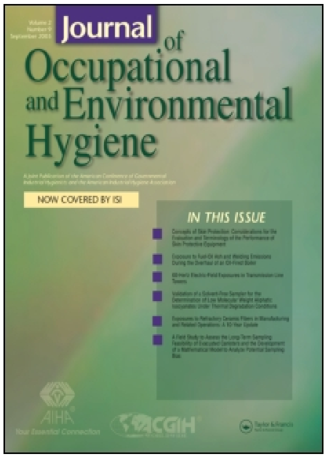

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Manganese and Welding Fume Exposure and Control in Construction

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Overexposure to welding fume constituents, particularly manganese, is of concern in the construction industry due to the prevalence of welding and the scarcity of engineering controls. The control effectiveness of a commercially available portable local exhaust ventilation (LEV) unit was assessed. It consisted of a portable vacuum and a small bell-shaped hood connected by a flexible 2 inch (50.8 mm) diameter hose, in both experimental and field settings. The experimental testing was done in a semienclosed booth at a pipefitter training facility. Five paired trials of LEV control vs. no control, each approximately 1 hr in duration and conducted during two successive welds of 6 inch (152.4 mm) diameter carbon steel pipe were run in random order. Breathing zone samples were collected outside the welding hood during each trial. In the field scenario, full-shift breathing zone samples were collected from two pipefitters welding carbon steel pipe for a chiller installation on a commercial construction project. Eight days of full-shift sampling were conducted on both workers ($n = 16$), and the LEV was used by one of the two workers on an alternating basis for 7 of the days. All samples were collected with personal sample pumps calibrated at 2 L/min. Filter cassettes were analyzed for total particulate and manganese concentration by a certified laboratory. In the experimental setting, use of the portable LEV resulted in a 75% reduction in manganese exposure (mean 13 $\mu g/m^3$ vs. 51 $\mu g/m^3$; $p < 0.05$) and a 60% reduction in total particulate (mean 0.74 mg/m^3 vs. 1.83 mg/m^3; $p < 0.05$). In the field setting, LEV use resulted in a 53% reduction in manganese exposure (geometric mean 46 $\mu g/m^3$ vs. 97 $\mu g/m^3$; $p < 0.05$) but only a 10% reduction in total particulate (geometric mean 4.5 mg/m^3 vs. 5.0 mg/m^3; $p > 0.05$). These results demonstrate that LEV use can reduce manganese exposure associated with welding tasks in construction.

Keywords construction, exposure control, local exhaust ventilation, manganese, welding

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The contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute for Occupational Safety and Health.

INTRODUCTION

As part of an ongoing research effort by the Center to Protect Worker's Rights (CPWR), this article presents

- a brief review of the literature examining neurological health risks associated with exposure to welding fume and, in particular, manganese;
- an overview of welding in construction; and
- the preliminary results of an evaluation of a portable local exhaust ventilation (LEV) unit used to reduce manganese exposure among construction welders.

Neurological Health Risks Associated with Exposure to Welding Fume/Manganese

Manganese poisoning or manganism was identified years ago, primarily in miners, ore crushers, and ferroalloy workers. Symptoms include headache; spasms; weakness in the legs; and a characteristic psychosis with euphoria, impulsiveness, and mental confusion. As the disease progresses, a range of neurological manifestations are possible, including speech disturbance, gait, balance problems, tremor, and excessive salivation or sweating. The neurological toxicity of manganese is well established, although there is variation in individual susceptibility.(1,2)

There is now considerable evidence that exposure to manganese at levels much lower than those observed historically can result in neurological impairment, and the term manganese-induced parkinsonism (MIP) appears more frequently in the literature.(2,3) An overview paper(4) identifies three different types of neurotoxicity from manganese exposure. The first is massive exposure producing manganism. Second is the decline in performance on neurological tests, noted in manganese-exposed workers. Finally, manganese exposure may play a role in some cases of Idiopathic Parkinson's Disease (IPD). The article raises the question "Are these all simply different manifestations of the same disease spectrum, at least partially reflective of differences in exposure circumstances?" and while the author outlines some of the research needed to answer the question, he concludes "... there is sufficient concern based on available evidence that preventive strategies should not await further research."[4,p.349]

The literature addressing the relationship between neurological disease and welding consists primarily of case reports and small-scale epidemiologic investigations. Parkinsonian symptoms in welders attributed to manganese exposure have been reported in numerous studies.[5−14] Epidemiologic investigations exploring the association between Parkinson's disease and welding exposures have been mixed and inconclusive. Studies by Racette et al.[15,16] provided some interesting associations between welding and Parkinson's disease. In the first study[15] they found a statistically significant difference in the age of onset for Parkinson's disease between the welders (46 years) and a control group (63 years).

