepiece or half face respirator. Exposures greater than 50 ug/m3 would require a PAPR or full face respirator.

Shop Inspection

Our group investigated a campus sheet metal shop to review applicability of standards and regulations in welding operations. The shop typically TIG and MIG welds mild and stainless steel for Heating, Ventilation and Air Conditioning (HVAC) applications. Oxygen-acetylene cutting is also conducted in the shop. No arc welding is conducted.

Local exhaust ventilation was examined and found to be in partial compliance with OSHA regulations for capture velocity. The plain duct unit exceeded the required 100 fpm for work at distance of 6, 9 and 12 inches from the hood. The flanged unit in the shop had capture velocities less than 100 fpm at 6 inches. If the unit was positioned close to the work (e.g. within 2-3 inches), it may meet federal or state requirements.

We also examined the units total exhaust volume and face velocities. Both the flanged and plain duct unit measurements were lower than those specified by ACGIH. Duct measurements were also taken, although the measurement was not taken in the main overhead duct and this measurement can be discounted.

Improvements could likely be made to this system. There were a few holes observed in the ducting and near the plain duct hoods opening. Investigation and preventative maintenance of the systems fan is recommended to ensure it is working at the designed capacity. Also, a galvanized metal hood would be preferable to the flex ducting that is currently installed on the plain ducts opening. Slag has melted numerous holes in the ducting. See the ACGIH diagram in the appendices below for an example.

It is also recommended that exposure monitoring be completed during stainless steel welding to ensure compliance with the OSHA Hexavalent chromium standard.

References:

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14. http://www.osha.gov/SLTC/weldingcuttingbrazing/report_boilermakers/boilermakers.html
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17. Public Health Statement for Nickel. Agency for Toxic Substances and Disease Registry, August 2005.
18. Public Health Statement for Chromium. Agency for Toxic Substances and Disease Registry, September 2000.
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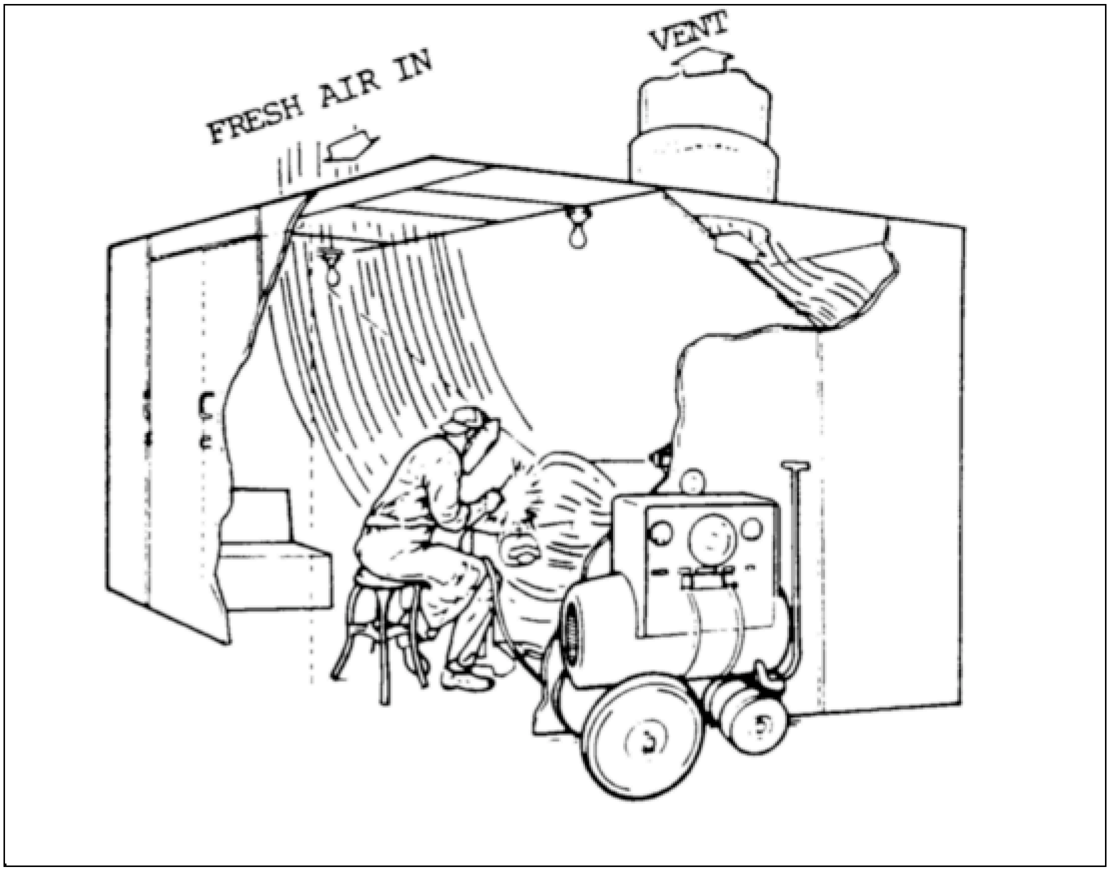
20. Occupational Safety and Health Administration, www.OSHA.gov
21. AWS/ANSI Z49.1, http://www.aws.org/technical/facts
22. Clayton Laboratory Online, http://labonline.claytongrp.com
23. 3M Respirator Selection Software, http://rsel.3m.com/rsel

