



2nd INTERNATIONAL WORKSHOP ADVANCES IN CLEANER PRODUCTION

"KEY ELEMENTS FOR A SUSTAINABLE WORLD: ENERGY, WATER AND CLIMATE CHANGE"

New Weld Fume Chamber Design to Assess HAP Emissions Potential and Promote Cleaner Production

B. Kura ^a, J. Jackens ^b, J. Keay^c

a. University of New Orleans, New Orleans, USA, bkura@uno.edu

*b. Concurrent Technologies Corporation, Johnstown, PA, USA,
jackensj@ctc.com*

*c. The Applied Research Laboratory at The Pennsylvania State University,
State College, PA, USA, jms32@psu.edu*

Abstract

Metal welding is an important production process in many industry sectors including automotive, aerospace, oil and gas exploration/refining/transportation, heavy manufacturing, and maritime. Though welding emissions are insignificant based on a mass basis within the maritime industry, their contribution to the overall risk to human health and the environment is significant because of the high toxicity associated with heavy metals emitted. These heavy metals include Cr, Cr⁺⁶, Mn, Ni, Pb and others which may pose carcinogenic and non-carcinogenic effects to exposed workers and the public. United States regulatory agencies including the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (U.S. EPA), have recently increased pressure on the industrial sector to reduce their annual emissions of these heavy metals. This recent concern from the regulatory community has led to increased research efforts to better quantify the actual amount of these metals emitted, and to develop a better understanding of their potential to cause adverse effects to public health and the environment.

Welding emission characteristics and quantities depend on a number of factors such as electrode and base metal composition, welding method, shielding gas characteristics and power supply characteristics. When considering the various combinations of these factors, thousands of welding scenarios are expected in the field, each of which presents a unique emissions scenario. Emission factors for the numerous welding scenarios are not available, and will require an extensive amount of research to develop and document. However, these emission factors are essential for several purposes including facility permitting, risk assessment, compliance demonstration, and to achieve cleaner production.

This paper documents the unique challenges faced by the authors to design and fabricate a weld fume chamber capable of capturing 100 % of weld fumes on filter media suitable for heavy metals analysis. The weld fume chamber had to meet the requirements of regulatory agencies, data quality objectives, approved analytical methods, and filter efficiency. Design parameters such as chamber size, blower capacity, experimental speed, filter size and type, and fume loading, along with their inter-relationships will be discussed. This paper provides valuable insight into welding emission evaluation methodology, which should be useful across many sectors.

Keywords: Welding emissions, heavy metals, health risks, fume chamber design, emission factors

1 Introduction

Welding is a common process used in many industrial, municipal and commercial activities to join metal. Industry sectors with considerable welding activity include automotive, aerospace, oil and gas exploration, refining, and transportation, heavy manufacturing and maritime. A variety of metals are joined using welding processes and may include mild steel, stainless steel, aluminum, and other specialty metal alloys depending on the application. The most commonly used welding processes in the maritime industry include Gas Metal Arc Welding (GMAW), Flux Cored Arc Welding (FCAW), Shielded Metal Arc Welding (SMAW), Gas Tungsten Arc Welding (GTAW) and Submerged Arc Welding (SAW) [Kura, 1998].

Published literature indicates that different welding processes have different emission potentials for both total fume and hazardous air pollutants (HAPs) including chromium (Cr), manganese (Mn), nickel (Ni), lead (Pb) and other heavy metals [CTC 2008, AP-42, EPA 1995]. Both, the quantity and characteristics of air emissions can change from one welding process to another. The composition of base metals, welding electrodes, and operating variables of each process can influence welding emissions. Some of the most important factors that influence the quantity and characteristics of air emissions are listed below:

- The welding process type (e.g., GTAW, GMAW, SMAW, FCAW, SAW)
- Base metal type and composition (e.g., mild steel, stainless steel, aluminum)
- Electrode or filler rod type, composition and manufacturer
- Welding amperage and wire feed speed
- Welding voltage
- Contact tip to work distance (GMAW and FCAW)
- Shielding gas type and flow rate (where applicable)
- Welding power source (for pulsed current GMAW)
- Base metal surface contamination and coatings (paint, zinc, etc.).

