RESEARCH ARTICLE

A comparison of direct-reading instruments for the measurement of hexavalent chromium during stainless steel welding

Hexavalent chromium (Cr(VI)), a known human carcinogen, is a potential exposure concern for workers performing tasks such as welding, soldering or brazing. Traditional monitoring methods for Cr(VI) require the use of a closed-face cassette with a polyvinyl chloride filter, followed by analysis using high-performance liquid chromatography with an ultraviolet and visible light detector, to measure an 8-hr time weighted average (TWA). Utilizing this method can produce a substantial lag time between sampling and results. The use of a direct-reading instrument would provide a useful tool to enable real-time estimation of Cr(VI) for rapid assessment of exposure controls. For this study, three direct-reading instruments were compared with the traditional sampling method: the TSI DustTrak 8520, the HazDust EPAM 5000 and the GRIMM 1.109. A total of 10 side-by-side sampling events were carried out in three different workplaces where welding of stainless steel was being performed. Results from all three instruments found they performed well when compared to the traditional method based on linear regression modeling, and with all R^2 greater than 0.80. This study demonstrated potential value for using direct-reading instruments to quickly estimate Cr(VI) in air during welding operations.

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INTRODUCTION

Epidemiological studies have found a relationship between cumulative hexavalent chromium Cr(VI) exposure among workers and increased risk for lung cancer compared with the general population.[1–10] As such, Cr(VI) has been listed as a known human carcinogen by the International Agency for Research in Cancer[11] and is considered a potential occupational carcinogen by the National Institute for Occupational Safety and Health (NIOSH).[12] Workers performing stainless steel welding are particularly at risk of developing lung cancer from airborne Cr(VI) exposures,[4,13,14] up to a 2.4-fold higher risk.[15] According to the Bureau of Labor Statistics, in 2012 there were 357,400 welders, cutters, solderers and brazers in the US.[16]

The US Occupational Safety and Health Administration (OSHA) have set a Permissible Exposure Limit (PEL) of 5 $\mu g/m^3$, as an 8 hr time-weighted average (TWA).[17] The OSHA Standard (29 CFR 1910.1026) specifically requires monitoring of employees with possible exposure to hexavalent chromium.

The current sampling methods for Cr(VI) used by both the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) require the use of a 37-mm closed-face cassette with a polyvinyl chloride (PVC) filter with a 5 μm pore size for sampling over a 4–8 hr period.[18,19] Laboratory analysis is performed using high performance liquid chromatography (HPLC), with an ultraviolet and visible light detector (UV–VIS) to determine the concentration of Cr(VI) in air over the entire sampling period.[18] Use of this methodology can take from days to weeks before results are available. This lag time in receiving sampling results delays verification of the acceptability of the existing exposure controls or determination of the need for additional or modified exposure controls that may need to be considered or implemented to assure continued protection of workers. Therefore, the availability of a direct-reading aerosol monitoring

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instrument, validated to rapidly provide usable estimates of Cr(VI) concentrations in air during stainless steel welding activities, would be beneficial in helping to ensure exposure levels are being adequately controlled. This tool would be a valuable supplement to required personal monitoring for Cr(VI).

Therefore, the purpose of this study was to determine if direct-reading aerosol monitoring instruments can provide acceptable estimates of Cr(VI) concentrations in air during stainless steel welding operations.

METHODS

Sampling instruments

Three direct-reading instruments were chosen for this study: TSI DustTrak 8520, HazDust EPAM 5000, and GRIMM 1.109, described in detail below. As a reference, three 37-mm closed-face cassettes containing 5 μm pore size pre-weighed PVC filters ("cassettes") were used simultaneously. Although a 2 L/min flow rate is typically used for these samples, due to the different flow rates used by the direct-reading instruments (between 1.2 and 1.7 L/min), cassette samples were also collected at pump flow rates of 1 L/min. This is within the purview of the relevant method, NIOSH 7600 (hexavalent chromium).[18] After sample collection, the cassette filters were desiccated and then weighed using a microbalance to determine the total particulate mass. The samples were then analyzed using HPLC equipped with a UV–VIS detector to separate, identify and quantify the Cr(VI) on the filter. Samples were analyzed by an American Industrial Hygiene Association (AIHA) accredited laboratory, certified for the analytical methods specified in NIOSH Method 7600. This method has an accuracy of $\pm$18.58% and an overall precision of 0.084 mg/m^3.[18]

