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Case Studies

Effectiveness of Local Exhaust for Reducing Welding Fume Exposure During Boiler Rehabilitation

Dawn Tharr, Column Editor

Reported by Marjorie Wallace and Thomas Fischbach

Fume exposures during stainless steel welding (using different rod types and rod diameters) and the effect of local exhaust ventilation during outdoor welding operations were evaluated with the assistance of a trade union. The union offered to participate in a simulation study, providing welders, welding equipment, and consumables at their training facility in Kansas, both inside a building and outside in a semienclosed tank. Two types of portable local exhaust ventilation units, supplied by Plymovent (Mississauga, ON, Canada), were evaluated for their ability to exhaust stainless steel welding fumes away from the worker's breathing zone at the point of generation. Four standard types of stainless steel rods used by the union welders were identified and evaluated: AWS 308, 309-16, 316, and 347. The 3xx series designated by the American Welding Society (AWS) has a high chromium-nickel makeup. Four standard rod diameters used by the union welders were also identified and evaluated: 3/32-in, 1/8-in, 5/32-in, and 3/16-in (0.24, 0.32, 0.40, and 0.48 cm, respectively). The rods were from a number of manufacturers, including Alloy Rods, Harris Welco Alloys, McKay, Tech Alloy, and Lincoln. Two of the instructors from the training center participated in this study, along with a welder from the local union hall.

At the training facility, union apprentices must learn shielded metal arc (SMAW), gas metal arc (GMAW), and gas tungsten arc (GTAW) welding techniques. During preliminary discussions with the instructors, it was noted that GTAW techniques are primarily used for tube work, and GMAW techniques are used for buildup work on walls. However, SMAW techniques are performed most frequently in the field during boiler rehabilitation work. Therefore, the focus of the study was narrowed to the evaluation of shielded metal arc welding (SMAW) of stainless steel.

The evaluation included 25 sample runs, most of which were conducted outdoors, inside a large semienclosed tank under a variety of ventilation and process conditions. Data were collected to determine air flow, temperature, and humidity, and the concentration of airborne fume (mass), hexavalent chromium, arsenic, chromium, manganese, iron, nickel, and other metals. The concentration of airborne contaminants in the welders' breathing zone was the dependent variable in an analysis of variance to evaluate the effect of study parameters such as ventilation, electrode type, and electrode diameter.

Welding Environment

A large tank used by the school to simulate a boiler was the site for 23 of the total 25 trial runs. It was located outdoors next to the welding school, and was 3.6 m (12 ft) tall and 6.1 m (20 ft) in diameter (see Figure 1). More than half of the tank's roof was missing during the study. The tank was constructed of 1.8-m (6-ft) high plates, with slight gaps between adjoining plates, and a 1.8 × 0.6-m (6 × 2-ft) opening that served as the entrance. Two workhorses were set up in the tank, with a plate of stainless steel affixed to each one.

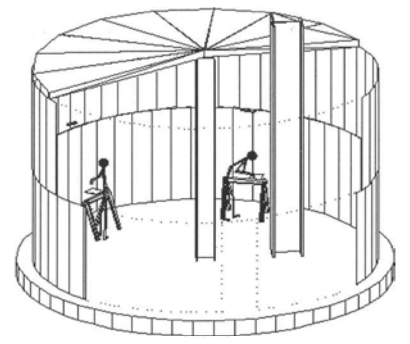

FIGURE 1
Diagram of the tank and welding setup.

During each sample run, the welders would lay several continuous beads (welds) along the 23-cm (9-in) length of the baseplate. Only flat-position welding was performed. Welder 2 was always positioned on the right side of the tank (when looking through the tank entrance). Welders 1 and 3 were interchangeably positioned on the left side of the tank. In addition, a room in the training facility was used for two of the trial runs. The room was approximately 21-m (70-ft) long by 10.4-m (34-ft) wide, and 3-m (10-ft) in height (see Figure 2). The room had a garage door to the outside at one end, which was open approximately 15 cm (6 in) during trial runs. During these runs, Welder 3 sat approximately 1.8 m (6 ft) from the garage door.

