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Case Studies

Comparing Exposure Levels by Type of Welding Operation and Evaluating the Effectiveness of Fume Extraction Guns

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Plant and Process Description

The evaluation was conducted in a plant that manufactured steam ovens for use in commercial and military kitchens. Fabrication of the steam ovens primarily involved straight-line welding of stainless and boilerplate (carbon) steel. The three main welding techniques used at this site were solid-wire gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and flux-cored arc welding (FCAW). GMAW and GTAW were used to weld stainless steel (SS) parts, while FCAW was used to weld boilerplate. During GMAW, a solid-core wire consumable is continuously fed through a welding gun while a shielding gas is supplied at the gun tip to prevent oxidation of the base metal. At this site, the GMAW shielding gas was a mixture of argon and carbon dioxide. The FCAW technique is similar to GMAW, except that the wire is hollow and filled with a flux core. The flux can be composed of various metals or minerals that promote the weld process by removing impurities and preventing oxidation. A carbon dioxide shielding gas was supplied during FCAW. In comparison, the GTAW technique uses a welding gun equipped with a fixed, non-consumable tungsten electrode to generate the arc. A consumable stainless steel electrode is held near the arc to supply filler metal. An argon-based shielding gas was used at this site during GTAW.

Most of the plant's 25 welders worked the first shift; the remainder worked the third shift. The plant layout is depicted in Figure 1. At the time of the visit, the plant was changing to a just-in-time (JIT) process flow to increase productivity. The management anticipated some rearrangement of the welding booths to accommodate the new process flow lines. All stainless steel welding was eventually to be performed in the area currently occupied by the stainless steel booths; the boilerplate welders would remain at their current location.

Overhead fans, wall fans, and free-standing fans were found throughout the plant; due to the summer heat and humidity during the survey, every welder had one in his work area. Doors were open to the outside. A five-foot long, enclosed walkway connected the trailer door to the plant door. Both doors were kept closed at all times when not in use. The ceiling in most parts of the plant was over 16 feet high. A variety of personal protective equipment was available

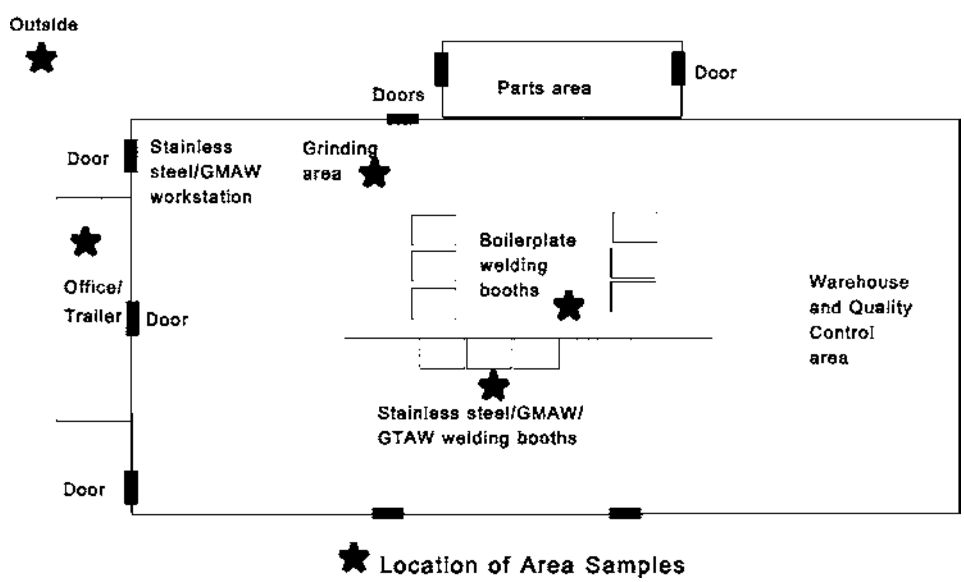

FIGURE 1

to the welders: cloth arm protectors, leather aprons, welding helmets, disposable fume masks, and hearing protection. Most welding stations were surrounded by welding curtains to prevent welder's flash from occurring in nearby work areas.