The authors concluded that welding may be a risk factor for Parkinson's disease and that a genetic contribution to susceptibility in the exposed individuals was possible. In the later study, Racette et al.[16] observed a higher prevalence of parkinsonism in welders than in the age adjusted general population. However, other studies[17,18] have not found any associations, and further research is needed to more specifically clarify the relationship between welding exposures and manganese-induced parkinsonism.

Welding in Construction

The construction industry represents a large and growing segment of the U.S. economy. From 2002 to 2012, the number of workers in the United States is expected to increase by 17 million, representing a 12.0% growth rate. In construction, during the same period, an increase of approximately 1.1 million workers is projected, representing a 16.4% growth rate. Trades expected to see the largest gains include welding trades, such as sheet metal workers and pipe fitter/plumbers, that are expected to see employment growth of 22.8% and 22.5%, respectively.[19] As of January 2006, the Bureau of Labor Statistics estimates there were 7.5 million construction workers based on seasonally adjusted data.[20]

Estimates on the number of workers exposed to welding fumes range from 410,000 full-time welders to more than 1 million who weld intermittently.[21] Within the construction industry, welding is performed routinely by pipe fitters, ironworkers, boilermakers, and sheet metal workers. Other trades may also weld (e.g., millwrights and glaziers) and perform thermal cutting of metals (e.g., laborers). Employment figures for these trades are presented in Table I.[22] Work often occurs in process vessels, such as tanks or boilers, or other poorly ventilated settings. Engineering controls for health hazards, such as local exhaust ventilation, are rarely used on most U.S. construction sites.[23] Given the potential for poorly controlled metal fume exposures, there is increasing concern that exposure to welding fumes may be a cause of manganese-induced parkinsonism and that construction workers may be at risk for these preventable disorders.

TABLE I. Employment of Selected Occupations in the United States

Occupation	Employment Number
Construction laborers/helpers	1,861,100
Pipe fitters/plumbers	478,523
Welding, soldering, and brazing	95,783
Sheet metal workers	88,867
Structural iron workers	43,674
Glaziers	28,181
Millwrights	13,988
Boilermakers	10,235

Note: Figures are from the Current Population Survey national household survey. Weighted estimates are generally reliable for subgroups over 30,000 but may not be accurate for smaller subgroups.

Welding is a major process in construction. It is used to join together structural steel used in buildings, bridges, and other structures; for piping used in heating and ventilation systems as well as industrial process piping; for duct work, laboratory hoods, tanks, boilers, and process vessels. Welding may also be used for ornamental purposes, such as handrails or other nonstructural applications. Thermal cutting, which also involves the generation of metal fumes, is common in construction for demolition and for cutting steel rebar and other materials.

There are a number of attributes of the construction industry that present different, often greater, occupational exposure risks than in other industries. First, the worksite is temporary, nonfixed, and changing as construction progresses. As a result, work process hazards are often not well controlled. Because work must be done in a highly mobile fashion and often outdoors or remote from ready access to power, work processes that conform to these limitations are generally required.

For example, shielded metal arc welding, which is less sensitive to wind than gas welding and allows for easy movement on the part of workers, is generally the preferred welding method. Construction workers are more likely to work longer hours and move from job to job over the course of their career. About 42% of construction workers report usually working more than 8 hours/day vs. 31% of workers in other occupations.[24] In such cases, occupational exposure limits based on 8-hour time-weighted average exposures may not be adequately protective. In addition, construction workers are often employed on large, multiemployer projects where other trades may generate hazardous exposures for which they are inadequately protected.

Although construction welding trades share similar skills, their specific job descriptions differ. Boilermakers fabricate, install, and repair boilers, vats, and other vessels. Often they are employed in power plants and industrial settings, such as refineries. The nature of their work involves regular entry into confined spaces. Pipe fitters install and repair piping used in power plants, industrial, and manufacturing facilities and in heating and cooling systems. Sheet metal workers fabricate and install heating and ventilation system components, duct work, laboratory hoods, restaurant equipment, and countertops, and test and balance air conditioning and ventilation systems. Ironworkers (or structural ironworkers) erect steel columns and girders that make up the structural framework of buildings, bridges, and other large structures such as water towers. Welding is involved in a large number of the tasks described above.