LEV Systems

The two LEV units selected for evaluation were as follows:

1. MEF—Mobile, wheeled fume extractor unit with a 2-m (6.56-ft) flexible arm
2. BSFM-2101—Portable fan unit on a support stand with a flexible arm

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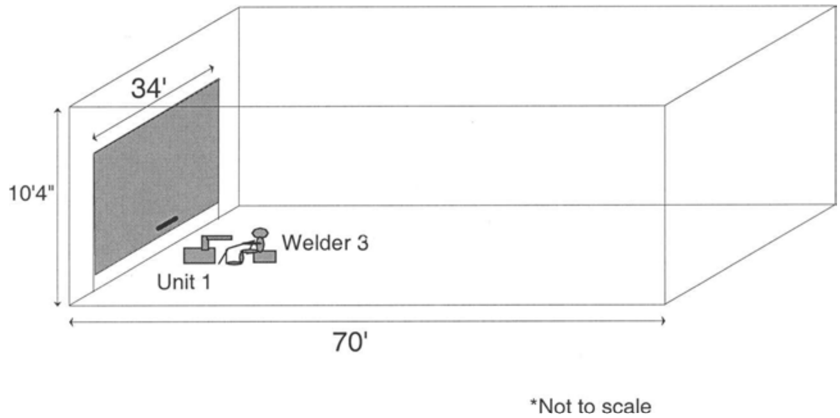

FIGURE 2
Room layout during indoor welding operations.

Neither of the local exhaust ventilation units were equipped with filters during the study. Instead, the captured fumes were exhausted via flex-duct to a point outside the tank.

Figure 3 depicts the MEF model (Unit 1). This unit's exhaust flexible arm was 160 mm (6.25 in) in diameter and was made of flame-proof, double-skin, PVC-coated woven polyamide with an internal steel spiral. The hood at the end of the arm was somewhat conically shaped. According to the manufacturer's product literature, the recommended air flow at the hood of Unit 1 is 800–1200 m^3/hour (470–706 cfm). With a 10-m (32-ft) outlet duct attached to the unit, the approximate air flow at the hood is expected to be 1,000 m^3/hr (588 cfm). The free-flow air volume is designed at approximately 1,400 m^3/hr (825 cfm). A one-half horsepower (HP) (370 watt) motor powers the fan. Unit 1 weighed approximately 35 kg (77 lbs); however, handles and two front wheels facilitated ease of mobility.

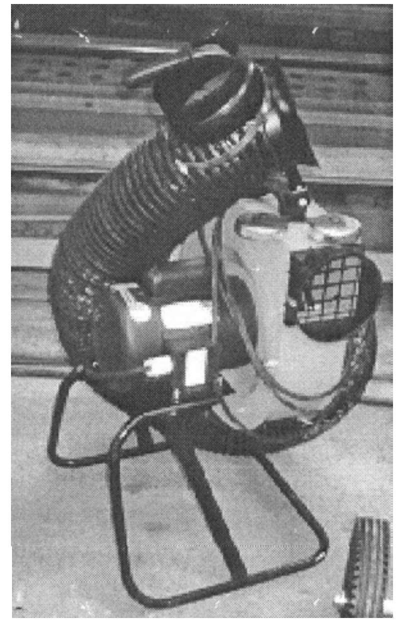

FIGURE 4
Local exhaust ventilation Unit 2 (BSFM model).

FIGURE 3
MEF model (Unit 1). This unit's exhaust flexible arm was 160 mm (6.25 in) in diameter, and was made of flame-proof, double-skin, PVC-coated woven polyamide with an internal steel spiral. The hood at the end of the arm was somewhat conically shaped.

The BSFM-2101 model (Unit 2) is shown in Figure 4. The exhaust arm of Unit 2 was similar to that of Unit 1, except that the hood was not as conically shaped. Product literature indicated that Unit 2 has a 1 HP (750 watt) motor, and a free-flow air volume of 2,200 m^3/hr (1,300 cfm).

