

## ORIGINAL ARTICLE

# Occupational Exposure to Welding Fumes Using Different Ventilation Scenarios

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## ABSTRACT

Welders may suffer from welding fumes generated during the process if the ventilation systems are improperly applied. The objective of the present work was to study the mitigation of air pollutants at welding stations, using different ventilation scenarios. Four air pollutants including iron oxide, respirable dust, ozone, and carbon monoxide were measured during four different ventilation scenarios using US OSHA and US NIOSH sampling and analysis methods. Meantime, face velocity, volumetric airflow rates, duct velocity, static, and velocity pressures at different locations of the ventilation systems were also measured using BS 1042 standard methods. The paired *t*-test revealed that with  $p < 0.05$  there was a significant difference between occupational exposure to air pollutants in 4 different ventilation scenarios. The results also showed that when local and general ventilation systems were both on, the occupational exposure to iron oxide and carbon monoxide were below than their TLVs, but the exposure to the respirable dust in two welding stations and ozone levels in three welding stations were higher than their respective TLVs. The duct air velocity in three welding stations is higher and in eight stations lower than 10.1 m/s recommended by ACGIH. The mean value of volumetric airflow rates in all 11 stations were 34.7% of the required volumetric airflow rates based on standard ventilation systems recommended value. The applied general exhaust ventilation was only 35.5% of standard required value. The local exhaust ventilation is expected to mitigate the air pollutants to acceptable levels at welding stations.

**Keywords:** *Welding Fumes, Ventilation, Iron Oxides, Respirable Dust, Carbon Monoxide*

## INTRODUCTION

The adverse occupational health effects of welding fumes have been recognized by different authors [1-4]. The studies have revealed that the influences of welding fumes and gases generated during the welding process may be in the form of bronchitis, sensitivity, respiratory function changes, pulmonary infections and so on [5, 6].

Historical cohort mortality studies on lung cancer risk of mild steel welders conducted from 1950s and extended through 1988 revealed that welders exposed to 6-7 mg/m<sup>3</sup> of total particulate and 3-4 mg/m<sup>3</sup> of iron oxide for an average duration of 8.5 years did not have a significantly higher relevant standard mortality ratios compared with non welders. The only other cause of death significantly elevated was emphysema among welders [7]. Historical follow up studies conducted among the arc welders exposed to fumes containing

chromium and nickel identified increased risk of lung cancer resulting from exposure to welding fumes [3].

Airborne manganese concentrations generated during welding within the range of 0.004 to 2.67 mg/m<sup>3</sup> could induce sub-clinical effects on the nervous system [4]. Workers exposed to manganese levels in the range of 1-5 mg Mn /m<sup>3</sup> for 20 years could develop early subclinical changes in neuropsychological parameters, such as hand tremor, reduced memory, and prolonged reaction times [8].

Epidemiological studies indicated that the welders might have a younger age of onset of Parkinson's disease compared to sequentially ascertained Parkinson's patients [1, 9]. Some studies suggested a standard risk assessment method for welding fumes related diseases [10].

More than 80 different types of welding technology and allied processes, including brazing and thermal cutting are in commercial use [11]. Metal arc welding, gas-shield welding, similar to metal inert gas (MIG)

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Fig 1. Welding stations in the study

welding and metal active gas welding (MAG), are the most common types of welding [12].

The type of generated welding fume depends on welding methods, electrodes used, welding temperature and the composition of the base metal. Fumes from welding mild steel as presented in this study mainly contain iron oxides. However, fumes from the base materials are not the only sources of air borne particles. Fluxes and filler metals used in powdered form may also enter the air as fugitive dust. Further more, ozone, nitrogen oxides, fluorides, carbon dioxide and carbon monoxide are relevant gases present in welding fumes. Consequently, during welding, different types of airborne hazardous substances are generated which can initiate obstructive respiratory tract and other symptoms [12].

The use of local exhaust ventilation can significantly reduce the mean exposures to welding fumes [13]. Different standards for local and general exhaust types of ventilation systems have been introduced to control unacceptable exposure to welding fumes [14]. However, their proper design, fabrication, operation and effectiveness may need to be investigated.

The objective of the present study was to measure the welding fumes and gases from mild steel welding using different ventilation scenarios. The factory under study manufactures vehicle axel. Ninety percent of the welding pieces contain iron and almost 10% carbon material.

## MATERIAL AND METHODS

Arc welding work was performed by professional welders using consumable welding cords who were permitted arbitrary operations with sufficient repeatability and precision. Four ventilation scenarios (A combination of local and general exhaust ventilation being on or off) were considered. The effectiveness of ventilation scenarios were evaluated by monitoring breathing zone concentrations of welding fumes, constituents such as ozone, CO and respirable particulate matter. Ventilation parameters including

capture velocity, face velocity, duct velocity and ventilation flow rate were also evaluated.

US OSHA-ID 121 method was used to monitor occupational exposure levels to iron oxide. A low volume air-sampling pump at a flow rate of 2 l/min equipped with a Mixed-cellulose-ester air filter was used for 240 minutes to collect samples. Samples were prepared for analysis at the researcher's laboratory using nitric acid and hydrogen chloride before their final analysis by an atomic absorption unit [15, 16].

The occupational exposure to respirable dust was measured using US NIOSH method 0600. A low volume air sampler at a flow rate of 2.5 l/min attached with a cellulose-ester air filter and an aluminum respirable dust cyclone was used for 150 minutes to collect samples. Filters were weighed before and after sampling to calculate the respirable dust concentration [17, 18]. The CO and ozone concentrations were measured with Gastec detector tubes [16].

