CPWR THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING

Welding Fume Local Exhaust Ventilation (LEV)Evaluation: the Eurovac II Welding Portable LEV System

Conducted between June 18-20, 2014 at Pipefitters Local 597 Training Center, Mokena, IL

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Background

This work is being carried out as part of a four year CPWR research project which has as one of its aims to test the efficacy and effectiveness of commercially available local exhaust ventilation (LEV) for reducing worker exposures to welding fumes. The project, called AIMS (Adoption of Innovations to Minimize Fumes and Dusts in Construction), uses an industry partnership in the selection of LEV systems to be evaluated and to promote use of LEV for welding fumes in the construction industry. Following an extensive review of commercially available portable LEV systems for welding fumes conducted by Dr. John Meeker, ScD, CIH, the Welding Partnership for Advancing Control Technologies in Construction (PACT) met on June 8, 2012 and selected and rated those systems they viewed as most promising This report describes the outcome of the third LEV system evaluation conducted in a “laboratory-like” setting.

Equipment Evaluated

According to the manufacturer’s website, the Eurovac II Welding Portable unit (Eurovac Inc., Concord, Ontario, Canada), offers the following features:

- Powerful 2.5 HP pump that provides 103 cubic feet per minute (cfm) air flow
- Has two ports to allow for fume extraction with two workers welding simultaneously
- Automatic or manual on/off
- Combination true cyclonic filtration plus secondary cartridge filter; 85% of particulate is removed by cyclone before the secondary filter which results in much more efficient operation compared to units without cyclone filtration.
- HEPA filtration is available by adding a chamber between the pump and regular filters
- Heavy duty construction of 14 gauge steel with a tough powder coat finish
- Quiet operation; motor housing is insulated and baffled for sound

The Eurovac II Welding Portable LEV retails for $1,575. The cylindrical unit is 42 inches tall with a diameter of 14 inches, and weighs 115 pounds. However, it comes with an upright cart with wheels similar to those used for oxyacetylene tanks making it easy to move. To maintain consistency with tests of other LEV equipment conducted in the previous two years, we used a simple “bell-shaped” hood distributed by Lincoln Electric (EN 20 Extraction Nozzle) with the vacuum. The flanged bell shaped hood was attached to corrugated duct 2 inches in diameter. Based on our previous experience with similar “high-vac/low-flow” LEV equipment and published hood entry

Figure 1: Eurovac II Welding LEV

losses (ACGIH, 2004), the bell shaped hood design was considered ideal for this system with regards to airflow and capture velocity compared to other hood shapes such as a “fish tail” nozzle which comes standard with many commercially available portable LEV systems.

The experimental “laboratory-like” testing of this system was conducted by Ms. Pam Susi, CPWR; Ms. Tanushree Chakravarty, Colden Corporation; and Dr. John Meeker, University of Michigan on June 18-20, 2014, at Pipefitter’s Local 597 Training Center in Mokena, Illinois. Welding fume control effectiveness for both stainless steel (specifically hexavalent chromium [Cr VI], manganese [Mn] and nickel [Ni]) and carbon steel (specifically Mn and iron [Fe]) was assessed in separate randomized trials.

Figure 2. Lincoln Electric EN 20 Extraction Nozzle

Study Methods

Senior level apprentice welders performed shielded metal arc welding (SMAW) of both stainless and carbon steels. Personal air monitoring samples were collected with and without LEV to test the ability of the ventilation unit to reduce exposures. Following an Institutional Review Board (IRB) approved protocol, the welders were provided with consent forms and given time to review them before agreeing to volunteer as welders in the study. The content of the form and the fact that their participation was voluntary were communicated verbally before they were asked to sign the forms indicating their agreement to participate in the study. They were also provided with a powered, air purifying respirator/welding hood for protection from welding fume exposure during the trials without LEV. While we attempted to have the same welder perform all the welding throughout the study to minimize variability introduced from differences in welding techniques and positioning between individuals, this was not feasible due to apprentice schedules at the training center. A different worker performed the welding trials on each of the three days. This was consistent with our previous tests of other LEV units. However, trials were randomized as described below and weld times and electrodes used per welder per trial were documented to minimize and/or identify important sources of inter-welder variability.