Study Methods

Details on all 25 sampling runs can be found in Table I, including the temperature and humidity data collected at the start of each sample run. The first 16 sample runs (1–16) in the tank were conducted to evaluate welding fume emissions using the different rod types and diameters (4 rod types × 4 diameters). Welders 1 and 2 were each set up

TABLE I
Sampling run information

Run	Day	Rod type	Rod diameter (in)	LEV, Welder 1	LEV, Welder 2	LEV, Welder 3	Temp. (°F)	Relative humidity (%)
1	1	308	3/32	None	None	—	55.0	38
2	1	309	3/32	None	None	—	—	—
3	1	316	3/32	None	None	—	69.2	22
4	1	347	3/32	None	None	—	70.0	22
5	1	308	1/8	None	None	—	71.0	22
6	1	309	1/8	None	None	—	72.6	20
7	1	316	1/8	None	None	—	73.3	21
8	1	347	1/8	None	None	—	72.9	21
9	2	308	5/32	None	None	—	63.3	33
10	2	309	5/32	None	None	—	62.8	38
11	2	316	5/32	None	None	—	63.7	37
12	2	347	5/32	None	None	—	66.0	37
13	2	308	3/16	None	None	—	67.9	36
14	2	309	3/16	None	None	—	70.0	34
15	2	316	3/16	None	None	—	81.2	26
16	2	347	3/16	None	None	—	83.0	23
17	2	308	3/16	Unit 2	None	—	84.7	22
18	3	308	3/16	—	Unit 2	—	68.4	46
19	3	308	3/16	—	Unit 1	—	67.9	39
20	3	308	3/16	—	None	—	68.8	34
21	3	308	3/16	—	Unit 1	Unit 2 (9 min)	69.4	25
22	3	308	3/16	—	Unit 1	Unit 2	71.3	22
23	3	347	3/16	—	Unit 1	Unit 2	—	—
24	3	308	3/16	—	—	Unit 1	—	—
25	3	308	3/16	—	—	None	—	—

to weld at a workhorse during these runs, and sample data were collected on them simultaneously. No ventilation was used other than natural dilution ventilation.

The next seven sample runs (17–23) were conducted in the tank to evaluate the local exhaust ventilation (LEV) units. Welder 2 participated in all seven of these runs. Welder 1 welded simultaneously with Welder 2 during one of the seven runs, while Welder 3 welded simultaneously with Welder 2 during another three of the runs.

The final two sample runs of this study (24–25) were conducted inside the welding school with Welder 3. Local exhaust ventilation was supplied by Unit 1 during sample run 24, while normal room ventilation alone was used during sample run 25.

Air Sampling

Short-term air samples were collected in the welders' breathing zones, while short-term and full-shift air samples were collected in general areas, using closed-faced, 37-millimeter (mm) diameter filter cassettes containing a tared, 5-μm pore-size polyvinyl chloride-(PVC) filter.

Two short-term personal air samples were collected simultaneously in each worker's breathing zone using high-volume pumps set at a flow rate of 13 liters per minute (Lpm). One filter sample was analyzed gravimetrically to determine the welder's total welding fume concentration. The analysis was conducted according to Method 0500 (for total particulate) in the National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods, 4th edition.[1] After determining the total welding fume weight on the filter, an element-specific analysis was performed on the filter samples, according to NIOSH Method 7300 (modified for microwave digestion).[1] The second filter sample collected on the welder was analyzed specifically for hexavalent chromium by visible spectroscopy, according to NIOSH Method 7600.[1]

A length of Tygon® tubing connected the filters on the welders to the high-volume pumps located on the floor nearby. The tubing length allowed the welders to work with minimal restriction during sampling. The filters were placed on the lapels of the welders' work shirts, 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. A distance of approximately 64 cm (25 in) was maintained between the face of Welder 1 and the weld arc. Welder 2 maintained a distance of approximately 50 cm (20 in). Distances were not measured for Welder 3. The filters were replaced with new ones at the beginning of each run.

In addition to the two personal air samples, an area sample was collected during each of the sample runs using a carbon vane pump set at a rate of 13 Lpm. The area sample was located in the middle of the tank, approximately 1 m (3 ft) off the floor, during sample runs 1–23. During sample runs 24–25, the area sample was located 152 cm (60 in) from the arc, at a height of 152 cm (60 in) off the floor. In all cases, the area sample was within 3 m (10 ft) of the welders, thus approximating personal exposures rather than emission source levels. The area samples were analyzed for total welding fume and elements according to the NIOSH methods listed previously.