The TSI DustTrak Model 8520 (TSI Inc., Shoreview, MN) is a direct-reading aerosol monitoring instrument that utilizes light-scattering technology to provide real-time estimates of particulate matter (PM) of various size ranges, including PM_{10}, $PM_{2.5}$, PM_1, and respirable particulate matter. According to the manufacturer calibration documentation, this instrument has an accuracy of $\pm$1% relative to Arizona road dust, although that accuracy will change depending on the dust being sampled and the particle size distribution. Previous studies have found a strong correlation in monitoring results between gravimetric sampling results and the DustTrak sampling results for measuring welding fumes and for residual fuel oil ash in the boilermaker industry,[20] as well as diesel particulate matter in underground hard rock mines[21] and oil- and water-based metalworking fluid aerosols.[22] The DustTrak has also been used to study aerosols such as environmental tobacco smoke, fumes from cooking oil, and smoke emissions from combustion of cedar-wood.[23] It has been reported that the accuracy of the DustTrak increased as the particle size got smaller (e.g., $PM_{2.5}$ vs. PM_{10}).[24] For this study, the DustTrak was operated at 1.7 L/min to provide an estimate of PM_{10} concentration, with data logging every second.

The HazDust EPAM 5000 (Environmental Devices Corporation, Plaistow, NH) is a portable aerosol monitor, with data logging capability, which uses light-scattering technology to provide mass concentrations of airborne particles. According to the manufacturer, the accuracy of this device is $\pm$10% of a gravimetric fine test dust filter measurement, with a precision of $\pm$0.003 mg/m^3. Different size-selective inlets are available for measuring particulate matter less than 10 μm (PM_{10}), $PM_{2.5}$, PM_1, and total suspended particles (TSP). It has been used by the United States Environmental Protection Agency (EPA) for ambient air quality surveys.[25] It has also been used to quantify seasonal changes in indoor and outdoor levels of PM_{10} in high-rise apartment buildings.[26] For this study, the HazDust was set to data log for PM_{10} concentrations every second.

The GRIMM 1.109 (GRIMM Technologies, Douglasville, GA) is a portable aerosol spectrometer that uses light scattering technology to detect airborne particles in a sample air stream, operating at 1.2 L/min. This instrument is capable of detecting particles ranging in 31 size ranges (bins) that measure aerosols from 0.22 to 32 μm in aerodynamic diameter. This capability allows for detailed size distributions that can be displayed in number of particles per cubic meter or in mass concentration (μg/m^3). For the mass concentration mode used in this study, the manufacturer certifies the accuracy as $\pm$5%. Previous studies have shown that, compared to standard gravimetric methods, the GRIMM 1.109 can provide acceptably accurate estimates of airborne metal concentrations in a smelter environment[27] and for diesel particulate matter from use of diesel engines in an underground mine.[28] For this study, the GRIMM logged data in mass concentration per unit volume (every μg/m^3) every 6 s.

Sampling set-up

Sampling was conducted at three separate welding sites, resulting in a total of 10 sampling events. Each of the three sampling sites used arc welding equipment and welded on type 304 stainless steel materials, which contain 18.0–20.0% chromium.[29] Two of the sites used flux-cored arc welding (FCAW) with DW-308LP flux-cored wire, which contains 19.1% chromium.[30] The third site used arc welding without a wire-feed mechanism.

Figure 1 shows the sampling chamber that was constructed to facilitate simultaneous measurements with the direct-read aerosol monitoring instruments and filter cassette samples equidistant from the welding site. The chamber was constructed of 4 m of galvanized duct, approximately 15 cm (6 in.) in diameter. A Fantech model FR150 (Fantech, Lenexa, KS) variable speed exhaust fan was positioned on one end of the duct to provide air movement and a rectangular capture hood, approximately 30 cm (12 in.) by 11 cm (4.4 in.), was positioned on the opposite end, close to the source of welding fume. The inlets to the direct-read instruments and filter cassettes were placed perpendicular to the airflow through holes drilled through the sampling chamber 1 m upstream of the exhaust fan and 3 m from the hood, as shown in Figure 2. The inlets to the direct-read instrument and cassettes were sealed to the duct to