Control vs. no control trial order was randomized to prevent systematic bias due to carryover exposures from one run to the next and other potential biases that might influence measured exposure levels. Carryover exposure was further prevented by allowing ample time between trials. The return of ambient particulate concentration to background level was verified prior to each run using a real-time particulate monitor (HazDust III; Environmental Devices Corp., Plaistow, N.H.). Five no-control and five LEV control trials were run for both stainless steel and carbon steel welding. Due to failure of one of the sampling pumps during a stainless steel welding trial, a sixth stainless steel trial was conducted.

Welding was conducted in a semi-enclosed welding booth used for training. The booth consists of three solid walls and a curtain on the fourth wall, which was closed during welding. The booth was equipped with a ventilation system which remained off during the trials to allow measurement of the effectiveness of the portable LEV system exclusively. Small (approximately 6 to 8 inches in length) sections of 6-inch diameter cylindrical steel pipe ("coupons") were welded together around the circumference of the pipe (18.8 inches).

Stainless steel welding. For stainless steel, only "fill" and "cap" passes were used on AWS 304 (schedule 80) stainless steel pipe coupons. Pipefitter/welders commonly use GTAW (TIG) welding for a root pass and then "stick out" the remaining fill and cap welds. However, since TIG welding generates much less fume than SMAW and our objective was to keep everything uniform except for use of the tested LEV system, we instructed the welder to only perform SMAW fill and cap passes. Root passes were performed prior to sampling. If in fact TIG welds are made for root passes on actual job sites, we would expect the full shift time weighted average (TWA) exposures measured in the field to be somewhat lower than what we measured during our stainless steel trials. Type 309L-16 electrodes (3/32"; 22–25% chromium) were used for all stainless steel trials.

Carbon/mild steel welding. Each pair of carbon steel schedule 80 pipe coupons were welded with two passes: a root pass followed by a fill pass. Shielded metal arc welding was used for both the root pass (6010 electrode; 1/8"), and the fill pass (7018 electrode; 3/32"). It was noted that not all trials included a root pass, and this was recorded in the data used in our multi-variable linear regression models.

Welding positions and durations. Both stainless and carbon steel pipe were rotated so welding was typically performed between the "9 o'clock" and "12 o'clock" positions on the circumference of the pipe. This allowed for optimum positioning of the LEV hood during controlled trials and for consistency between all trials. During LEV-controlled trials, an effort was made to have no more than 4 to 6 inches between the weld and the hood opening.

Each trial/run ranged between 13 and 40 minutes in duration for stainless steel welding (13 – 20 minutes without LEV and 30 – 40 minutes with LEV), and 12 and 25 minutes for carbon steel welding (12 – 14 minutes with no LEV, 24 – 25 minutes with LEV). Sampling durations were determined based on the sensitivity of the analytical methods used for each metal of interest Our goal was to collect enough sample mass that the laboratory limit of quantification was no higher than the occupational exposure limit we used for performance criteria.

Static pressure measurements were made between each of the LEV-controlled trials at a pressure tap positioned several duct diameters downstream from the hood to assess potential loss of air flow over time due to filter loading. Finally, detailed notes were recorded regarding the sampling location and conditions, any factors or variables that occurred during runs which may have affected welding time or exposure, as well as any observations related to usability or feasibility of the LEV system being evaluated.