Ventilation System

At the time of the study, only the boilerplate welders were using local exhaust ventilation systems; specifically, fume extraction guns. These guns were connected to a central vacuum system, which exhausted the fumes out of the workplace. Many of the welders in the stainless steel booths had previously used fume-extraction guns and small suction hoods; however, these units were disconnected from the central vacuum system during the process layout changes. Installation of new duct work to these welding stations was in progress, and the local exhaust units for the stainless steel welders were expected to be operable as soon as the JIT process flow was implemented.

Prior to the purchase of the fume-extraction guns and central exhaust system, the welding operations had an exhaust ventilation system consisting of canopy hoods, moveable exhaust hoods, and electrostatic precipitators. Management considered this earlier ventilation system ineffective.

The fume-extraction guns used in the boilerplate area were purchased approximately 18 months before the study occurred; as such, the welders were well acquainted with handling the guns. Two types of fume-extraction guns were used. One gun, manufactured by Lincoln, incorporated the ventilation directly into the gun design. Lines for the shielding gas and exhausted air were encased in a large, single line leading from the gun. The second type of gun was a conventional, non-ventilated Lincoln model with a Tweco suction attachment connected to the gun nozzle. On this model, the shielding gas and exhausted air lines remained separate; the former led from the gun, the latter from the Tweco attachment. Welders could choose to use either gun, depending on their personal preference. Welders who felt the all-in-one fume extraction gun was bulky and cumbersome were more prone to use the conventional gun with the suction attachment.

The fume-extraction guns were each attached to three-inch diameter ducts, dropped from the main header of the central exhaust system. Air captured by the fume extraction system was filtered through a bag house and exhausted to the outside. The filters in the bag house were changed out every two to three weeks by a contractor.

Methods

Air Sampling

Conventional industrial hygiene air sampling was performed on the welders during the study. Samples were collected on closed-faced, 37-millimeter (mm), polyvinyl chloride (PVC) filters, which were analyzed gravimetrically to determine the total welding fume concentration. The analysis was conducted according to Method 0500 in the National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods.[1] In this method, a known volume of air is drawn through the preweighed PVC filter. The weight gain of the filter is then used to compute the milligrams (mg) of particulate per cubic meter of air. The limit of detection (LOD), or lowest measurable amount, for total particulate for this study was 0.02 mg. The limit of quantification (LOQ) for total particulate, or the level at which the laboratory can confidently report precise results, was not provided by the analytical laboratory. An element-specific analysis was also performed on the filter samples, according to NIOSH Method 7300,[1] to differentiate and quantify the different metal species in the welding fume.

Personal samples were collected on nine workers: one welder at the stainless steel workstation (A), three welders in booths on the stainless steel line (B–D), four welders in the boilerplate area (E–H), and one grinder (I). The samples were collected in the worker's breathing zone using portable pumps set at a flow rate of 3 liters per minute (lpm). Filter cassettes were placed on the lapel of the welders' overalls, just outside of their welding helmets, since the purpose of the study was to evaluate the control effectiveness of the ventilation, not the personal protective gear. To prevent overloading, the filters were occasionally changed out during the shift and replaced with new filters.

Area samples were also collected using portable sampling pumps set at a rate of 3 lpm. The samples were located in the grinding, boilerplate, and stainless-steel work areas. Baseline area samples were obtained inside the air-conditioned trailer and just outside the plant. The outside plant sample was hung on a cyclone fence at about eye level.

Ventilation Measurements

The fume-extraction system was assessed by measuring capture velocities using a hot-wire anemometer. This instrument measures air velocity in feet per minute (fpm). Capture velocities are measured to determine the ability of the system to remove welding fumes at certain distances away from the fume-generation source. The capture velocity is the velocity necessary to overcome opposing air currents and cause the welding fume to be exhausted. Work methods regarding the use of the ventilation systems were also observed, such as differences in positioning the "choke" collar on the fume-extraction guns. This collar allows the welder to increase or decrease the amount of ventilation. In addition, airflow patterns around the workers during welding were observed using smoke tubes and aspirators. From this, an understanding of how air contaminants are transported into the worker's breathing zone can be developed. Smoke tubes were also used to observe airflow patterns at the plant entrance ways.

Gas Measurements

Gases from the welding operation were monitored manually using direct-reading colorimetric indicator tubes and bellows pumps. Sampled gases included carbon monoxide, ozone, and nitrogen dioxide. Since the base metals did not appear to have undergone any degreasing operations, the presence of phosgene was unlikely and was not monitored.

