Welding Fume Local Exhaust Ventilation (LEV)Evaluation: the Lincoln Electric X-Tractor Portable LEV System

Conducted between July 22-24, 2013 at Pipefitters Local 597 Training Center, Mokena, IL

Report Prepared by John Meeker, ScD, CIH

Edited by Pam Susi, MSPH, CIH

March 28, 2014

LEV-E-W2-Xtractor

CPWR, the research and training arm of the Building and Construction Trades Dept., AFL-CIO, is uniquely situated to serve construction workers, contractors, practitioners, and the scientific community. This report was prepared by the authors noted. Funding for this research study was made possible by a cooperative agreement with the National Institute for Occupational Safety and Health, NIOSH (OH009762). The contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH or CPWR.

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 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 fume 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. The three highest rated units were selected for evaluation in a “controlled” or “laboratory-like” setting to be followed by testing in a real field setting. This report describes the outcome of the *second* LEV system evaluation conducted in a “laboratory-like” setting.

Equipment Evaluated. The Lincoln Electric X-Tractor® 1C (Lincoln Electric, Cleveland, OH; manufactured in Norway) received the second-highest rating by the PACT (behind only the Trion AirBoss One-Man Portable LEV system which was evaluated in 2012). It was therefore selected as the second LEV system to be evaluated. According to the manufacturer’s website, it offers the following features:

- Two motors offering up to 115 cfm extraction capacity
- Two speed settings (high or low)
- Automatic or manual on/off
- High efficiency, cleanable polyester filter
- Filter is easily cleaned while inside the machine using a unique compressed air rotary jet cleaning system
- 16 foot flexible hose with a magnetic base nozzle for positioning near the weld
- 12 foot power cord; unit available in either 120V or 220V model
- Low noise operation (74 dBA)

Figure 1. Lincoln Electric X-Tractor Portable LEV system and EN 20 Extraction Nozzle

The Lincoln X-Tractor Portable LEV retails for $2,875. However, the manufacturer is a participant in the PACT and provided a unit for testing at no cost. The system was equipped with a simple “bell-shaped” hood distributed by Lincoln Electric (EN 20 Extraction Nozzle).3-

Based on our previous experience with similar “high-vac/low-flow” equipment and published hood entry 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 the “fish tail” nozzle shown with the X-Tractor in the top picture.

The experimental “laboratory-like” testing of this system was conducted by Ms. Pam Susi, CPWR; Ms. Tanushree Chakvarty, Colden Corporation; and Dr. John Meeker, University of Michigan on July 22-24, 2013, at Pipefitter 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.

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 IRB approved protocol, the welders were provided with consent forms and given time to review before agreeing to volunteer as welders in the study. The content of the form was also presented 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. 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 the 2012 testing of the Trion AirBoss One-Man Portable LEV unit. 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 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.

Welding was conducted in a semi-enclosed booth used for pipe fitter 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 would 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. Thus, exposure levels measured for the stainless steel trials likely represent a “worst case” scenario when compared to welding operations that also use TIG welding for a root pass. Type 308/308L electrodes (3/32”; 19–21% chromium) were used for all stainless steel trials.

Figure 2. Stainless steel welding with no LEV

Carbon/mild steel welding. Carbon steel schedule 80 each pipe welds consisted of 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 trials that included the root pass were not equally distributed between no-control and LEV control trials.

Welding position and durations. Both stainless and carbon steel pipe were rotated so welding was typically performed between “9 o'clock” and “12 o'clock” 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 20 and 46 minutes in duration for stainless steel welding (20-26 minutes for no LEV and 37-46 minutes for LEV control), and 10 and 31 minutes for carbon steel welding (10-12 minutes for no LEV, 30-31 minutes for LEV control). Sampling durations were determined based on the minimum amount of sample time needed to collect sufficient mass for the analytical methods used for each metal of interest.

Figure 3: Welding carbon steel with LEV

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 occur during the 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). Sample pumps were pre- and post-calibrated each day using an electronic dry piston primary flow meter (DryCal DC-Lite; Bios International Corp., Butler, N.J.). Following each trial/run, sample filter cassettes were collected, sealed, and prepared for shipment to the 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 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.

Statistical Analysis

Descriptive statistics were tabulated for LEV and non-LEV trials. 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. Use of the tested LEV system resulted in a statistically significant 87% reduction in geometric mean Cr VI exposure levels when welding stainless steel (Table 1). 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. It is important to note that the Cr VI mean and geometric mean concentration without LEV use (9.1 and 3.2 ug/m^3, respectively) were greater than the OSHA PEL and Action Level for an 8-hour time-weighted average (5 and 2.5 ug/m^3, respectively). The mean, geometric mean and maximum Cr VI concentration for trials where LEV was used, on the other hand, were all lower than the PEL and Action Level (0.52, 0.40 and 1.45 ug/m^3, respectively). Nickel concentrations were all below the limit of detection (LOD) for both no-control and LEV control trials (not shown).