Sample Collection and Analysis. Personal exposure measurements were made using a personal sampling pump (GilAir5, Sensidyne Inc., Clearwater, Fla.) drawing air through a 37-mm, 5-µm pore PVC filter at approximately 2.0 L/min. The sampling cassette was placed on the welder's lapel (outside of the welding helmet). All sampled welders were right handed. Sampling cassettes for Cr VI were placed on the left side of each welder and the sampling cassette used for all other metals was placed on the right side of each welder. Sample pumps were pre-calibrated each day using an electronic dry piston primary flow meter (DryCal DC-Lite; Bios International Corp., Butler, N.J.). Flow rates were measured again at the end of the day to verify there was not a change in flow rate over the sampling periods. Following each trial/run, sample filter cassettes were collected, sealed, and prepared for shipment to a laboratory (RJ Lee Group, Inc.) for analysis using OSHA method 215 for hexavalent chromium, NIOSH 7300 for nickel and manganese, and NIOSH method 0500 for particulates not otherwise regulated or general welding fumes and particulate.

For stainless steel welding, two separate samples were collected simultaneously for each trial - one for hexavalent chromium and the other for manganese, nickel, iron, and total particulate. Hexavalent chromium samples were analyzed within 8 days following the OSHA ID 215 method protocol. For carbon steel welding, only one sample was collected for each trial and analyzed for total welding fumes, manganese and iron.

Figure 3: Stainless Steel Welding without LEV

Statistical Analysis. Descriptive statistics were tabulated for trials with and without LEV. Differences between exposure levels with and without LEV use were explored using a student's t-test. In the event an assumption of normality of the data could not be made, even after transformation by the natural logarithm, the non-parametric equivalent test (Mann-Whitney U-test or Wilcoxon rank-sum test) was utilized. Finally, multivariate linear regression was utilized to assess effectiveness of LEV use when also taking into account effects of day/worker, number of rods/electrodes used, or, for carbon steel welding, whether or not a root pass was included in a particular trial.

Results

Hexavalent Chromium. Results from trials involving stainless steel are presented in **Tables I and 2**. Use of the tested LEV system resulted in a 70% reduction in geometric mean Cr VI exposure levels (55% reduction in arithmetic mean) when welding stainless steel (**Table 1**). However, the difference in geometric means between LEV and no LEV trials was not statistically significant. We compared geometric means because personal breathing zone Cr VI concentrations, particularly when LEV was not in use, were highly variable between repeated trials and demonstrated a right-skewed (i.e. lognormal) distribution – that is, there was a 119higher frequency of low values measured and fewer measurements of higher concentrations. It is important to note that the Cr VI mean and geometric mean concentration with LEV use (7.0 and 3.3 μg/m^3, respectively) were greater than the OSHA Permissible Exposure Limit (PEL) of 5 μg/m^3 and the Action Level of 2.5 μg/m^3, respectively, as an 8-hour time-weighted average. However, the mean and geometric mean Cr VI concentration for trials where LEV was *not* used were both well above the PEL (more than 2 and 3 times the PEL, respectively).

Figure 4: Welding Stainless Steel with LEV

Nickel. Geometric mean nickel concentrations were reduced by 47% with use of LEV, but this difference was also not statistically significant **(Table 1).**

Table 1. CrVI and nickel concentrations (µg/m^3) from welding stainless steel

	N	Mean	Geometric Mean	Range	Hazard Ratio (mean/PEL)
CrVI					
No LEV	6	15.6	11.0	3.23 – 38.7	3.1
LEV	6	7.08	3.26[a]	0.48 – 18.8	1.4
Nickel					
No LEV	6	16.2	12.5	4.14 – 41.9	0.016
LEV	5	10.4	6.61[b]	1.53 – 29.8	0.010

[a]p-value = 0.14 comparing No LEV to LEV; [b]p-value = 0.31 comparing No LEV to LEV. A p-value of 0.05 or less is considered statistically significant.