Results and Discussion

During data analysis of the samples, short-term exposures were combined to give a single concentration value over the total sampling time measured each day. These are not time-weighted averages; however, they are compared to occupational exposure limits as possible worst-case exposures as if the concentrations were measured over a full 8 or 10 hour shift.

Gravimetric Analysis (Total Welding Fume)

The personal-sampling data for total welding fume concentrations were analyzed with respect to the welding process, the sample location, and exposure differences between individual welders. The area-sampling data was analyzed with respect to sampling location.

Personal welding fume levels vs. welding process. The three welding processes evaluated at this site were FCAW of boilerplate carbon steel and GMAW and GTAW of stainless steel. Based on information from the plant, and the preceding literature search, the FCAW process was expected to produce the most total welding fume particulate, and the GTAW process was expected to produce the least. This assumption was verified upon analysis of the data (Table I). Visually, it was also apparent that the flux-cored process was the heaviest fume producer, regardless of whether or not the welders used the fume extraction gun ventilation.

TABLE I
Descriptive statistics for total particulate concentrations by welding process (in milligrams per cubic meter [mg/m^3])

Welding process	n	Mean	GM	Median	Std dev	Range
FCAW (Boilerplate)	20	8.97	5.50	5.61	12.0	1.17–55.46
GMAW (SS)*	11	1.61	1.44	1.47	0.73	0.49–2.67
GTAW (SS)*	10	0.16	0.14	0.17	0.07	0.06–0.27

*Includes one sample collected on boilerplate (carbon steel).
One sample that was collected during both GMAW and GTAW was not included in this table.

The highest total particulate concentration during the study was measured on a welder performing unventilated, flux-cored arc welding of boilerplate steel. The second highest total particulate concentration of the study was measured on the same welder during ventilated, flux-cored arc welding of boilerplate steel. Overall, the flux-cored welders' exposures were almost four times higher than the exposures for the GMAW welders, and approximately 40 times higher than the exposures for the GTAW welders.

Statistical analyses of the total welding fume data were conducted to determine the significance of the findings presented in Table I. Statements of statistical significance make use of adjustments for multiple comparisons. When using all 41 data points described in Table I, no significant difference was found between the total welding fume exposures for FCAW and GMAW welders ($p > 0.3$), where lack of statistical significance results from the adjustment for multiple comparisons. However, GTAW welding exposures were significantly lower than both FCAW and GMAW exposures ($p < 0.01$). A second evaluation of the data set was conducted after elimination of a potential outlier data point (Sample #2341—very low exposure during non-ventilated FCAW). With the removal of this data point, the FCAW exposures were found to be significantly higher than the GMAW exposures ($p < 0.04$). The other results for GTAW remained the same as before. An additional analysis was conducted to eliminate the impact the ventilation may have had on exposures. In this analysis, only the non-ventilated FCAW, GMAW, and GTAW data were used; the potential outlier point was excluded. The results showed FCAW exposures to be significantly higher than the GMAW and GTAW exposures ($p < 0.03$). From the analysis of the data with the possible outlier removed, we find evidence to conclude that at the 95 percent level, FCAW > GMAW > GTAW.

Personal welding fume levels vs. sample location. The three main sampling locations during this study were those of welders at the stainless steel workstation, the boilerplate area, and the stainless steel line. Table II shows that welders in the boilerplate area have the highest exposures as they perform FCAW; their exposures were almost four times those of the welder at the stainless steel workstation, and approximately 15 times that of the welders at the stainless steel

TABLE II
Descriptive statistics for personal total particulate concentrations by sample location (in mg/m^3)

Sample location	n	Mean	GM	Median	Std dev	Range
Stainless steel workstation (GMAW)	6	1.39	1.22	1.31	0.70	0.49–2.22
Boilerplate (FCAW)*	22	8.29	4.64	5.44	11.7	0.27–55.46
Stainless steel line (GMAW/GTAW)	14	0.61	0.30	0.21	0.79	0.06–2.64
Grinding	2	0.37	0.36	0.37	0.10	0.30–0.44

*Includes one sample that was collected during GTAW of the boilerplate.
One sample was collected during GMAW of the boilerplate.

line. Additionally, the welder at the stainless steel workstation had higher exposures than the welders at the stainless steel line. This was attributed to the fact that only GMAW was performed at the workstation, while welders in the stainless steel line area performed GTAW in addition to GMAW, resulting in a lower overall average exposure for them. The data in Table II reinforces the previous findings that FCAW operations in the boilerplate area produced the highest total welding-fume concentrations, while GTAW in the stainless steel line produced the lowest.