Welding emission related data available in the literature can be classified into two main categories, (1) environmental emissions data for public health risk assessment, and (2) worker exposure data for employee health risk assessment.

The first category of data deals with emission factors for welding processes which will assist in (a) air permitting, (b) facility compliance with air permit requirements (quantifying annual emission inventories), (c) evaluating impact on the ambient air quality, and (d) evaluating public health risks. Emission factors for welding are typically expressed as the ratio of "mass of pollutant emitted (milligrams or grams)" to "mass of electrode consumed (pound or kilogram)." In the United States, this type of data is mainly used by the United States Environmental Protection Agency (U.S. EPA) to set compliance requirements and by the industry to demonstrate compliance with the U.S. EPA and the state regulatory requirements.

The second category of data mainly deals with individual worker exposures during the typical 8-hr work period. Often this data is reported as an 8-hr time weighted

average (TWA) value. The Occupational Safety and Administration (OSHA) specifies the 8-hr TWA permissible exposure limits (8-hr TWA PELs) for each type of air contaminant expected in the welding environment. Industries have to comply with these standards by routine monitoring of their work force.

2 Background

The U.S. EPA is currently conducting the residual risk and technology (RTR) review process on source categories with MACT (maximum achievable control technology) compliance dates of 2002 or earlier. Because this review is to assess the remaining or “residual” risk after complying with current MACT standards, the U.S. EPA used 2002 National Emissions Inventory (NEI) data to represent post-MACT emissions from these source categories. The U.S. EPA conducted an initial review of this data and a preliminary analysis of inhalation risks associated with the data. This data, along with a summary of the RTR process, was presented to the public in the Advanced Notice of Proposed Rule Making (ANPRM) published in the Federal Register on March 23, 2007.

The shipbuilding and ship repair industry is included as a source category under the current RTR process and could potentially be impacted by an upcoming ruling. It could cost the industry a significant amount of money to comply with the more stringent emission regulations that could result from this ruling. To ensure that the industry is proactively working with the U.S. EPA during this process, the National Shipbuilding Research Program (NSRP) established an initiative to provide the shipbuilding and ship repair industry with technical support to assist them in preparing for and complying with the upcoming RRR.

One of the top priorities of the NSRP funded research team was to generate correct emission factors for the various HAPs emitted from welding processes used in the shipbuilding industry. It was widely believed that the emission factor data available in the U.S. EPA’s emission factors inventory (AP-42 Document) was not of high quality and contained data generated using conservative assumptions. In addition, this data does not accurately represent the emissions produced from actual shipyard process conditions and variables. Thus, any “residual risk” calculations done under RRR by the U.S. EPA could inaccurately represent the industry. Hence, emission factor development took top priority under the NSRP’s initiative.

3 Methodology

As part of this study, literature was reviewed to see how emission factors are generally developed by other industry sectors and for various processes. Emission factors are defined as the, “mass of pollutant emitted per; unit amount of work done, unit amount of product produced, or unit amount of raw materials consumed”. For welding, the most appropriate unit of measure is “mass of pollutant per unit amount of electrode consumed.” The generation of new emission

factors for various welding process requires that the following critical parameters are accurately quantified and documented:

- Mass of each pollutant emitted (Cr, Cr+6, Mn, Ni, Pb).
- Mass of electrode consumed.

In major industry sectors such as chemical plants, utilities, and production plants, emitted pollutants are measured using U.S. EPA's source test methods. The U.S. EPA has source test methods for measuring a variety of parameters required as part of determining pollutant mass emission rates which are listed below:

Method 1:	Sample and Velocity Traverses for Stationary Sources
Method 1A:	Sample and Velocity Traverses for Stationary Sources with Small Stacks or Ducts
Method 2:	Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
Method 2A:	Direct Measurement of Gas Volume through Pipes and Small Ducts
Method 2C:	Determination of Gas Velocity and Volumetric Flow Rate in Small Stacks or Ducts (Standard Pitot Tube)
Method 2D:	Measurement of Gas Volume Flow Rates in Small Pipes and Ducts
Method 3:	Gas Analysis for the Determination of Dry Molecular Weight
Method 4:	Determination of Moisture Content in Stack Gases
Method 5:	Determination of Particulate Matter Emissions from Stationary Sources