Manganese. Manganese concentrations (**Table 2**) also followed a right-skewed distribution, with a high degree of variability between trials. For **stainless steel,** all samples, collected with and without use of LEV, had manganese concentrations well below the 2012 American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) (0.2 mg/m^3)[1] and the NIOSH Recommended Exposure Limit (REL) (1.0 mg/m^3). Use of LEV reduced (geometric) mean manganese concentrations by 37%, but this difference was not statistically significant. For **carbon steel**, use of LEV resulted in a statistically significant 75% reduction in (geometric) mean manganese exposures. Two of the five samples collected without the use of LEV exceeded the TLV. On the other hand, zero of five samples exceeded the TLV when LEV was used.

Iron. Iron is the predominant metal in welding fumes, and iron oxide fume concentrations serve as a useful measure of LEV exposure reduction. As shown in **Table 3**, the difference in iron concentrations with and without LEV was not statistically significant for either type of steel, but it was noted that iron concentrations were below the TLV for all samples. Finally, due to the short durations of the welding trials and the limited sensitivity of the analytical method (NIOSH 0500 for total particulate), most samples had total particulate concentrations below the limit of detection (not shown), which prevented us from being able to test the influence of LEV use on concentrations of total particulate in the workers' breathing zone.

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[1] The ACGIH TLV for manganese was modified in 2013 and now defines two TLVs for manganese, one at 0.02 mg/m^3 as respirable particulate matter and the other at 0.1 mg/m^3 as inhalable particulate matter. Measurement of respirable and inhalable size particulate requires use of size selective samplers which were not used in our previous trials or included in our study protocol. Given the 2012 TLV was defined as our criteria for LEV effectiveness as part of our proposed study funded in 2010 and used for the previous evaluation, we continue to use the 2012 TLV as our criteria for effectiveness for this evaluation.

Table 2. Manganese concentrations (mg/m^3) from welding of carbon and stainless steels

	N	Mean	Geometric Mean	Range	Hazard Ratio (Mean/TLV)
Carbon Steel					
No LEV	5	0.22	0.17	0.078 – 0.52	1.1
LEV	5	0.057	0.042[a]	0.014 – 0.15	0.29
Stainless Steel					
No LEV	6	0.057	0.051	0.027 – 0.113	0.29
LEV	5	0.035	0.032[b]	0.020 – 0.065	0.18

[a] p-value = 0.03 comparing No LEV to LEV for carbon steel welding.

[b] p-value = 0.15 comparing No LEV to LEV for stainless steel welding.

Table 3. Iron concentrations (mg/m^3) from welding of carbon and Stainless steels

	N	Mean	Geometric Mean	Range	Hazard ratio (Mean/TLV)
Carbon Steel					
No LEV	5	1.33	1.09	0.63 – 3.21	0.27
LEV	5	0.59	0.52[a]	0.30 – 1.19	0.12
Stainless Steel					
No LEV	6	0.27	0.26	0.17 – 0.42	0.05
LEV	5	0.23	0.21[b]	0.09 – 0.31	0.046

[a] p-value = 0.09 comparing No LEV to LEV for carbon steel welding.

[b] p-value = 0.45 comparing No LEV to LEV for stainless steel welding.

We used multivariable linear regression models to estimate the effects of individual variables on exposure. Potentially important variables included in this model were the worker, number of rods used, and in the case of carbon steel welding, whether or not a root pass was included in a particular trial. Our intent was to determine whether any of these variables impacted reduction in exposure levels. We found that inclusion of number of rods used in the model somewhat strengthened the statistically suggestive association between LEV use and reduced Cr VI concentration for stainless steel welding (p = 0.06). None of the other models were impacted by inclusion of covariates.

Estimated LEV flow rates following each LEV trial are appended to this report. We used static pressure measurements taken in the duct downstream of the hood, the coefficient of entry for the hood (derived empirically in an earlier study), and area dimensions of the duct to calculate these estimated flow rates. Although the LEV system was advertised to provide 103 cfm of airflow, we estimated an initial flow rate of 130 cfm out of the box. The LEV system maintained an average air flow of 130 cfm throughout the three days of sampling. Airflow estimates fluctuated somewhat between trials. This could have been due to measurement errors, actual fluctuations in the motor's operation, or differences in the amount of filter loading or duct/hose positioning and bending between measurements.