Appendix

Welding or Cutting Operation	Electrode Size Metal Thickness or Welding Current	Filter Shade Number
Torch soldering	-	2
Torch brazing	-	3 or 4
Oxygen cutting		
Light	Under 1 in., 25 mm	3 or 4
Medium	1 to 6 in., 25 to 150 mm	4 or 5
Heavy	Over 6 in., 150 mm	5 or 6
Gas welding		
Light	Under 1/8 in., 3 mm	4 or 5
Medium	1/8 to 1/2 in., 3 to 12 mm	5 or 6
Heavy	Over 1/2 in., 12 mm	6 or 8
Shielded metal-arc	Under 5/32 in., 4 mm	10
welding (stick)	5/32 to 1/4 in., 4 to 6.4 mm	12
electrodes	Over 1/4 in., 6.4 mm	14
Gas metal-arc welding (MIG)		
Non-ferrous base metal	All	11
Ferrous base metal	All	12
Gas tungsten arc welding (TIG)	All	12
Atomic hydrogen welding	All	12
Carbon arc welding	All	12
Plasma arc welding	All	12
Carbon arc air gouging		
Light	-	12
Heavy	-	14
Plasma arc cutting		
Light	Under 300 Amp	9
Medium	300 to 400 Amp	12
Heavy	Over 400 Amp	14

(Table courtesy of www.fortunecity.com)



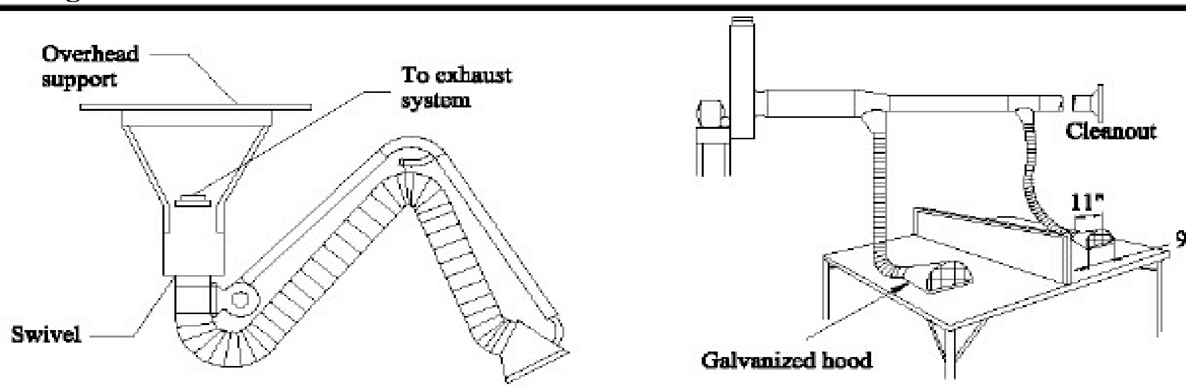
(Drawing courtesy of www.fortunecity.com)

Welding Exposure Limits

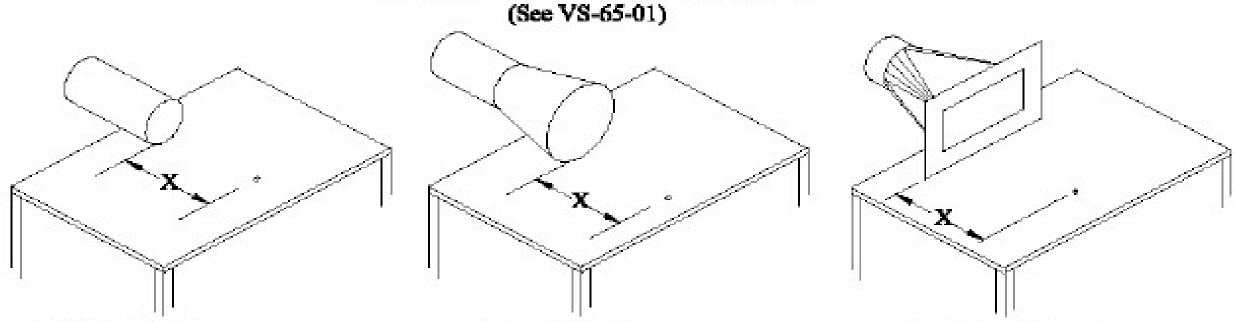
Component Description	OSHA PEL-TWA (µg/m3)	NIOSH REL-TWA (µg/m3)	ACGIH TLV-TWA (µg/m3)
Aluminum Fume	15000 (Total) 5000 (Respirable)	5000	5000
Arsenic	10	2(Ceiling)	10
Barium compounds, sol, as Ba	500	500	500
Beryllium & compounds,a s Be	2	.5(Ceiling)	2
Calcium oxide	NA	2000	2000
Cadmium Fume	5	LFC(Ca)	10(Total) 2(Respirable)
Chromium VI compounds, sol	NA	1	50
Cobalt oxide, as Co	100	50	20
Copper fume, as Cu	100	100	200
Iron Oxide, as Fe	10,000	5000	5000
Lithium	NA	NA	NA
Magnesium oxide	15000	NA	10000
Manganese	5000(Ceiling)	1000	200
Molybdenum	5000(Soluble) 15,000(Insoluble)	NA	5000(Soluble) 10,000(Insoluble)
Nickel, insol compunds as Ni	1000	15(Ca)	1000
Lead	50	100	50
Phosphorous	100	100	100
Platinum	2(Soluble)	1000(Metal) 2(Soluble)	1000
Selenium	200	200	200
Silver	10	10	100
Sodium	NA	NA	NA
Tellurium	100	100	100
Thallium	100	100(Soluble)	100
Titanium Dioxide	15,000	LFC(Ca)	10000
Vanadium pentoxide	100(Ceiling)	50(Ceiling)	50
Yttrium	1000	1000	1000
Zinc Oxide, fume	5000	5000	5000
Zirconium	5000	5000	5000
Welding Fume	NA	LFC(Ca)	NA