According to union safety and health representatives from the United Association, International Brotherhood of Boilermakers and the Ironworkers, the most common welding process used by pipe fitters, boilermakers, and ironworkers is shielded metal arc or stick welding. A representative from the Sheet Metal Workers Union states that manual inert gas welding (MIG) is the most common welding process for their members followed by tungsten inert gas welding (TIG). According to a laborers' union representative, oxy-acetylene torch cutting is the most common "hot work" process in their trade. Torch cutting is also often done by pipe fitters, sheet metal workers, and ironworkers.

The second most common welding process employed among boilermakers and pipe fitters is gas tungsten arc (TIG) welding. Flux-cored welding is the second most common welding process among ironworkers and is also used to a lesser extent by boilermakers, pipe fitters, sheet metal workers, and laborers.

Pipe fitters, boilermakers, sheet metal workers, and ironworkers often weld both mild and stainless steels. In addition, ironworkers and sheet metal workers often weld aluminum and galvanized. The most common metal worked by sheet metal workers is galvanized. As for environmental conditions, boilermakers and sheet metal workers often work in confined or enclosed spaces. Ironworkers work in such environments occasionally and pipefitters rarely. Ventilation is often used on pipe fitter jobs; however, this is generally limited to fans used to dilute welding fumes as opposed to local exhaust ventilation. Ventilation is occasionally used on boilermaker jobs, depending on the contractor and U.S. location. Ventilation is often used in sheet metal shops, but rarely used in the field among sheet metal workers.

EXPOSURE/CONTROL STUDIES

Numerous welding exposure and control studies have been conducted, some of which include information on manganese. A good overall review of welding exposures can be found in Burgess.[25] Table 10.11 of that text identifies ranges of exposures to manganese (in mg/m^3) for various types of welding. Shielded metal arc (stick welding) has a range of 0.01–1.0; gas metal arc is reported at 0.01–0.05; gas metal flux core is listed as 0.02–2.0; and gas welding is 0.01–0.05.

In one study on the effectiveness of fume extraction guns for welding operations the authors conclude: "The geometric mean data show that the use of ventilation resulted in less than half the exposures than when no ventilation was used."[26,pp.219–220] The authors noted that, in general, flux cored arc welding (FCAW) had the highest exposures, followed by gas metal arc (GMAW), and then gas tungsten arc (GTAW). The geometric mean exposures to manganese (in mg/m^3) for the various welding processes are as follows: FCAW = 0.56 (N = 20), GMAW = 0.11 (N = 11), and GTAW = 0.003 (N = 10).

In the case of flux cored welding, comparisons for the effectiveness of ventilation indicated that with ventilation on, the geometric mean exposure to manganese was 0.49, with it off 0.96. The ventilation was either a Lincoln integrated unit with the extraction built right into the gun, or a conventional unit with a Tweco suction attachment. The authors concluded that using substitute welding methods instead of FCAW was the most important factor for control.

In a control technology assessment[27] of welding operations at the Boilermaker's National Apprentice Training School, National Institute for Occupational Safety and Health (NIOSH) investigators concluded that welders were overexposed to hexavalent chromium, arsenic, total chromium, iron, manganese, and nickel. They further stated that while LEV did help to reduce levels, the reductions were not completely effective and that the wind and position of the welder may have adversely impacted the ventilation. The investigators found, not unexpectedly, that the welder who "had his face in a direct line with the welding plume" had higher exposures than the worker who "kept his face at an angle to the plume."

Significant exposures to welding fume have also been reported in the construction industry during excavation support operations when steel crossbeams are welded.[28] Personal samples meeting or exceeding threshold limit values (TLV) values for total fume (5 mg/m^3), fluoride (2.5 mg/m^3), and manganese (0.2 mg/m^3) were reported. Verma et al.[29] also report excessive total fume exposures due to arc welding, gouging, soldering, and thermal cutting in the construction trades especially ironworkers, laborers, plumbers, and pipe fitters. Exposures as high as 28.3 mg/m^3 total fume and 17.3 mg/m^3 inhalable were reported.