A statistical analysis was conducted to determine the effect of sample location on exposure. The data was evaluated in several ways. The combined ventilated and non-ventilated data from the boilerplate area were compared separately to data from the stainless steel line area and from the stainless steel workstation area. Boilerplate exposures were greater than the other areas, but at the 95% confidence level, no significant differences were noted ($p > 0.09$) after adjusting for multiple comparisons. Then, the GMAW and GTAW data from the boilerplate area were compared to the GMAW and GTAW data from the stainless steel line. Boilerplate exposures were greater than at the stainless steel line, but again no statistically significant difference was observed. Data from the stainless steel line compared to data from the stainless steel workstation also did not result in a statistically significant difference. Finally, the GMAW data from the stainless steel line were compared to the GMAW data from the stainless steel workstation; no statistically significant difference was observed. The overall statistical significance findings reported above did not change whether or not the previously mentioned outlier point was excluded. Differences that are close to statistical significance (boilerplate versus workstation or workstation versus line) are not close to significance when comparisons are limited to like processes. The apparent differences between locations are more likely due to differences between processes.

TABLE III
Welders' total welding fume exposures over three sampling days

Worker	Welding technique	n	Day 1 (mg/m^3)	n	Day 2 (mg/m^3)	n	Day 3 (mg/m^3)
A	GMAW	2	1.22	2	1.08	2	2.20
B	GTAW	2	0.12	1	0.18	1	0.09
C	GTAW	2	0.10	1	0.13	1	0.21
D	GMAW/GTAW	1	1.43	2	1.04	3	1.03
E	FCAW	2	32.91	3	3.28	3	6.66
F	FCAW	2	10.04	4*	4.34	3	7.05
G	FCAW	2	7.25	0	–	0	–
H	FCAW	1	2.96	0	–	2	1.37
I	Grinding	0	–	0	–	2	0.54

The samples collected on Worker F on Day 2 were actually composed of three FCAW and one GTAW.

An additional analysis was conducted to eliminate the impact the ventilation may have had on exposures. In this analysis, only the non-ventilated FCAW, GMAW, and GTAW data were used. With or without the outlier data point, the results showed boilerplate exposures to be significantly higher statistically than the stainless steel line exposures ($p < 0.05$). In both data sets, boilerplate exposures were not statistically significantly higher than stainless steel workstation exposures.

Personal welding fume levels for individual welders. Total welding fume exposures for the welders for each day of sampling are shown in Table III. The highest total welding fume exposure occurred on Day 1 on Worker E, a boilerplate welder. During this sampling day, Worker E performed flux-cored welding without the ventilation system attached, resulting in an exposure level above the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 15 milligrams per cubic meter (mg/m3) for total particulate (welding fume).[2]

On the same day, two other boilerplate welders, Workers F and G, who were using ventilated fume-extraction guns, had exposure levels above the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) time-weighted average (TWA) level of 5 mg/m^3 for total welding fume.[3] Exposures in excess of the TLV were also found on Day 3 for Workers E and F.

From Table III, it is observed that Worker F had a higher total welding fume level than Worker G on Day 1, although both workers used ventilated welding guns. Information gathered on work practices in the boilerplate area can help to explain this result. Workers F and G used a Lincoln welding gun with a Tweco fume extraction system. The collar on the gun could be moved up and down to change the exhaust level. On the first day of sampling, Worker F positioned his welding collar high to reduce the exhaust ventilation level. Worker F indicated he was concerned that the ventilation would remove the shielding gas and interfere with the weld. Worker G was also concerned about possible interference from the ventilation; he tried to circumvent any problems by increasing the amount of shielding gas delivered to the weld area rather than decrease the gun ventilation rate. Worker F also noted that the ceiling fan over his workstation seemed to pull the fumes upward, in opposition to the fume extraction gun that tried to pull the fumes inward. As a result, Worker F felt the two exhaust systems created turbulence in his work area. No observations were made of Worker H, which would explain his lower exposure.