Ventilation Measurements

The ventilation systems were assessed by measuring capture and face velocities with a hot wire anemometer (TSI VelociCalc, TSI, Inc., St. Paul, MN). This instrument measures air velocities in feet per minute (fpm) and air volumes in cubic feet per minute (cfm). Capture velocities were 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, thus allowing the welding fume to be exhausted. Face velocities were measured to compute air volumes. Work methods regarding welding techniques and the use of the ventilation systems were observed. In addition, air flow patterns around the workers during welding were observed using smoke tubes and an aspirator. From this, an understanding of how air contaminants are transported into the worker's breathing zone was developed.

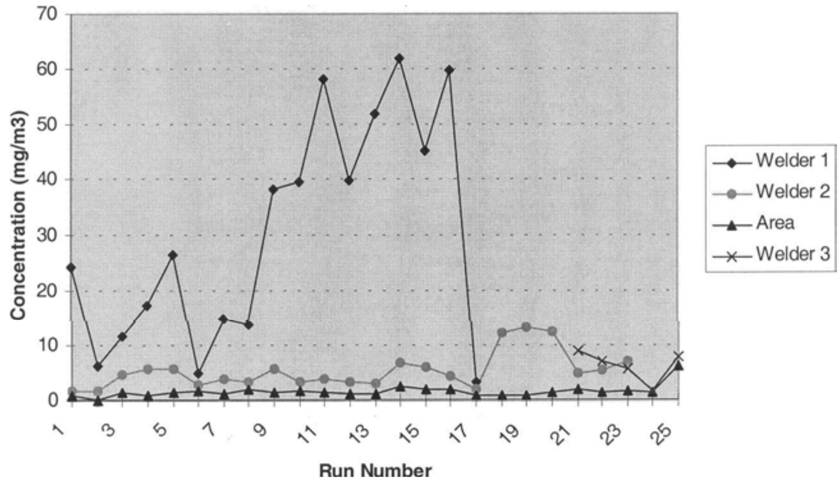

FIGURE 5
Total welding fume filter data.

Results and Discussion

Several study parameters could not be held constant, and their effects, though averaged out in some cases, did influence the results. These parameters include worker habits, wind/air currents, and temperature and humidity fluctuations.

The welders' work habits were all somewhat different. Welder 1 stood fairly erect, with his face positioned directly over the base plate. Welder 2 also stood, but bent over at the waist when welding, resting his arms on the workhorse, and keeping his face angled slightly away from the weld area. Welder 3 sat on a stool when welding. Welders 1 and 2 were right-handed; Welder 3 was left-handed. The welders worked at approximately the same rate, using approximately the same number of electrodes during a single run. Throughout the survey, the total number of electrodes used by each welder during a sample run fluctuated between 10 and 21. This was primarily dependent on the diameter of the electrode; as the diameter increased, the number of rods used during the 15-minute run decreased.

The effect of the wind was not well documented. The air currents inside the tank shifted directions during the day, with velocities generally ranging between 6–12 m/min (20–40 fpm), but occasionally higher. Temperature and relative humidity measurements are shown in Table I for each sampling run. Typically, as the day progressed, the temperature increased, and the relative humidity decreased.

Air Sampling Results

Total welding fume. The results for total airborne welding fume concentration are displayed in Figure 5. The figure shows results from both personal and area air samples, collected as described above. The SAS General Linear Models Procedure was used to perform several analyses of variance (ANOVA) on the filter data to evaluate the effect of study parameters such as electrode type, electrode diameter, and ventilation on worker exposure. Note that the personal sampler results are not 8-hour time-weighted average exposures, since the purpose was to evaluate the process controls, not to determine compliance with exposure criteria. However, to establish a reference point for this discussion, the air concentration data obtained (for all airborne contaminants) are compared to exposure criteria as if they were 8-hour exposures. Of the 45 results in Figure 5 that represent personal samplers, 29 results exceed the 5 mg/m^3 American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Value (TLV®)[(2)] for welding fumes. Fifteen of the 29 were for Welder 1, 10 for Welder 2, and 4 for Welder 3. Only 1 of the 30 area samples exceeded the TLV®.