A comprehensive study of manganese and fume exposure to construction workers involved in welding and related hot tasks was conducted by the Center to Protect Workers' Rights (CPWR) in 1995 and 1996 and summarized in two distinct but related publications.[23,30] The study by Susi et al.[23] reported 61 personal exposures to manganese collected during 1995 and 75 such measurements in 1996. The 1995 measurements ranged from 0.0005 to 1.31056 mg/m^3 with a mean of 0.2 mg/m^3, and the 1996 measurements ranged from 0.001 to 0.47 mg/m^3 with a mean of 0.07 mg/m^3. Seventy-two percent of boilermaker exposures exceeded the TLV.

Among ironworkers and pipefitters, 15% and 7%, respectively, of the sampled exposures were above the TLV. Some LEV and mechanical blowers and fans were implemented in 1996. Total fume personal exposure measurements (N = 22) collected during tasks with these controls were compared with exposures collected with no ventilation or natural ventilation only (N = 57). The respective means were 1.79 mg/m^3 and 5.26 mg/m^3, which were significantly different ($p < 0.0001$). Susi et al. concluded that significant health hazards existed from welding and thermal cutting fume, manganese, nickel, and hexavalent chromium.

In addition, they noted that "Use of local or mechanical ventilation reduced mean exposures to fumes significantly."[23,p.26] Analysis of the same data set by Rappaport et al.[30] concluded, "Local-exhaust or mechanical ventilation reduced exposure to total particulate (but not Mn) by as much as 44%, and shielded or manual arc welding increases exposure to Mn (but not total particulate) by about 80%."

Preliminary results from a series of studies conducted by CPWR, designed to evaluate the effectiveness of a commercially available portable LEV unit to reduce manganese exposure among construction welders, are presented below.

METHODS

Portable LEV Unit Description

The control equipment tested was the MINIFLEX Portable High Vacuum Fume Extraction Unit (Lincoln Electric, Cleveland, Ohio). The portable unit weighs 33 lb (15 kg) and has a filter efficiency rating of 99.97%. A bell-shaped nozzle (Lincoln EN 20 Extraction Hose), with a magnetic foot to allow it to be fastened to the pipe, was attached to the end of a flexible 2 inch (50.8 mm) diameter hose to capture fume. The entry of the hood was placed 2–3 inches (50–75 mm) above the weld.

The coefficient of entry (C_e) for the LEV hood was calculated in the laboratory prior to experimental and field testing. A C_e value of 0.96 was calculated, which was consistent with published C_e values for a bell-shaped hood ($C_e = 0.98$).[31] Hood static pressure was then measured in both the experimental (before and after each run) and field (before and after each work shift) tests using a static pressure tap located four duct diameters from the hood face, and airflow through the hood was calculated:

$$Q = C_e(4005)(A)(SP_h)$$

where

Q	=	flow rate (ft^3/min)
C_e	=	hood coefficient of entry
A	=	cross–sectional area of the duct at static pressure tap (ft^2)
SP_h	=	hood static pressure (inches H_2O)

EXPERIMENTAL SETTING

Working with the Plumbers and Pipefitters Union at a local training center, CPWR first tested the ability of the portable unit to reduce metal fume exposures during welding within an experimental setting. An instructor from UA Local 120, Cleveland, Ohio, performed shielded metal arc welding (SMAW) of carbon steel. Personal air monitoring samples were collected in both LEV-controlled and LEV-uncontrolled operations to test the ability of the ventilation unit to reduce exposures. The welder was provided with a powered, air purifying respirator/welding hood for protection from welding fume exposure during the trials.

Control vs. no control trial order was randomized to prevent systematic bias due to carryover exposures from one run to the next and to prevent any other potential biases. Carryover exposure was further prevented by allowing ample time between trials and the use of the training school's fixed general ventilation to flush residual fumes between tests. The return of ambient particulate concentration to background level was verified prior to each run using a real-time monitor (HazDust III; Environmental Devices Corp., Plaistow, N.H.).

Welding was conducted in a semienclosed booth used for pipe fitter training. The booth consisted of three solid walls and a curtain on the fourth wall, which was closed during welding. The booth was equipped with a ventilation system, but the system was not operated during the trials so that the effectiveness of the portable LEV system could be assessed directly. Small (approximately 6 to 8 inches [152 to 203 mm] in length) sections of 6 inch (152 mm) diameter cylindrical steel pipe (coupons) were welded together around the circumference of the pipe (18.8 inches [478 mm]; Figure 1). Each pipe weld consisted of a root pass followed by a fill pass. For carbon steel (schedule 40), the root pass was done using SMAW and an E6010 electrode (Lincoln Electric), while the fill pass used SMAW and an E7018 electrode (Lincoln Electric).