Among the stainless steel welders, Workers B and C, who performed the GTAW process in adjacent booths at the

TABLE IV
Effect of ventilation on total welding fume personal exposures during FCAW of boilerplate carbon steel (in mg/m^3)

Ventilation	n	Mean	GM	Median	Std dev	Range
On	13	6.31	4.64	5.77	5.38	1.33–21.36
Off	3	24.15	10.1	15.83	28.09	1.17–55.46
Unknown	4	6.24	6.06	5.44	1.87	5.04–9.04

stainless steel line area, had similar exposures. Worker D, who also welded on the stainless steel line, had higher exposures than Workers B and C. This was attributed to the fact that Worker D performed both GMAW and GTAW, and the GMAW process was shown to produce more fume than did GTAW (see Table I). Worker A, who welded on stainless steel at the separate workstation using only GMAW, had an exposure level comparable to Worker D.

Impact of ventilation on personal total welding fume exposures. To determine the impact of ventilation, comparisons were made between the ventilated and non-ventilated FCAW operations (see Table IV). The geometric mean data show that the use of ventilation resulted in less than half the exposures as those when no ventilation was used. A comparison can also be made of the geometric means of the non-ventilated FCAW data in Table IV and the non-ventilated GMAW and GTAW data in Table I. Non-ventilated FCAW operations resulted in total welding fume exposures approximately seven times higher than GMAW operations, and approximately 70 times higher than GTAW operations.

A statistical analysis of the FCAW data shown in Table IV was conducted to determine the impact of the ventilation. The inclusion or exclusion of the potential outlier data point affected the data results greatly. With that value included, there was no significant difference ($p > 0.8$) in FCAW values between ventilation systems. With the outlier point excluded, the exposures to the workers were significantly higher statistically when not using ventilation as compared to with ventilation ($p \sim 0.05$).

Area welding fume levels. Results showed the background level in the boilerplate area to be highest and the level inside the air-conditioned trailer to be lowest (Table V). The higher area sample concentrations in the boilerplate area, as compared to the stainless steel area, agree with the personal sample results.

Elemental Analysis Results

To obtain a picture of the overall concentration levels of the welding fume components for the welders at this site, descriptive statistics were developed for the personal sample concentrations for each element. The same was conducted for area samples.

The personal sampling data were then broken down by welder, welding process, and sample location for further insight on where the highest welding fume component exposures were occurring. Results of these analyses are shown in Tables VI through IX, and are discussed below.

Personal welding fume component levels for individual welders. Table VI presents the workers' overall exposures for selected elements during each day of the survey. None of the personal exposure levels exceeded the PELs. However, Worker E, a boilerplate welder, exceeded the NIOSH recommended exposure limit (REL) (5000 μg/m^3)[4] and the ACGIH TLV (5000 μg/m^3) for iron oxide fumes during the first day of sampling when the ventilation on his welding gun was not turned on. Workers E and F (also boilerplate welders) also exceeded the NIOSH REL (1000 μg/m^3) for manganese on Day 1. During all three days of sampling, Workers E and F exceeded the ACGIH TLV (200 μg/m^3) for manganese. Fellow boilerplate welders, Workers G and H, also exceeded the ACGIH TLV (200 μg/m^3) for manganese on Day 1. In addition, Workers A, D, and E exceeded the NIOSH REL (15 μg/m^3) for nickel during all three sampling days. Arsenic levels were all below the limit of detection; therefore, concentration data reported in the tables are maximum possible values. Cadmium, titanium, beryllium, and total chrome were detected in some samples; however, exposures were all below the PELs.

Personal welding component fume levels vs. sample location. Table VII lists the personal geometric mean concentration and standard deviation for welding fume components, broken down by sample location. As expected, due to the composition of the base metal, the highest chromium (Cr) and nickel (Ni) levels occurred during the stainless steel operations, while the boilerplate welders had much higher iron (Fe) and manganese (Mn) levels than the stainless steel welders.

