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Confined space ventilation by shipyard welders: Observed use and effectiveness

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Abstract

Shipbuilding involves intensive welding activities within enclosed and confined spaces and, although ventilation is commonly used in the industry, its use and effectiveness has not been adequately documented. Workers engaged in welding in enclosed or confined space in two shipyards were observed for their use of ventilation and monitored for their exposure to particulate matter. The type of ventilation in use, its placement and face velocity, the movement of air within the space, and other ventilation-related parameters were recorded, along with task characteristics such as the type of welding, the welder's position, and the configuration of the space. Mechanical ventilation was present in about two thirds of the 65 welding scenarios observed, with exhaust ventilation used predominantly in one shipyard and supply blowers predominantly in the other. Welders were frequently observed working in apparent dead-spaces within the room, even where ventilation was in use. Respiratory protection was common in the two shipyards, observed in use in 77% and 100% of the cases. Welding method, the proximity of the welder's head to the fume, and air mixing were found to be associated with the welder's exposure, while other characteristics of the dilution ventilation did not produce appreciable differences in exposure level. These parameters associated with exposure reduction can be assessed subjectively and are thus good candidates for training on effective ventilation use during hot work in confined spaces. Ventilation used in confined space welding is often inadequate for controlling exposure to welding fume.

Introduction

More than 13,000 welders worked in the US shipbuilding industry in 2012 (BLS 2012) performing tasks in a variety of different workspaces, including confined spaces. Confined and enclosed spaces are common in shipbuilding because the structure of the ships and nature of their construction frequently require hot work in the interior of the vessel.

Mechanical ventilation is an effective means of reducing exposure levels. The preferred approach is local exhaust ventilation (LEV), as it captures the contaminant at the source and, when placed properly, has been found to be significantly more effective than dilution ventilation at reducing welder exposure levels in confined spaces (Wurzelbacher et al. 2002). The reduction of exposure using either local exhaust or dilution ventilation is highly dependent on the effective positioning of the supply or exhaust hoods with respect to the point of fume generation. Positioning is particularly challenging in the shipyard environment where spaces may be irregularly shaped and tightly confined (Flynn and Susi 2012).

We report here the results of an observational study at two shipyards primarily using dilution ventilation to reduce welding fume exposure. The primary goals of this study were to characterize ventilation use among shipyard welders working in confined spaces and to identify the characteristics of the job and the ventilation parameters which influence breathing zone welding fume levels in real confined-space work environments. Although the parameters of the proper design and use of ventilation for contaminant control are well-known, there is a relative paucity of data on ventilation effectiveness in real-world situations, especially in confined-space conditions.

Methods

Data were collected at two shipyards in the Puget Sound region of Washington State as part of a confined-space ventilation training intervention study. All methods were approved by the University of Washington Institutional Review Board.

While the participating welders performed their usual work tasks, characteristics of the space, task, and ventilation were assessed and recorded. Characteristics of the job that were recorded included the degree of space enclosure, size of the space and whether it had any internal obstructions, whether the job was new construction or repair work, the method of welding being used, and the welder's use of respiratory protection. The position of the welder's breathing zone was classified as in, near, or away from the fume based on the posture and proximity of the welder to the visible plume. The diameter of each ventilating outlet was recorded and the linear flow rate through the vent was measured with a hand-held vane anemometer, (TSI 9565-P Velocicalc, TSI 5725 anemometer) moved in a traversing grid over the hood opening. This measurement was made for ten seconds after the anemometer reached equilibrium with the ventilation velocity and measured velocities were averaged over that time.

The type and placement of the exhaust ventilation, presence of cross-drafts (i.e., air currents traveling across the microenvironment of the weld), and air movement in the space ("mixing") were recorded. Observers also recorded whether the welder was working in a "dead space"; that is, if the welder was working in a portion of the space where air movement was restricted, potentially resulting in a "pocket" of fume. Such spaces were found to be present even if air mixing was observed in the rest of the space. For observations in which exhaust ventilation was used, the placement of the vent hood was described by two factors: proximity and elevation. Proximity of the ventilation to the weld was graded as local (within about two hood diameters of the weld), regional (within about 1.2 meters of the weld and in the proximity of the rising plume), and general (greater than 1.2 meters from the weld or out of the plume). The height of the exhaust ventilation relative to the weld (above, even, or below) was also recorded.