Welding Ventilation - ACGIH Ventilation Manual

FIGURE VS-90-02



FLEXIBLE EXHAUST CONNECTIONS
(See VS-65-01)



PLAIN DUCT | CONE HOOD | FLANGED HOOD

RATE OF EXHAUST

X, inches	Plain duct cfm	Flange or cone, cfm
Up to 6	335	250
6-9	755	560
9-12	1335	1000

Face velocity = 1500 fpm
Minimum duct velocity = 3000 fpm
Plain duct entry loss = 0.93 VP_d
Cone entry loss = 0.25 VP_d
Flange entry loss = 0.50 VP_d

Notes:

1. Locate work as close as possible to hood.
2. Hoods perform best when located to the side of the work.
3. Ventilation rates may be inadequate for toxic materials.
4. Velocities above 100-200 fpm may disturb shield gas.

GENERAL VENTILATION, where local exhaust cannot be used :

Rod, diam.	cfm/welder
5/32	1000
3/16	1500
1/4	3500
3/8	4500

OR

A. For open areas, where welding fume can rise away from the breathing zone:
cfm required = 800 x lb/hour rod used

B. For enclosed areas or positions where fume does not readily escape breathing zone:
cfm required = 1600 x lb/hour rod used

For toxic materials higher airflows are necessary and operator should use respiratory protection equipment.

Other types of hoods
Bench, see VS-90-01
Booth, for design see VS-90-30
Q = 100 cfm/ft^2 of face opening

ACGIH® WORLDWIDE

TITLE
WELDING VENTILATION
MOVABLE
EXHAUST HOODS

FIGURE VS-90-02

DATE 1-91

AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS

Ventilation Requirements

Face Velocity Standards

Standard	Requirement (fpm)
ACGIH	1500

Exhaust Rate Standards - ACGIH

Distance from Hood (in)	Flanged Units (CFM)	Plain Duct Units (CFM)
6	250	335
9	560	755
12	1000	1335

Capture Velocity Standards/Regulations

Standard	Requirement (fpm)
OSHA	100
ACGIH	100-170
ANSI/AWS	100 max.

Duct Velocity Standard

Standard	Requirement (fpm)
ACGIH	3000

Face Velocity Standards - Canopy Hood

Standard	Requirement (fpm)
ACGIH	50-500 fpm

Sheet Metal Shop Inspection Results

Measured Velocity

	Flanged Unit (fpm)	Plain Duct Unit (fpm)
Face Velocity	271	1306

Face Velocity Standards

Standard	Requirement (fpm)
ACGIH	1500

Exhaust Rate

	Flanged Unit (fpm)	Plain Duct Unit (fpm)
Rate (Q)	213	256

Exhaust Rate Standards - ACGIH

Distance from Hood (in)	Flanged Units (CFM)	Plain Duct Units (CFM)
6	250	335
9	560	755
12	1000	1335

Capture Velocities

Distance from Hood (in)	Flanged Unit (fpm)	Plain Duct Unit (fpm)
6	60	160
9	50	110
12	30	60

Capture Velocity Standards/Regulations

Standard	Requirement (fpm)
OSHA	100
ACGIH	100-170
ANSI/AWS	100 max.

Duct Velocity

Distance Upstream from Hood	Plain Duct Unit ("of H2O)	Plain Duct Unit (fpm)
1 foot	0.17	1650

Duct Velocity Standard

Standard	Requirement (fpm)
ACGIH	3000

Velocity - Canopy Hood

	Canopy Hood (fpm)
Face Velocity	50

Face Velocity Standards - Canopy Hood

Standard	Requirement (fpm)
ACGIH	50-500 fpm