TABLE V
Descriptive statistics for area total particulate concentrations by sample location (in mg/m^3)

Sample location	n	Mean	GM	Median	Std dev	Range
Outside plant	3	0.04	0.06	0.04	0.03	0.02–0.08
Inside trailer	3	0.02	0.02	0.02	0.00	0.02–0.03
Boilerplate area	3	0.64	0.69	0.49	0.29	0.46–0.98
Stainless steel line area	4	0.11	0.11	0.10	0.04	0.08–0.17
Grinding area	2	0.29	0.27	0.29	0.14	0.18–0.39

Note: No sample was obtained for the stainless steel workstation area.

TABLE VI
Welders' combined exposures for selected elements by day (in $\mu g/m^3$)

Worker–day	n	Al	Cr	Cu	Fe	Mn	Ni	Pb	Ti	Zn
A–1	2	7.9	126	7.3	352	112	49.3	0	0.8	1.9
A–2	2	4.2	100	6.8	316	83.1	46.6	0	0.7	8.6
A–3	2	3.6	184	12.3	556	192	79.1	0	0.7	1.0
B–1	2	3.7	3.7	0.2	14.0	4.0	1.4	0	0.2	0.6
B–2	1	0.7	3.1	0.4	10.8	8.3	1.2	0	0.1	0.2
B–3	1	0.9	2.1	0.3	10.6	2.7	0.8	0	0.1	0.3
C–1	2	5.4	2.8	0.4	13.1	1.9	0	0	0.2	4.0
C–2	1	0.8	2.6	0.2	11.5	3.0	1.2	0	0	0.2
C–3	1	1.5	3.8	0.4	32.9	4.6	2.0	0	0.2	0.4
D–1	1	3.6	100	9.0	348	93.2	57.3	0	0.7	0.7
D–2	2	3.9	76.6	6.5	269	68.8	40.7	0.7	1.0	0.7
D–3	3	1.7	61.1	4.7	218	51.6	35.2	0	1.0	0.6
E–1	2	15.4	15.4	25.0	8580	4370	39.1	14.2	281	33.3
E–2	3	7.6	40.0	5.5	1160	241	23.4	0	83.1	4.9
E–3	3	30.3	26.5	7.7	2040	688	28.2	3.7	129	8.6
F–1	2	20.2	8.3	13.7	2320	1320	11.5	3.8	88.5	12.6
F–2	4	6.3	7.5	8.2	1040	566	5.4	2.1	46.6	5.4
F–3	3	9.8	7.5	8.7	1570	958	7.9	3.8	61.2	8.7
G–1	2	8.7	9.6	11.9	1870	802	10.5	3.2	69.5	9.8
H–1	1	4.1	7.0	3.0	823	354	5.8	0	32.1	5.3
H–3	2	2.5	6.7	3.2	411	72.1	2.5	0	21.3	1.7
I–3	2	11.6	10.6	0.7	55.4	6.8	4.8	0	0.4	0.7

TABLE VII
Descriptive statistics for personal elemental concentrations by sample location (in $\mu g/m^3$)

	Boilerplate (n = 22)		SS line (n = 14)		SS station (n = 6)	
Element	GM	Std dev	GM	Std dev	GM	Std dev
As	**3.59**	3.34	2.28	1.77	2.77	2.55
Al	**8.88**	17.45	2.44	2.05	4.67	1.97
Ba	**1.34**	0.94	0.14	0.09	0.19	0.10
Be	**0.07**	0.06	0.05	0.04	0.06	0.05
Cd	**0.31**	0.23	0.17	0.12	0.20	0.18
Co	**0.73**	0.68	0.46	0.35	0.58	0.49
Cr	11.39	15.50	9.61	63.27	114.19	57.12
Cu	**7.78**	8.10	1.00	4.54	7.59	3.91
Fe	**1299.33**	2961.59	41.96	214.92	349.21	166.43
Mg	**8.05**	12.29	2.44	3.67	3.64	1.46
Mn	**428.50**	1587.86	9.78	53.33	108.83	59.70
Mo	0.72	0.67	0.62	0.87	**1.42**	0.33
Ni	10.39	13.59	5.32	34.97	**50.11**	24.91
Pb	**3.58**	5.04	1.38	1.08	1.66	1.53
Ag	**0.29**	0.40	0.16	0.15	0.19	0.19
Ti	**57.75**	94.60	0.36	0.70	0.65	0.37
V2O5	**1.08**	1.38	0.46	0.35	0.58	0.49
Zn	**6.67**	11.70	0.60	2.47	1.62	2.26

Note: Bold type highlights the sample location with the highest elemental concentration.