Comparison of all the personal total welding fume concentration geometric means (GM) indicates that Welder 1 had exposures up to almost five times higher than Welders 2 and 3. Welder 1 used all four diameters and all four rod types, but used ventilation during only one sample run. Welder 2 used all four diameters and all four rod types, and used ventilation during five sample runs. Welder 3 used only 3/16-in-diameter rods and rod types 308 and 347; he used ventilation during four sample runs, and worked indoors during two sample runs. During the first 16 runs alone, Welder 1 had significantly higher exposures ($p < 0.0001$) than Welder 2. (Welder 3 did not participate in these runs.)

All four diameter sizes were evaluated at least twice for each rod type. The 3/16-in diameter was used by all three welders, including 10 sample runs with ventilation, and 2 runs indoors. The other diameters were used only by Welders 1 and 2, without ventilation. The diameters of the welding rods appeared to correlate with welding fume concentrations in unventilated conditions, with larger-diameter rods resulting in higher concentrations. Air concentrations of 9.1, 9.4, 24, and 24 mg/m^3 resulted from the use of the 3/32-, 1/8-, 5/32-, and 3/16-in (0.24-, 0.32-, 0.40-, and 0.48-cm) rods, respectively. All 4

TABLE II
Descriptive statistics for personal total welding fume concentration data, by ventilation used (in mg/m^3)

Ventilation used	GM	Std. dev.	n	Range	Mean
Unit 1, tank	7.00	3.76	4	4.82–13.08	7.58
Unit 2, tank	6.76	3.38	5	3.23–12.15	7.42
None, tank	9.28	19.44	34	1.54–62.00	17.43
Unit 2, indoors	1.59	—	1	—	1.59
None, indoors	7.69	—	1	—	7.69

rod types were evaluated at least twice for each diameter. Rod type 308 was used by all three welders, including 8 sample runs with ventilation and 2 runs indoors. Rod types 309 and 316 were used only by Welders 1 and 2, without ventilation. Rod type 347 was used by all three welders, including two sample runs with ventilation. Comparisons of the geometric means show that the use of rod types 316 and 347 generally resulted in higher concentrations than the other two types. However, statistical analysis of runs 1–16 showed no significant effect on welding fume concentration based on rod type or diameter.

With regard to ventilation, descriptive statistics given in Table II for the personal total welding fume concentration data show the differences. Four sample runs were conducted outdoors (in the tank) using Unit 1. All four runs were performed by Welder 2 with 0.48-cm- (3/16-in-) diameter rods, using rod types 308 and 347. Five sample runs were conducted in the tank using Unit 2. These runs were performed by all three welders using 0.48-cm- (3/16-in-) diameter rods, types 308 and 347. The geometric mean of the concentration data for the two types of ventilation were very similar, with Unit 2 resulting in a slightly lower value. Thirty-four sample runs were conducted in the tank with no ventilation. These runs were performed by Welders 1 and 2 using all four diameter sizes and all four rod types. The geometric mean for this data showed that worker concentrations were greater when no ventilation was used, as compared to when welding with either Unit 1 or Unit 2. Two sample runs were conducted indoors—one using Unit 2, and one without ventilation. Both runs were performed by Welder 3 using a 0.48-cm- (3/16-in-) diameter size, type 308 rod. The use of ventilation indoors resulted in almost five times less fume to the worker than when no ventilation was used.

To further analyze the impact of ventilation on the total welding fume exposure data, statistical analyses were performed. From the ANOVA table, ventilation was shown to have a significant effect on the exposure data ($p < 0.02$). Thus, although the ventilation did not always control the fumes to below the TLV®, it did help to significantly reduce the welders' fume exposure levels. Upon comparing least square means, a significant difference was found between Unit 2 and Unit 1 ($p = 0.03$), and between Unit 2 and no ventilation ($p = 0.006$). In other words, the welders' exposures when using Unit 2 were significantly lower than when using Unit 1 or when using no ventilation at all. The ability of Unit 2 to capture the visible welding fumes is apparent from Figure 6. The welders' exposure data when using Unit 1 was lower than when no ventilation was used; however, the difference was not statistically significant ($p = 0.64$).