For each observation period, the welder wore a personal nephelometer (MIE Personal DataRAM-1200) with a 0.64 cm i.d. conductive silicone tube upstream with opening placed in the breathing zone and a personal sampling pump (SKC AirChek XR5000) downstream calibrated to approximately 2 L/min before each sampling day using a primary calibrator (Bios Defender 520). For this analysis, the average particle concentration over the observation period was calculated (mg/m^3) and examined.

The measured average concentration was modeled, after log transformation, using multiple linear regression to examine the association of ventilation and job characteristics. A base model was constructed using variables assumed to be associated with welding fume concentration regardless of ventilation characteristics: welding method and the proximity of the welder's breathing zone to the fume. Ventilation characteristics that were viewed as likely to be important to breathing zone concentration were added to the base model one at a time and compared to the base model using a likelihood ratio test. Variables and interactions to be tested for inclusion were identified *a priori*. Those variables which showed significant improvement (using an alpha level criterion of 0.1) over the base model or were part of a significant interaction were included in the final model.

Results

Sixty-five complete and independent observations were made for this analysis. The geometric mean and standard deviation of measured particulate concentrations stratified by relevant variables is presented in Table 1. The measured respirable particulate concentrations were high (GM = 2.4 mg/m^3, and highly variable (GSD=4.2). Shipyard B had considerably higher concentrations (GM=4.9 mg/m^3) compared to Shipyard A (GM=1.9 mg/m^3), at least partly because the work at Shipyard B was generally in much smaller spaces. Overall, 26% of the samples exceeded the ACGIH occupational exposure limit of 5 mg/m^3 (ACGIH, 1998b), with over half of the samples exceeding this level in Shipyard B. Most participants (75%) were using dual-shield flux-cored arc welding (FCAW) at both yards. Proximity of the welder's breathing zone was clearly associated with the level of particulate matter. Shipyard B consistently used supply ventilation while at Shipyard A, almost 40% of the welders observed used no mechanical ventilation. In Shipyard A, the use of ventilation of any kind was associated with a lower exposure level when compared to those observations using no ventilation, although the amount of ventilation (air changes per minute) did not produce a clear reduction in exposure. Mixing and use of a cross-draft clearly was associated with a lower level of exposure, although welding outside of the mixed air, that is in a dead space, was only associated with increased exposure level in Shipyard B. Other than using the exhaust ventilation as a LEV hood, which was observed only twice, placement of the ventilation with respect to the welding plume had little effect on exposure level. Each of the observed workers in Shipyard B wore a respirator while welding, while 23% of welders in Shipyard A used no respiratory protection.

The results of the multivariable regression on exposure level are presented in Table 2. As expected, FCAW produced severalfold higher exposure than shielded metal arc welding, and work with the welder's head in or near the welding plume was associated with a higher exposure. In addition, mixing of confined-space air produced a halving of exposure concentration. None of the other ventilation characteristics: air changes per minute, presence of a cross-draft, height and proximity of the exhaust ventilation hood, or work in a dead space produced any additional effect on fume concentration. Thus, even while controlling for type of welding and breathing zone proximity, placement of general ventilation hoods produced little effect on exposure levels. Use of ventilation to mix the room air and positioning to keep the head away from the welding plume are the most important methods of limiting exposure if local exhaust is not feasible.

Discussion

Despite the known advantages of local exhaust ventilation, the shipyards in this study employed exhaust or supplied dilution ventilation for welding fume contaminant control. In about one third of the observations no mechanical ventilation was used, despite hot work occurring within an enclosed or confined space. Despite the existence of well-known design characteristics for contaminant control using local and dilution ventilation, our results suggests that these may rarely be followed in shipyard welding operations and, even when dilution ventilation is present, it may be ineffective in controlling exposure.

About half of the welders were perceived to be working in a dead air space, despite their use of mechanical ventilation in 60% of these work areas. However, working in a dead space did not significantly affect exposure concentration. However, more significant mixing of air in the whole space, using either using a supply blower, a box fan, or natural ventilation, was found to significantly reduce breathing zone concentrations. Whether the air in a space is being mixed is a factor which is conveniently and quickly assessed in a subjective fashion even if some of the particulate is not visible. Thus, mixing is an attractive option for reduction of contaminant concentration, despite the fact that it does not directly remove aerosol from the confined space.