TABLE VIII
Descriptive statistics for personal elemental concentrations by welding process (in $\mu g/m^3$)

	FCAW (n = 20)		GMAW (n = 11)		GTAW (n = 10)	
Element	GM	Std dev	GM	Std dev	GM	Std dev
Al	**9.13**	18.17	4.60	3.78	2.18	1.83
As	3.34	1.93	**3.39**	4.43	2.22	1.98
Ba	**1.31**	0.93	0.21	0.26	0.16	0.88
Be	**0.07**	0.03	0.07	0.09	0.05	0.04
Cd	**0.30**	0.16	0.24	0.31	0.16	0.14
Co	0.68	0.41	**0.70**	0.88	0.44	0.40
Cr	12.61	15.86	**89.67**	64.62	2.74	0.86
Cu	**7.96**	8.42	7.77	3.70	0.45	1.69
Fe	**1511.72**	3057.24	389.84	221.65	17.12	25.90
Mg	**8.35**	12.72	4.37	4.52	2.06	1.48
Mn	**556.46**	1641.58	111.46	69.94	3.21	2.09
Mo	0.67	0.39	**1.63**	0.84	0.44	0.40
Ni	11.76	13.78	**44.84**	31.32	1.57	0.54
Pb	**3.50**	5.12	2.07	2.65	1.33	1.19
Ag	**0.27**	0.28	0.22	0.47	0.18	0.17
Ti	**69.89**	96.15	1.12	10.80	0.27	0.74
V2O5	**1.05**	1.37	0.70	0.88	0.44	0.40
Zn	**7.03**	12.13	1.27	1.84	0.73	3.07

Note: Bold type highlights the welding process with the highest elemental concentration.

TABLE IX
Effect of ventilation on elemental personal exposures during flux-cored arc welding (FCAW) of boilerplate carbon steel (in $\mu g/m^3$)

	Ventilation on (n = 13)		Ventilation off (n = 3)		Ventilation unknown (n = 4)	
Element	GM	Std dev	GM	Std dev	GM	Std dev
Al	7.58	9.45	8.17	8.81	**18.16**	36.17
As	**3.56**	2.30	3.34	1.17	2.71	0.39
Ba	1.08	0.83	1.33	1.42	**2.41**	0.26
Be	**0.07**	0.04	**0.07**	0.02	0.05	0.01
Cd	0.33	0.17	**0.34**	0.15	0.19	0.03
Co	0.71	0.46	**0.77**	0.49	0.54	0.08
Cr	9.05	13.73	15.33	2.18	**32.04**	17.45
Cu	7.43	5.20	**10.72**	19.55	7.94	1.08
Fe	1196.46	1179.42	**2977.43**	7196.28	1944.54	420.66
Mg	7.05	6.07	**12.69**	27.54	10.56	12.41
Mn	485.32	757.09	**958.92**	3798.19	577.05	273.74
Mo	0.71	0.46	0.67	0.23	0.54	0.08
Ni	8.14	7.82	**24.86**	25.62	22.20	7.87
Pb	3.27	2.32	**5.97**	12.18	2.91	1.76
Ag	0.25	0.14	**0.59**	0.5	0.20	0.13
Ti	50.18	46.18	**136.65**	212.39	124.08	29.17
V2O5	1.01	0.70	**1.87**	3.11	0.75	0.11
Zn	5.81	6.70	**12.24**	27.72	8.64	1.82

Note: Bold type highlights the control condition with the highest elemental concentration.

Personal welding component fume levels vs. welding process. Table VIII lists the personal geometric mean concentration and standard deviation for welding fume components, broken down by welding process. From this table, it is apparent that the GTAW operations contribute very little to fume exposure of the welders, even during stainless steel welding. GMAW operations, which were performed primarily on stainless steel, and even FCAW operations on boilerplate (carbon steel) resulted in higher chromium and nickel levels than the GTAW operations on stainless steel.

Impact of ventilation on personal elemental exposures. Elemental exposure comparisons can also be made between the ventilated and non-ventilated FCAW operations of the boilerplate (see Table IX). The geometric mean data shows that the use of ventilation generally resulted in lower exposures than when no ventilation was used.