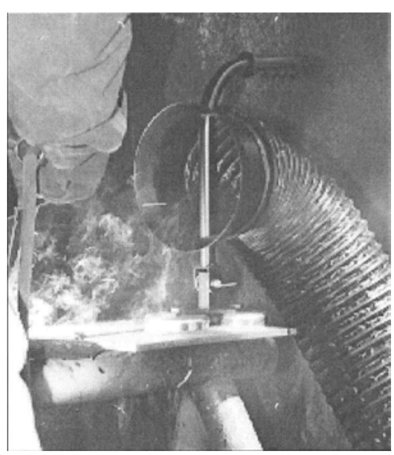

FIGURE 6
Unit 2 effectively exhausted the welding fumes away from the work area.

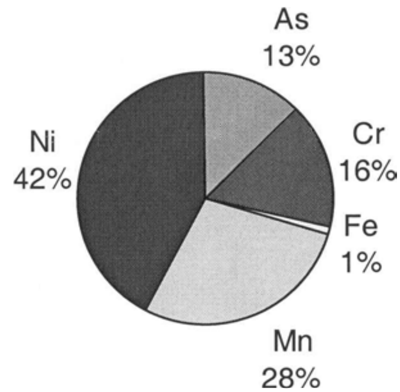

FIGURE 7
Five elements account for 100% of the concentrations exceeding an applicable exposure guideline.

Elements. The elemental analysis showed that, out of 28 measured elements, 5 metals were of concern: arsenic, chromium, iron, manganese, and nickel. Forty-four of the 45 personal samples (98 percent) and 8 of the 30 area samples (27%) were found to have at least one of these five fume constituents above an applicable elemental exposure guideline. The applicable exposure guideline, for purposes of this discussion, was taken to be the most stringent TLV®[2] or Recommended Exposure Limit (REL).[3] Using this approach, manganese and nickel accounted for 70 percent of the personal and area "overexposures." The breakdown is shown in Figure 7.

Some concentrations were very high compared to the most stringent standard. For example, the NIOSH REL is 15 μg/m^3 for nickel, and the highest nickel concentration measured was 667 μg/m^3, which is 45 times the REL. However, of the five metals, only arsenic (seven samples) and chromium (10 samples) were found in concentrations above the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL)[4] levels. These high concentrations included 16 samples collected while the local exhaust ventilation units were operational. Of the 16, two exceeded an OSHA PEL (for arsenic), while the others exceeded an REL or TLV®. Again, the local exhaust ventilation did not appear to be effectively controlling the welding fume constituents to below the recommended exposure levels. Finally, the data indicate that changing rod type or rod diameter did not significantly influence the elemental exposure levels.

Hexavalent chromium analyses. The results of the personal and area sampling data for hexavalent chromium fume concentrations show that the majority of samples were in extreme excess of the 50 $\mu g/m^3$ ACGIH® TLV®[2] and the 1 $\mu g/m^3$ NIOSH REL[3] for hexavalent chromium. NIOSH considers hexavalent chromium to be a potential occupational carcinogen. OSHA currently enforces a ceiling value of 0.1 mg/m^3 for hexavalent chromium as chromic acid (CrO_3) and chromates.[4] Differences in personal concentrations between the welders were very similar to what was found for total welding fume. Welder 1 had higher exposures, probably for the same reasons—primarily, position of the head relative to the work.

Statistical analyses were performed to further evaluate the effect of ventilation on the hexavalent chromium fume exposure data. The use of ventilation was shown to have a significant effect on reducing the exposure data ($p < 0.04$), even though all the samples collected with ventilation were still above the TLV. Upon comparing least square means, a significant difference was found to exist between Unit 2 and no ventilation ($p = 0.02$). In other words, the use of Unit 2 significantly reduced the amount of hexavalent chromium fume in the welders' breathing zones when compared to welding with no ventilation. The exposure to hexavalent chromium fume when using Unit 1 was not statistically significantly different from when no ventilation was used ($p = 0.9$). Overall, the hexavalent chromium fume levels were lower when the welders used Unit 2 as compared to Unit 1; however, this difference was not proven to be statistically significant ($p = 0.09$).