For example, the U.S. EPA has a source test method for estimating total particulates or total fume using Method 5, which has to be used in combination with other methods such as: Method 1 or 1A (for traverse locations), Method 2 or 2A, 2C or 2D (stack gas velocity and stack gas volumetric flow rate), Method 3 (molecular weight of the stack gas), and Method 4 (stack gas moisture content). Methods 1 through 5 are used to measure particulate matter emission rates. Collected particulate matter can be subjected to chemical analysis to find out the mass fraction of specific HAPs such as Cr, Cr⁺⁶, Mn, Ni, and Pb.

The mass of weld fume generated is considerably lower than the particulate mass generated in utilities, production plants, and chemical plants. In determining welding emission factors, the relatively low mass may pose several analytical challenges such as:

- (1) Increased error percentage due to low particulate emission potential of welding processes.
- (2) Need for increased sampling time to be able to collect measurable mass on the filter.
- (3) Higher percentage error in case of certain HAPs that have low emission potential.

Instead of the using the U.S. EPA source test methods discussed above where only a portion of the flow in a duct is sampled, an alternative method using a Weld Fume

Chamber was considered. The advantages of using the weld fume chamber include:

- (1) Ability to collect the fume from the entire gas flow, thus reducing the errors associated with sampling a portion of the flow (eliminates problems associated with iso-kinetic sampling).
- (2) Avoidance of long sampling time; because the entire flow is collected on the filter paper, the mass accumulated is considerable and can easily be measured.
- (3) Adequacy of mass of fume collected for most chemical analyses so even the metals with low emission potential can be determined with reasonable accuracy.

4 Design of Weld Fume Chamber

The design of the weld fume chamber required a close analysis of many parameters such as quality assurance and quality control, specific pollutants to be measured, type of filter media required to measure specific pollutants, filter characteristics such as the air handling capacity, and availability of the filters. Each of the above parameters influenced one or more of the other parameters.

The selection of particulate filters for use in this testing provided a unique challenge due to the numerous equipment and sampling limitations including, linear velocities and pressure drops across the filters, established American Welding Society (AWS) flow rate requirements, filter material compatibilities with established analytical methods, and availability of the required filters in the necessary size.

The design of the weld fume chamber, the selection of filter materials and their commercial availability, and the selection of appropriate analytical methods having regulatory approval were all interrelated and required many iterations to arrive at the final solution.

In order to measure emissions for the selected welding process/electrode combinations, it was decided that the testing would be conducted within a fume chamber which would meet the requirements of the AWS specification, AWS F1.2:2006. AWS F1.2:2006 specifies a conical welding chamber with a 12" opening at the top, where a 12" glass fiber filter is placed for fume collection. In this unit, air is drawn upward through the filter, the fumes are deposited, and the filter is removed and analyzed gravimetrically to calculate Fume Generation Rates (FGR's).

When the chamber was constructed for this project, the top opening (outlet) of the chamber was reduced in diameter to 8" (rather than the specified 12") to allow the use of an 8" high-volume fiber filter. After an extensive search for filters that would meet a number of requirements and still fit within the chamber, it was determined that the appropriate filters were available in a maximum size of 8" in diameter. The selection of these filters involved consideration of a number of factors:

- ability to filter fine fume particulates generated by welding

- capacity to handle AWS requirements for high velocity flow rates
- suitability for use in the selected OSHA and NIOSH methods for the analysis of heavy metals Cr, Mn, Ni, Pb, Cr⁺⁶, and insoluble nickel, and
- availability in sizes large enough for the 8" diameter weld fume chamber.