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Table 1

Personal welding particulate concentrations (mg/m^3) stratified by select ventilation and job characteristics

	All Observations			Shipyard A			Shipyard B		
	n	GM	(GSD)	n	GM	(GSD)	n	GM	(GSD)
All samples	65	2.40	(4.2)	48	1.86	(3.9)	17	4.90	(4.1)
Descriptive Variables									
Welding Method									
SMAW	5	0.75	(4.5)	5	0.75	(4.5)	0	-	(-)
FCAW (Dual Shield)	49	3.18	(3.6)	32	2.53	(3.2)	17	4.90	(4.1)
FCAW (Inner Shield)	5	3.67	(4.9)	5	3.67	(4.9)	0	-	(-)
Oxyacetylene	6	0.44	(2.9)	6	0.44	(2.9)	0	-	(-)
Proximity of Welder's Head to Fume									
In	12	3.98	(1.9)	9	3.60	(1.7)	3	5.39	(2.8)
Near	30	3.42	(4.3)	19	2.50	(4.0)	11	5.89	(4.5)
Away	23	1.16	(4.3)	20	1.05	(4.2)	3	2.27	(5.3)
Space Volume									
<28 m^3	45	2.47	(4.6)	29	1.73	(4.3)	16	4.74	(4.3)
28 m3 – 56 m^3	18	2.39	(3.7)	17	2.22	(3.7)	1	8.28	(-)
>56 m^3	2	1.23	(2.3)	2	1.23	(2.3)	0	-	(-)
Ventilation Characteristics									
Ventilation Used									
No	19	2.31	(4.4)	19	2.31	(4.4)	0	-	(-)
Yes	46	2.43	(4.2)	29	1.61	(3.7)	17	4.90	(4.1)
Air Changes per Minute									
<1	34	2.35	(4.4)	29	2.05	(4.1)	5	5.26	(6.6)
1–2	12	1.76	(3.5)	10	1.58	(3.8)	2	2.96	(2.2)
2–3	2	2.39	(1.2)	2	2.39	(1.2)	0	-	(-)
>3	17	3.11	(4.8)	7	1.48	(5.3)	10	5.23	(3.9)
Mixing Used									
No	42	2.67	(4.9)	34	2.04	(4.4)	8	8.26	(5.1)

		All Observations			Shipyard A			Shipyard B		
	Yes	23	1.97	(3.1)	14	1.48	(3.0)	9	3.08	(3.0)
Dead space										
	No	31	2.37	(3.8)	21	1.84	(3.8)	10	4.02	(3.5)
	Yes	34	2.42	(4.7)	27	1.88	(4.2)	7	6.50	(5.4)
Crossdraft Used										
	No	55	2.65	(4.5)	42	1.97	(4.1)	13	6.94	(3.9)
	Yes	10	1.38	(2.6)	6	1.25	(2.7)	4	1.58	(2.7)
Exhaust Proximity										
	Local	2	1.08	(47.1)	2	0.61	(7.2)	0	-	(-)
	Regional	6	2.09	(1.9)	6	1.53	(3.7)	0	-	(-)
	General	19	1.57	(3.5)	18	1.55	(3.7)	1	2.04	(-)
Relative Exhaust Height										
	Below	6	1.53	(3.7)	6	1.74	(3.5)	0	-	(-)
	Even	7	1.50	(5.4)	6	1.43	(6.3)	1	2.04	(-)
	Above	14	1.74	(3.5)	14	1.53	(3.7)	0	-	(-)

Table 2

Linear regression model of welding fume concentration (ln(mg/m^3) on space and ventilation characteristics (n=65).

	exp(β)*	**exp(SE)***	**p**	**exp(95% CI)***
Intercept	0.51	1.74	0.23	(0.17, 1.54)
Proximity of Breathing Zone to Fume				
Away	-	-	-	- -
Near	2.62	1.40	0.01	(1.33, 5.16)
In	2.90	1.55	0.02	(1.21, 6.94)
Welding Method				
SMAW	-	-	-	- -
FCAW (Inner Shield)	4.33	1.79	0.02	(1.35, 13.93)
FCAW (Dual Shield)	5.23	2.20	0.04	(1.07, 25.43)
Oxyacetylene	0.60	2.08	0.48	(0.14, 2.58)
Mixing				
No	-	-	-	- -
Yes	0.46	1.38	0.02	(0.24, 0.87)

*Values have been exponentiated to represent the ratio of the breathing zone concentration in the specified group relative to the concentration of the reference group.