Ventilation Results

Smoke tubes showed that air was flowing into the plant at most of the doors open to the outside. Air flow appeared fairly stagnant at one of the doors in the parts area, and at one of the back doors near the stainless steel line. The door across from the boilerplate area was measured to have an air velocity of 100–250 feet per minute (fpm) coming into the plant.

Measurements taken on the fume extraction system showed an air velocity of more than 6000 fpm at the duct drop, where a fully operational fume-extraction gun was positioned (Worker F's workstation). At the time of this measurement, no other fume-extraction guns were in use. At a distance of one inch from the gun nozzle, a capture velocity of 3500–4000 fpm was measured. The ACGIH *Industrial Ventilation Manual*[5] indicates that a velocity of 100–200 fpm should be used to capture welding fumes, with higher values used for poor conditions such as disturbing room air currents, high toxicity contaminants, and high production/heavy use [ACGIH 1995]. The manual indicates that capture velocities above 200 fpm may disturb the shielding gas. The manual also suggests that the minimum duct design velocities for welding fumes should be between 2000–2500 fpm to prevent settling and plugging of the duct.

Gas Sampling Results

Results of grab sampling showed no detection of ozone or nitrogen dioxide in the air. Carbon monoxide was found to exist in the boilerplate area at a concentration of 10 parts per million (ppm) during welding. This level is below the OSHA PEL of 50 ppm (TWA) and the NIOSH REL of 35 ppm (TWA).

Conclusions and Recommendations

The flux-cored arc welding of boilerplate steel resulted in the highest welding fume exposures. Use of the fume-extraction guns appeared to help reduce exposures during boilerplate welding; however, the units did not effectively control all of the welding fume emissions. The data analysis showed that non-ventilated, boilerplate welding resulted in one full-shift, personal sample exceeding the OSHA PEL for total particulate. Out of the four boilerplate welders, three had total welding fume exposures above the ACGIH TLV during at least one day of the study, even with the ventilation on. Review of the fume component exposure data showed that the non-ventilated, boilerplate welding resulted in exposure levels above the NIOSH RELs for iron oxide fumes, manganese, and nickel. In addition, all four of the boilerplate welders were found to have exposure levels above the ACGIH TLV for manganese for most of the survey, even with the ventilation on. This showed that even when using the fume-extraction guns, the boilerplate welders were still being overexposed to welding fume and its components. Two of the stainless steel gas metal arc welders were found to have nickel exposures in excess of the NIOSH REL during all three sampling days. No ventilation was used during the stainless steel gas metal arc welding.

Discussions with the welders showed there was a major concern among them that the fume-extraction guns might be removing the shielding gas along with the welding fume emissions. Removal of the shielding gas could increase the likelihood of weld porosity. Therefore, to prevent the occurrence of bad welds, some of the welders were moving the collars on the fume-extraction guns in order to decrease the amount of air exhausted. This may be reducing the effectiveness of the ventilated guns. Another way the welders were trying to avoid the possibility of bad welds was to increase the shielding gas flow rate. This may be increasing shielding gas usage costs.

It was also noted during the survey that the operation of multiple fans in the welding areas may be interfering with the capture efficiency of the fume-extraction guns. The fans are set up to keep the welder cool in the heat of the summer. However, depending on their orientation, the strong air currents from the fans may affect the ability of the fume-extraction guns to easily capture welding fumes. In order for the ventilated guns to be used effectively, the use of fans, the level of shielding gas, and the best positioning of the collar on the fume-extraction gun should be addressed and discussed with the welders.

The results from this study support the argument that excess exposures during welding operations are primarily due to the type of welding operation since certain welding techniques, such as flux-cored arc welding, are likely to produce more fume than other techniques (i.e., gas tungsten arc welding). Secondary factors that affect the exposure amount are the composition of the base metal, work practices (i.e., how close the worker gets to the fumes), and the type and effectiveness of local exhaust ventilation. Additional factors may include ceiling height and the shape of the object being welded. Efforts to control welding fume should focus on processes that generate the most fume. At this site, it is recommended that, if possible, the flux-cored arc welding should be replaced with another process technique that generates less fume, or the ventilation system for the boilerplate welders should be improved. In addition, the ventilation system for the gas metal arc welders should be reconnected to the central vacuum system as soon as possible to lower the exposure levels during the stainless steel welding.

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