AWS F1.2:2006 calls for the use of a pad of glass fiber insulation to filter the fume from the test chamber exhaust stream. Chris Halm, at the California Air Resources Board (CARB), reported that the AWS-recommended filter pad did not efficiently capture all fumes that were generated; at times over 10% of the fume mass passed through the glass fiber filter pad (Halm). Halm therefore recommended the use of Whatman Glass Microfiber filters, EPM-2000 for more complete capture of particulates.

Whatman Glass Microfiber EPM-2000 filter, Pall Tissuquartz™ quartz fiber filter, and Pall A/E glass fiber filter are all specifically designed for use with high volume air samplers (VWR, Pall). All of these filters have capture efficiency in excess of 99.9% for particles larger than 0.3 µm diameter in size. However, the Whatman filters recommended by Halm are currently not available in sizes larger than 47 mm, while both Pall filters are available in 8"x10" sheets, the largest air sampling filters that were found to be commercially available. Since suitable filters for sampling particulates could not be found in sizes larger than 8" x 10", it was decided to reduce the exhaust of the new fume chamber to 8" diameter size while keeping all other parameters of AWS F1.2:2006 the same.

An opening of 8"x10" was considered in order to keep the filters as large as possible to reduce the pressure drop and to avoid the need to cut the filters, but it was decided to keep the opening round to achieve uniform deposition of particles on the filter. Because the fume chamber has a conical shape for the main body, by keeping the circular cross section for the exhaust pipe instead of a rectangular cross section, it was thought that a more streamlined air flow would be achieved.

OSHA method ID-215 was identified as the most appropriate method for the analysis of hexavalent chromium because it had the lowest method detection limit. OSHA ID-215 calls for the use of PVC or quartz filters for the sampling media. However, PVC membrane filters are not commercially available in sizes larger than 4" diameter, and are therefore not suitable for use in the AWS chamber. Discussions with the environmental testing lab revealed that Pall quartz membrane filters could be used for Cr⁺⁶ analysis if they were presoaked in a sodium hydroxide (NaOH) solution prior to sample collection in order to quench the conversion of Cr⁺⁶ to Cr⁺³ on the filters. The NIOSH 7300 method was identified as the most appropriate method for the analysis of heavy metals, again because of its method detection limit and the NIOSH 7029 method was identified as the most appropriate method for the analysis of insoluble nickel. Both of the NIOSH methods require the use of glass fiber filters, such as the Pall AE glass fiber filters.

Thus, for the purposes of this test plan and based on the discussion above, Pall Tissuquartz quartz fiber filters were used for Cr⁺⁶ analysis and Pall A/E glass fiber

filters were used for Cr, Mn, Ni, and insoluble Ni analyses. The specifications for the filters used in this project are listed in Table 1.

Table 1. Filter specifications for total metals and Cr⁺⁶ sampling

Use/Test Parameter	Filter Type	Filter Size	Specifications and Special Treatment
Total mass of fume, total metals (Cr, Mn, Ni, Pb) and insoluble Ni generated in AWS fume chamber	Pall AE glass fiber filter, binder free	8"x10", cut to 8" diameter	>99.9% of DOP 0.3 µm particulates
Total mass of fume and hexavalent chromium generated in AWS fume chamber	Pall Tissuquartz™ quartz fiber filter, binder free	8"x10", cut to 8" diameter	>99.9% of DOP 0.3 µm particulates; pretreated with sodium hydroxide

Authors had an opportunity to use the above described fume chamber in a study sponsored by the NSRP [CTC, 2008]. Figure 1 shows the fabricated fume chamber and the filter handling sequence. Figure 2 shows the welding in action within the fume chamber and weld rod measurements using a lab scale.

Prior to sampling, the 8"x10" Pall AE glass fiber filters and Pall Tissuquartz™ quartz fiber filters were cut down to 8" diameter size with a custom made cutting die. The Pall Tissuquartz filters that were to be used for the analysis of hexavalent chromium were immersed in a 1% NaOH solution and hung up to dry in an environmentally stable room. The NaOH treatment was done to inhibit the conversion of Cr⁺⁶ to Cr⁺³ on the filters during the time between sample collection and analysis. After drying, the treated quartz filters and the (untreated) Pall AE glass fiber filters were allowed to stabilize in an environmentally stable room (66-70°F, 45-55% RH). They were then pre-weighed on an analytical balance to the nearest 0.1 mg and inserted into individually labeled sample containers.