Ventilation data. The LEV units were positioned 7 cm (3 in) away from the end of the 23-cm-long (9-in) baseplate. Face velocities were not measured on Unit 1. However, a face velocity of 555 m/min (1,820 fpm) was measured at the midpoint of the hood face of Unit 2. This computes to an air flow of approximately 660 m^3/min (390 cfm) with the exhaust hoses attached. Capture velocities were measured for the two ventilated units, and are shown in Table III.

For movable exhaust hoods, at a distance of up to 15 cm (6 in) from the hood, the rate of exhaust should be 425 m^3/hr (250 cfm) for a cone-shaped hood, or 570 m^3/hr (335 cfm) for a plain hood.[5] At distances of 15–23 cm (6–9 in) from the hood, the rate of exhaust for a cone hood should be 950 m^3/hr (560 cfm), or 1,280 m^3/min (755 cfm) for a plain hood.[5] Noting that the hood on Unit 1 was slightly more conical than the hood on Unit 2, the volume of air moved by Unit 1 at a point 15 cm (6 in) from the hood was approximately 550 m^3/hr (325 cfm), and around 1,360 m^3/min (800 cfm) for Unit 2. The air flow was approximated using the following equation:

$$Q = V(10X^2 + A)$$

where:
Q = air flow, cfm
V = centerline velocity at X distance from the hood, fpm
X = distance outward along the axis, ft
A = area of hood opening, ft^2

The Industrial Ventilation manual[5] also states that the above equation is only accurate for limited distances of X, where X is within 1.5 times the diameter of the hood (pages 3–7). For distances greater than this, the flow rate increases less rapidly.

The data collected during sample runs 24 and 25 inside the building showed that the local exhaust ventilation helped to reduce fume exposures to the worker. This was most evident when analyzing the filter data: The total welding fume exposures for the personal and area samples were both five times lower with the ventilation on than with it off. The hexavalent chromium filter data collected on the worker also showed the ventilation to reduce fume exposure by a factor of five.

TABLE III
Capture velocities for the local exhaust ventilation units

Distance from hood (in)	Unit 1 (fpm)	Unit 2 (fpm)
6	120	300
9	60	220
12	30	50

Conclusions and Recommendations

The results of the sampling data show that the welders were exposed to high levels of stainless steel welding fume almost two-thirds of the time during the study. (Note: As stated above, these were not actual exposures. The samples were short-term samples taken outside the welders' masks. Although the data collected are not time-weighted averages, they are compared to occupational exposure limits as possible worst-case exposures, as if the concentrations were measured over a full eight- or ten-hour shift.) Several of the personal samples were extremely high; the highest level of welding fume measured on a welder was 60 mg/m^3, almost 12 times the ACGIH TLV of 5 mg/m^3. In addition to exceeding the recommended levels for total welding fume, many of the personal and area samples exceeded levels set for arsenic, total chromium, hexavalent chromium, iron, manganese, and nickel.

A significant difference was established between the fume concentrations measured on Welders 1 and 2 using the filter data. Welder 1 was found to have significantly higher levels of welding fume concentrations than Welder 2. It is likely that much of the difference between the two welders' exposures can be attributed to wind direction and work methods. (Welder 1 stood erect but had his face in a direct line with the welding plume, while Welder 2 leaned over his work but kept his face at an angle from the plume.)

Measurements collected on the ventilation units showed that Unit 2 (the fan) had better capture velocities than Unit 1 (the elephant trunk). Statistical analyses of welding fume concentrations also show a difference in the effectiveness of the two exhaust units. Unit 2 was found to be better at removing the welding fumes than Unit 1, and was significantly better than when no local ventilation was used. Also, although using Unit 1 did help to reduce welding fume levels, it was not found to be significantly better than normal ventilation.

When workers are welding outside, even in a semienclosed tank, air currents play a significant role in how much fume is carried into each worker's breathing zone. The use of local exhaust ventilation may not significantly reduce worker exposure when welding outside, even in a semienclosed area, due to the strong effect of wind currents. Ventilation will help to reduce fume exposures, but the ability of the welder to always stand upwind of the fumes may be even more important when working outside.

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