Summary and Conclusion

Here we report our findings from the third and final LEV system for controlling welding fumes that was tested as part of the AIMS project, the Eurovac II Welding Portable. Although the tested LEV unit is larger and heavier than the systems tested in Years 1 and 2, it was selected by the PACT primarily due to its unique design and the inclusion of a cyclonic separator. It was thought that the cyclone pre-separator may make the system more durable on dusty jobs and require less maintenance compared to other LEV designs since it could preventing larger particles from loading onto the filters. The unit also comes with a hand held cart similar to those used to transport oxyacetylene tanks commonly used for hot work operations. The Eurovac II Welding Portable had an estimated initial flow rate of 119 cfm and ranged from 112 to 124 cfm throughout the trials. These flows were somewhat greater than advertised (103 cfm). It may be worthwhile to investigate potential explanations for discrepancies in air flow between advertised flow rates and what is measured and estimated in the field.

The Eurovac II system was associated with significantly lower concentrations of manganese measured in the worker's breathing zone when SMAW welding carbon steel in an experimental setting. Use of the tested system also reduced Cr VI concentrations by 70% during stainless steel welding, which met our goal of achieving at least a 50% reduction in exposure.

While mean Cr VI concentrations were reduced during stainless steel welding, the difference was not statistically significant. In addition, three of six samples collected when using LEV during stainless steel welding had Cr VI concentrations above the OSHA PEL of 5 $\mu g/m^3$. Geometric mean nickel levels during stainless steel welding were reduced by almost one half. Iron levels were reduced with use of LEV during both stainless and carbon steel welding. However, with the exception of manganese levels measured during carbon steel welding, none of the measured reductions were statistically significant.

We tested the Eurovac LEV system as sold, which did not include a HEPA filter[2]. It may be possible that ultrafine fume particles containing Cr VI may have escaped the standard cartridge filter. While the effectiveness of the Eurovac in reducing manganese concentrations during carbon steel welding may argue against this explanation, we did notice a trend for decreasing Cr VI concentrations over time for the six LEV use trials for stainless steel welding. This may represent increased filter efficiency due to particulate loading as it was used more; also note

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[2] Although advertised as having a HEPA filter , the unit was delivered with a brochure which indicated a HEPA filter was an optional accessary available for additional cost.

that the carbon steel welding trials were performed after the stainless steel trials with no cleaning of the LEV filtration system in between.

In conclusion, ***the Eurovac II Welding Portable LEV reduced worker breathing zone concentrations of manganese to below the 2012 ACGIH TLV during both mild and stainless steel welding. In addition, the LEV unit reduced Cr VI exposures during stainless steel welding by 55% when comparing arithmetic means and 70% when comparing geometric means but not always below previously defined OEL criteria, in an experimental setting***. Given our criteria of reducing exposure by at least 50% or to below the appropriate OEL, we consider the Eurovac II to be effective in reducing exposures to manganese and Cr VI – key welding fume constituents of occupational health concern. A study of the effectiveness of this LEV system on an actual job site where SMAW welding of stainless or carbon steels is taking place may be warranted, but preferably with the addition of the optional HEPA filter.

Appendix 1. Hood static pressure (SP_h) and estimated flow rate in cubic feet per minute (cfm) for the Eurovac II Welding Portable following each LEV control trial

	Trial #	SP_h (inches water)	Flow rate (cfm)
Initial Measure	0	2.02	119
Stainless Steel	1	1.87	115
	2	2.03	120
	3	2.2	124
	4	2.1	122
	5	2.12	122
	6	1.91	116
Carbon Steel	1	2.11	122
	2	2.11	122
	3	1.79	112
	4	2.04	120
	5	1.98	118

ACGIH (2004) Industrial Ventilation: A Manual of Recommended Practice, 25th Edition. American Conference of Governmental and Industrial Hygienists, Cincinnati, OH.