5 Summary and Conclusions

The methodology used in this study resulted in the design and development of a suitable weld fume chamber that complies with AWS recommended quality requirements and allows an efficient collection of new emission factor data. Features and benefits of this modified weld fume chamber are listed below:

- Complies with AWS quality requirements to reproduce the results obtained in the past, thus ensuring the total collection of fume generated without any loss during sampling events



Figure 1. Weld fume chamber and filter handling sequence [CTC, 2008].



Figure 2. Welding in action and some close up shots [CTC, 2008].

- Commercially available Pall AE glass fiber filters can be used by cutting to 8-inch diameter size for quantifying total fume and metals such as Cr, Mn, Ni, and Pb using appropriate NIOSH analytical methods; promotes generation of total fume, Cr, Mn, Ni, and Pb emission factor data
- Commercially available Pall Tissuquartz™ quartz fiber filters can be used by cutting to 8-inch diameter size for quantifying total fume and Cr⁺⁶ using OSHA ID-215 analytical method; promotes generation of total fume and Cr⁺⁶ emission factor data
- Design of easy-to-handle filter cassette allows easy loading and unloading of filters promoting speed and accuracy of sample collection

- Portable design (whole unit mounted on wheels) with flow meter, pressure gauge (to measure pressure drop across the filter), and other controls promotes collection of acceptable samples in an efficient manner avoiding sampling errors. The extra controls help to track minimum flow rate and maximum pressure drop across the filter to comply with AWS and other data quality requirements).

Ultimate direct and indirect benefits of this well designed weld fume chamber include the benefits derived from the good emission factor data such as:

- Understanding the emission potential of various welding processes, alternative low polluting materials, and multiple consumables will assist shipyards in material substitution and environmental compliance.
- Understanding of process variables which lead to reduced emissions, thus avoiding control costs (source reduction) and improved cleaner production.
- Reduced weld fume emissions, thus minimizing adverse impacts on human health and the environment.
- Improved public image with reduced court litigation, reduced worker compensation, and increased worker commitment and retention.
- Increased environmental compliance including the compliance with health risk criteria.

Overall, the new weld fume chamber design should be helpful in many ways to the scientific community, industry representatives and the regulators.

6 References

American Welding Society (AWS), 2006. AWS F1.2:2006, Laboratory Method for Measuring Fume Generation and Total Fume Emission of Welding and Allied Processes.

Concurrent Technologies Corporation (CTC), 2008. Shipbuilding and Ship Repair Industry Initiative to Prepare for and Comply with the Residual Risk Ruling, Control Technologies Demonstration, Final Summary Report.

Halm, C., July 2005. Improving Welding Toxic Metal Emission Estimates in California - Final Report to California Air Resources Board.

Kura, B., 1998. Evaluation of Cr(VI) Exposure Levels in the Shipbuilding Industry, GCRMTC Project Report No. 32 (ONR Cooperative Agreement No. N00014-94-2-0011).

Pall, Inc. Brochure entitled Filtration Products for Air Monitoring and Sampling, Retrieved November 5, 2007 from the World Wide Web: <http://www.pall.com>

U.S. EPA. EPA Emission Test Methods, Emission Measurement Center (EMC) of the Environmental Protection Agency, 401 M Street S.W., Washington, D.C., 20460, Retrieved March 1, 2009 from the World Wide Web: <http://www.epa.gov/ttn/emc/>

U.S. EPA, January 1995. AP-42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Section 12.19: Development of Particulate and Hazardous Emission Factors for Electric Arc Welding.

VWR Website. Catalog entry for Whatman EPM 2000 high-volume air sampling filter paper. Retrieved May 23, 2007 from the World Wide Web:

http://www.vwrsp.com/catalog/product/index.cgi?catalog_number=28495-330&inE=1&highlight=28495-330