The material safety data sheet (MSDS) for the Lincoln Electric AWS E6010 covered electrode lists manganese and/or manganese alloys and compounds as 1% by weight. The MSDS for the Lincoln Electric AWS E7018H4R lists manganese and manganese compounds as less than 5% by weight. By definition, carbon steel contains 1.65% or less manganese (higher than that and it would be termed an alloy steel).[32] Certified test reports for ASTM A53B carbon steel pipe, provided by the pipe fitter training center where controlled evaluations were conducted, ranged from 0.96 to 1.07% manganese by weight.

During each pass, the pipe was rotated four times so welding was always performed between "9 o'clock" and "12 o'clock" on the circumference of the pipe (for controlled runs, the LEV hood face was placed at the "12 o'clock" position). Each run was approximately 50 to 60 min in duration and consisted of two welds, with each weld taking approximately 30 min to complete. Actual arc time for each run was also recorded using a stopwatch, and run arc times ranged from 25 to 32 min. Five no-control and five LEV control trials were run.

Field Survey

Following the experimental tests, a field survey was also conducted to evaluate the effectiveness of the portable LEV unit to control worker exposures in an actual work setting. Surveyed work involved SMAW of schedule 40 carbon steel by pipefitter journeymen during the installation of chiller pipes, ranging in size from 6 to 20 inches (152 mm to 508 mm) in diameter, in the lower level of a commercial construction project (a new 6-story, 125,000 ft^2 [11,613 m^2] building). Welding electrodes used on the worksite were the same type used in the experimental setting (E6010 / E7018).

Prior to the introduction of the LEV unit, the work area was provided general ventilation only by way of a small number of wall openings and a single small fan on each side

FIGURE 1. Pipe section and hood placement used in the experimental setting

of the mechanical room area (total work area dimensions were approximately 40 ft by 70 ft [12.2 m by 21.3 m]). The nearest fan was approximately 30 ft (9.1 m) from where most of the welding was being performed. The portion of the chiller installation work surveyed consisted of "bench" (or "stand") welding of pipe on the ground (pipe placed on stands approximately waist high), followed by "position" (or "field") welds located near the ceiling. The position welds required welding from a scissors lift, where the height of the weld was at or above the welder's head.

The surveyed welding tasks also included some thermal cutting and grinding during part of the sampling period, likely contributing to exposure levels. Other potential sources of dust exposure in the work area included plumbers installing copper pipe and operating engineers moving pipe and other material with forklift trucks.

The survey involved 8 days of full-shift, personal breathing zone sampling on two welders. Welding performed while using the portable LEV unit for the entire shift was tested on one of the two welders for 7 of the 8 survey days. LEV use was randomly assigned to one of the two welders at the beginning of each day. For bench welds, the entry of the hood was placed 2–3 inches (50–75 mm) above the weld, to the degree possible, with the back end of the hood and vacuum hose angled upward and away from the welder (Figure 2). For position welds, the hood was affixed to the top of the pipe with the attached magnet or hung vertically from another pipe (when available) that was located closer to the ceiling and above the pipe being welded (Figure 3).

Sample Collection and Laboratory Analysis

Personal exposure samples were collected with a personal sampling pump (GilAir5, Sensidyne Inc., Clearwater, Fla.) drawing air through a 37-mm, 5-μm pore PVC filter at 2.0 L/min. In the field survey, breathing zone samples were obtained by placing the sample cassette on each worker's left shoulder lapel near their nose and mouth (both welders were right-handed). In the experimental setting, initially, two sample pumps were used and one sample cassette was placed on both right and left shoulder for each run to assess intershoulder variability.

Once it was determined that there was a high level of agreement between left and right samples, sampling on both sides of the welder was discontinued. One sample pump with a cassette placed on the opposite side of the welder's dominant hand was used for the remaining samples collected. Sample pumps were pre- and postcalibrated using an electronic bubble meter (Gilibrator; Sensidyne, Inc.). Following each shift, sample filter cassettes were collected, sealed, and sent for laboratory analysis of total welding fumes and manganese concentrations according to NIOSH Methods 0500 (Particulates Not Otherwise Regulated, Total) and 7300 (Metals in Air).