Table 1. CrVI (μg/m^3) concentrations, stainless steel welding

	N	Mean	Geometric Mean	Range	Hazard Ratio (mean/PEL)
No LEV	5	9.12	3.17	0.63 – 30.6	1.8
LEV	5	0.52	0.40[a]	0.25 – 1.45	0.10

[a]p-value = 0.02 comparing No LEV to LEV.

Manganese. Manganese concentrations also followed a right-skewed distribution, with a high degree of variability between trials, especially when LEV was not in use. For **stainless steel,** all samples, collected with and without use of LEV, had manganese concentrations well below the 2012 ACGIH TLV (0.2 mg/m^3)[1] and the NIOSH REL (1.0 mg/m^3).

For **carbon steel**, use of LEV resulted in a statistically significant 91% reduction in (geometric) mean manganese exposures. Three of the five samples collected without the use of LEV exceeded the TLV, in some trials by over an order of magnitude. On the other hand, zero of five samples exceeded the TLV when LEV was used. The geometric mean manganese concentrations were higher in the no-control scenario for both types of steel, and these differences were statistically significant (Table 2).

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	1.28	0.38	0.058 – 3.58	6.4
LEV	5	0.037	0.035[a]	0.024 – 0.065	0.19
Stainless Steel					
No LEV	5	0.022	0.019	0.008 – 0.038	0.11
LEV	5	0.011	0.008	<0.005 – 0.025	0.05

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

[b]p-value = 0.05 comparing No LEV to LEV for stainless steel welding.

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 also statistically significant (p-value = 0.007) for carbon steel (iron was not analyzed in stainless steel samples). Finally, due to the short durations of the welding trials, 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.

[1] The ACGIH TLV for manganese was modified in 2013 and now defines 2 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 will continue to use the 2012 TLV as our criteria for effectiveness for this evaluation.

Table 3. Iron concentrations (mg/m^3) from welding of carbon steel

	N	Mean	Geometric Mean	Range	Hazard ratio (Mean/TLV)
No LEV	5	7.1	3.1	0.70 – 26	1.4
LEV	5	0.33	0.28[a]	0.09 – 0.60	0.07

[a]p-value = 0.007 comparing No LEV to LEV.

Using multivariable linear regression models to estimate the effects of individual variables on exposure when taking other potentially important variables into account, inclusion of variables such as worker, number of rods used, or, for carbon steel welding, whether or not a root pass was included in a particular trial were explored to determine whether it would strengthen the reduction in exposure levels attributable to LEV use. We found that inclusion of worker in the model strengthened the association between LEV use and reduced manganese exposure for carbon steel welding ($p < 0.0001$). 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 115 cfm of airflow on its "high" setting, we estimated a flow rate of 229 cfm out of the box. The LEV system maintained an air flow of greater than or equal to 189 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/bending between measurements.

Summary and Conclusion

We found that use of the tested portable LEV system was associated with significantly lower concentrations of Cr VI and manganese measured in the worker's breathing zone when SMAW welding stainless steel in an experimental setting. Likewise, LEV use was associated with significantly reduced manganese and iron concentrations when SMAW welding carbon steel. The short sample durations and analytical sensitivity limitations prevented us from testing differences in total particulate and nickel in relation to LEV use.

Our results provide strong evidence that the tested system – the Lincoln X-Tractor Portable LEV unit – provided substantial reductions in Cr VI exposures when welding stainless steel and manganese when welding carbon steel. Given the high priority of preventing exposures to these two fume constituents due to serious adverse health effects, these data support the need and benefit for use of this LEV system on construction jobs when "stick" welding stainless or carbon steels.

For the system that was tested in Year 1 of the project (the Trion Airboss One-man Portable LEV), we measured a significantly lower airflow out of the box compared to what was advertised (136 cfm measured vs. 220 cfm advertised). In this test, we found the opposite. The X-Tractor was advertised as providing an air flow of 115 cfm on the "high" setting, but using hood static pressure measures several duct diameters away from the hood opening we estimated an air flow of 229 cfm out of the box. It may be worthwhile to investigate potential explanations for these discrepancies in air flow between LEV units and when comparing advertised flow rates with what is estimated in the field.

Our primary goal is to determine the effectiveness of individual LEV units relative to defined criteria (below the OEL or at least a 50% reduction in exposure) rather than compare tested systems. However, we found that the Lincoln X-Tractor was associated with more substantial reductions in manganese and iron concentrations compared to the Trion Airboss, likely due to greater airflow with the former. More data on the ability of the system to maintain flow rate and other durability and maintenance issues should also be investigated further.

In conclusion, ***the Lincoln Electric X-Tractor portable LEV reduced worker breathing zone concentrations of the primary metals of interest by over 90%, and below previously defined OEL criteria, in an experimental setting***. A study of the effectiveness of this LEV system on an actual job site is warranted.

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

	Trial #	SP_h (inches water)	Flow rate (cfm)
Initial Measure	0	3.56	229
Stainless Steel	1	3.04	195
	2	3.15	202
	3	3.14	202
	4	3.05	196
	5	2.94	189
Carbon Steel	1	3.27	210
	2	3.23	207
	3	2.99	192
	4	2.98	191
	5	2.98	191

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