Statistical Analysis

Descriptive statistics were tabulated for LEV and non-LEV conditions in both the experimental and field settings. Distributions were assessed for normality and transformed where appropriate. In the experimental setting, total particulate

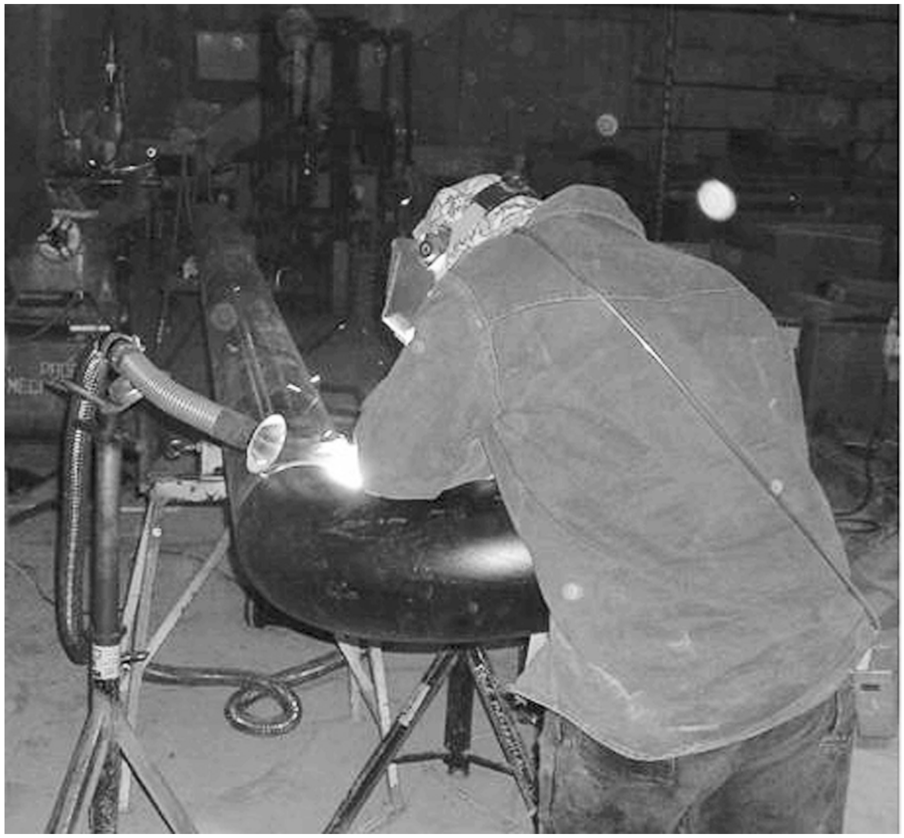

FIGURE 2. Example of portable LEV placement for a bench weld in the field survey

and manganese exposure levels followed the normal probability distribution, while in the field setting the data were skewed right and transformed using the natural log in further statistical analyses. Differences between exposure levels with and without LEV use were explored using the student's t-test.

RESULTS

During the 10 welding trials that were run in the experimental setting, sample filters were placed on the worker's lapel near both shoulders simultaneously to explore influence of sample filter placement on welding exposure estimates. For both manganese and total particulate concentrations there was good agreement between left and right shoulder samples (both r = 0.96), suggesting that placement on either shoulder was acceptable for the field monitoring.

The portable LEV unit, with an estimated airflow of 103 to 110 ft^3/min (0.049 to 0.050 m^3/s), was effective at controlling manganese exposures in both the experimental and field settings (Table II). In the experimental setting, LEV use reduced mean breathing zone manganese concentrations by 75% (p-value = 0.002), whereas in the field setting, use of the LEV reduced geometric mean full-shift time-weighted average manganese concentrations by 53% (p-value = 0.04). Use of the LEV unit was associated with a smaller decline in total particulate exposure (Table III). In the experimental setting, mean total particulate concentration was reduced by 60% (p-value = 0.002), whereas in the field, geometric mean total particulate exposure was reduced by 10% (p-value = 0.6).

Concentrations of total fume and manganese were moderately associated with one another in the field study, with a Spearman rank correlation coefficient (r) of 0.51 (p-value = 0.04). Interestingly, among only those samples where the LEV was used, total fume and manganese concentrations were not correlated (Spearman r = −0.07; p-value = 0.9). Conversely, these two concentrations were highly correlated among the uncontrolled samples where LEV was not used (Spearman r = 0.78; p-value = 0.01). In the experimental setting, manganese made up on average 1.8% and 2.8% of total particulate concentration with and without use of LEV, respectively, while in the field setting manganese on average accounted for 1.2% and 2.1% of total particulate with and without LEV, respectively.

DISCUSSION

There are currently no specific occupational exposure limits in the United States with which to compare welding fume exposure levels. However, the use of an 8-hr time-weighted average exposure limit of 5 mg/m^3 is a reasonable benchmark with which to compare results, given this served as both the OSHA permissible exposure limit (PEL) and the American

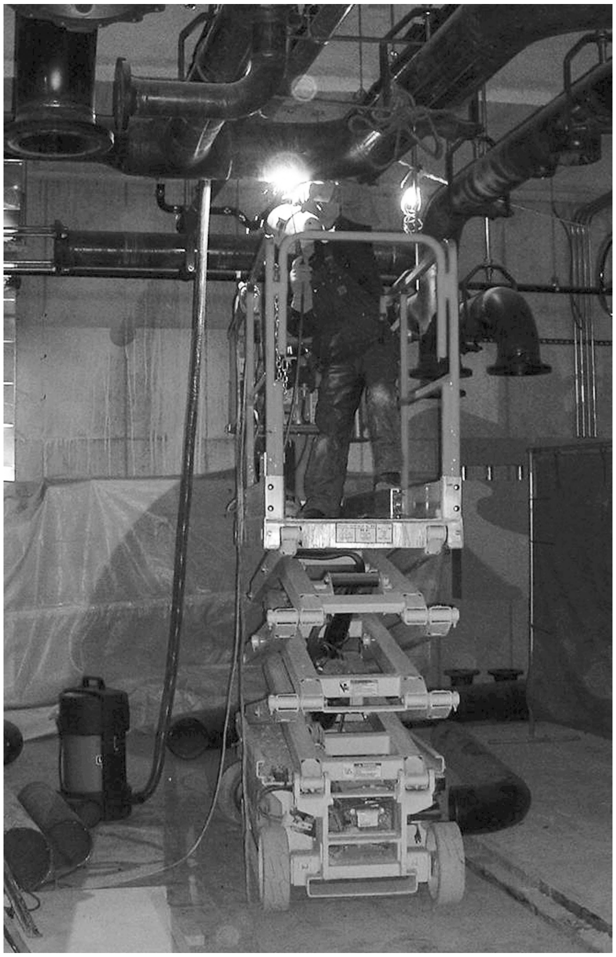

FIGURE 3. Example of portable LEV placement for a position weld in the field survey

Conference of Governmental Industrial Hygienests (ACGIH®) threshold limit valve (TLV) for welding fumes until relatively recently. Using this criteria for the results of the field data, nine (56%) of welding fume exposure levels exceeded a time-weighted average of 5 mg/m^3.

The proportion of samples exceeding 5 mg/m^3 did not differ between groups following stratification by LEV use,

TABLE II. Manganese Exposure in Experiment and Field Settings (mg/m^3)

	Manganese Concentration				
	N	Mean	Geometric Mean	Range	p-value
Experimental					
No LEV	5	0.051	0.050	0.035–0.071	
LEV	5	0.013	0.013	0.001–0.018	0.002
Field					
No LEV	9	0.124	0.097	0.045–0.300	
LEV	7	0.055	0.046	0.025–0.114	0.04

TABLE III. Total Particulate Exposure in Experiment and Field Settings (mg/m^3)

	Total Particulate Concentration				
	N	Mean	Geometric Mean	Range	p-value
Experimental					
No LEV	5	1.83	1.80	1.33–2.47	
LEV	5	0.74	0.74	0.64–0.87	0.002
Field					
No LEV	9	5.60	4.95	2.65–11.6	
LEV	7	4.55	4.47	3.15–5.44	0.6

as five of nine (56%) samples collected while LEV was not being used were greater than 5 mg/m^3 compared with four of seven (57%) samples collected when LEV was being used. The impact of LEV was more evident in reducing Mn exposure. For manganese, two of the nine samples (22%) from the survey where the portable LEV unit was not being used exceeded the ACGIH TLV of 0.2 mg/m^3, whereas none of the samples exceeded the OSHA PEL of 5.0 mg/m^3 or the NIOSH recommended exposure limit (REL) of 1.0 mg/m^3 (Table II). None of the seven samples collected while the LEV unit was in use exceeded the ACGIH TLV, the OSHA PEL, or the NIOSH REL.

Visually, the unit appeared to be most effective during the fill pass and cap, as fume was observed to travel inside the pipe and escape out the open ends of the pipe during the root pass. Completion of the root pass served to close off this escape route for fumes, allowing most of the generated fume to then be collected through the LEV hood for the remainder of the weld. The LEV unit demonstrated adequate durability for collecting welding fume in construction. Airflow through the unit was 110 CFM ($SP_h = 2.96''$ H_2O [740 Pa]) when measured before its first use and 103 CFM ($SP_h = 2.58''$ H_2O [645 Pa]) following the final day of the survey, equaling just a 7 ft^3/min (0.003 m^3/s) drop in flow rate after 7 full days of use without emptying the vacuum or purging the filters.

Results from the field survey suggest the LEV unit was effective at reducing manganese exposure but less effective at reducing exposure to total fume. This could be explained partly by the nature of the method used to measure total fume, which is done gravimetrically, meaning it includes all dust collected on the sample filter. It is likely that other trades working in the area, such as plumbers installing copper pipe and operating engineers using forklift trucks to move pipe and other materials, contributed dust levels to the samples. In addition, the welders performed several tasks besides welding that would contribute to total particulate levels. On each weld, they used an electric grinder to clean the metal after tacking and after finishing the cap. The welders would also occasionally sweep the work area, which would create high exposures to dust.

Welding fumes consist of very small respirable particles relative to the larger particles likely to be generated during sweeping or mechanical grinding. Smaller, respirable fume may have contributed less mass (weight) to sample filters than did grinding dust in some cases. Smaller particles are generally of greater concern because they can easily penetrate to the lower portions of the lungs and alveoli, potentially leading to adverse health effects depending on the solubility of the agent and the target organ of concern.

Also, there appeared to be a correlation between manganese and total fume levels without use of LEV but not with use of LEV. This suggests that particulate sources other than welding fume contributed to total sampling mass (i.e., when LEV was in use, manganese levels were reduced substantially but particulate from other nonwelding sources led to poor correlation between manganese and particulate measures). The lower contribution of manganese to total particulate concentrations in the field setting compared with the experimental setting provides additional evidence for nonwelding sources of particulate matter. This would limit our ability to find a considerable difference in total particulate levels between control and noncontrol scenarios.

The portable LEV unit tested in this survey appeared durable, effective, and feasible, particularly in reducing manganese exposure. Even for position or field welds near the ceiling, the unit came with a 16-foot (4.9 m) hose that was adequate for the hood to be well positioned to collect welding fumes most of the time. At times it was somewhat cumbersome to position the vacuum unit in the proper place as welding tasks were not stationary within the work zone. However, if the unit were to be incorporated as part of normal work procedure, the extra effort associated with this additional step would likely be minimal.

As a potential limitation, effective use of the LEV unit hinges on correct use. If the hood is placed below or too far away from the weld, the LEV's effectiveness would be greatly compromised. Thus, if these LEV units are to be used in construction, workers would need to be trained in proper use and basic guiding principles related to maximizing fume collection. Considering economic feasibility, the LEV unit tested in this survey costs approximately $1000.

Besides routine cleaning, periodic filter changes, and the use of electricity, the maintenance and operating costs associated with the LEV unit should be minimal, though more research on the optimal maintenance schedules and the burden of these factors on real-world use is needed. Thus, the recommendation to use portable LEV units to control weld fume exposure in construction seems technologically, logistically, and economically feasible, with minimal effort required for introduction, worker education, and unit maintenance.

CONCLUSION AND RECOMMENDATION

Exposure to welding fume, especially manganese, is of concern in the construction industry. The use of local exhaust ventilation should be incorporated into welding tasks on a routine basis to reduce exposure. Mechanical/dilution ventilation alone may be inadequate, and local exhaust ventilation should be the primary means of reducing exposure to manganese and other toxic metals.[33] The portable LEV unit tested in this survey appears to be an effective and feasible approach for reducing worker exposures to manganese during welding tasks. Greater use and evaluation of this and similar equipment are needed to verify effectiveness in a variety of settings. In addition, instruction on the proper use of portable local exhaust ventilation should be incorporated into apprenticeship and journeymen upgrade training for the welding trades.

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