Capture velocity, face velocity, volumetric flow rate and air pressures along the ducts were measured according to BS method 1042 using anemometer, monometer and static Pitot tube manufactured by Air Flow Company, UK. All instrumentations were calibrated prior to their application [19].

Samples were taken for each air pollutant from each welding station leading to 11 samples. Air velocities and pressures were measured at all ventilation systems. All welders wore suitable respirators to be protected from accidental overexposure to the welding fumes during the experiments.

## RESULTS

**Iron oxide:** Lower iron oxide concentrations were resulted when both general and local exhaust ventilation systems were operating (Table 1). The minimum, maximum and mean concentrations of 11 iron oxide samples were 0, 5.20 and  $2.70 \pm 1.65$  mg/m<sup>3</sup>, respectively. In this ventilating scenario, the occupational exposure to iron oxide was less than TLV recommended by ACGIH (2005) of 5 mg/m<sup>3</sup> in all

**Table 1.** The concentration of air pollutants with different ventilation operating settings

Vent Setting		Quantity	Iron Oxide mg/m <sup>3</sup>	Ozone ppm	Res Dust mg/m <sup>3</sup>	CO ppm
Gen	Loc					
on	on	Min	0.00	0.01	1.03	5.00
		Max	5.20	0.03	5.76	10.0
		Mean	2.17	0.02	3.53	7.50
		Std dev	1.65	0.01	1.83	2.11
		N	11	11	11	11
off	on	Min	1.08	0.01	1.20	6.00
		Max	6.77	0.04	7.30	13.0
		Mean	2.86	0.03	4.48	9.68
		Std dev	1.88	0.01	2.23	2.10
		N	11	11	11	11
on	off	Min	4.70	0.01	5.10	15.0
		Max	10.2	0.05	24.8	20.0
		Mean	7.13	0.04	11.1	18.9
		Std dev	1.78	0.01	5.57	1.70
		N	11	11	11	11
off	off	Min	7.13	0.03	8.93	22.0
		Max	16.5	0.07	48.5	32.0
		Mean	10.4	0.05	20.9	27.0
		Std dev	2.49	0.01	14.2	3.26
		N	11	11	11	11

welding stations except one station which the level exceeded the limit.

The welders experienced a higher occupational exposure level when both ventilation systems were off. The minimum, maximum and mean concentrations of 11 iron oxide samples were 7.13, 16.5 and 10.4±7.13 mg/m<sup>3</sup>, respectively leading to occupational exposure levels of higher than exposure limit in all welding stations.

**Ozone:** Lower ozone concentrations were detected while both local and general exhaust ventilation systems were on. The minimum, maximum, and mean concentrations of 11 ozone samples were equal to 0.01, 0.03 and 0.02±0.01 ppm, respectively. With both ventilations off, higher concentrations of ozone were measured; the minimum, maximum and mean concentrations of 11 ozone samples were equal to 0.03, 0.07 and 0.05±0.01 ppm, respectively.

**Respirable Dust:** With both ventilation systems on, lower respirable dust exposure levels was observed; the minimum, maximum and mean concentrations of 11 respirable dust samples were 1.03, 5.76 and 3.53±1.83 mg/m<sup>3</sup>, respectively. The results show that higher exposure levels to respirable dust were experienced with both ventilations set to off position; the minimum, maximum and mean concentrations of 11 respirable dust samples were 8.93, 48.5 and 20.9±14.2 mg/m<sup>3</sup>, respectively.

**Carbon monoxide:** With both ventilation systems on, the welders experienced a lower exposure levels to carbon monoxide; the minimum, maximum, and mean concentrations of 11 carbon monoxide samples were 5.00, 10.0 and 7.50±2.11 mg/m<sup>3</sup>, respectively. Higher levels of exposure to carbon monoxide were detected when both ventilation systems were off; the minimum, maximum, and mean levels of 11 carbon monoxide samples were 22.0, 32.0, and 27.0±3.26 ppm, respectively.

**General Ventilation:** The measured ventilation flow rate of the general exhaust system was 18884.5 m<sup>3</sup>/h.

**Local Exhaust Ventilation:** The duct velocity pressure was measured for all welding stations. The duct air velocities were calculated from the measured duct velocity pressures using BS method 1042. The face and the capture velocities were also measured directly using Air Flow anemometer; the minimum, maximum, and mean value of 88 face velocity samples were 1.25, 24.5 and 7.36±3.63 m/s, respectively. The average face velocity was almost equal to the face velocity recommendation of 7.62 m/s by the American Conference of Governmental Industrial Hygienists (ACGIH, 1995) in VS - 90 - 02 for plain opening hoods. Table 2 shows the minimum, maximum and average values of parameters measured for the local exhaust ventilation system.

**DISCUSSION**

**Iron oxide:** The results revealed that with a p<0.05, there was a significant difference between concentrations of the iron oxide during different ventilation operating settings. The results also revealed that when only local exhaust ventilation system set to on and GV off, the concentration of iron oxide exceeded the TLV of 5 mg/m<sup>3</sup> recommended by ACGIH. Since the average capacity of local exhaust ventilation system is only 34.7±10.7 percent of its recommended value, the ability of local exhaust ventilation system to control the welding fumes in the present study is expected.

The results from 6 similar studies are tabulated in Table 3. With local exhaust ventilation on, the measured concentration of iron oxide in the present study is less than that in 5 studies [20] and it is more than another study [20].

The difference between the present study and the Hiterbrink et al study [20] could be mainly due to the sampling methods and type of hoods used. They used

**Table 2.** The local exhaust ventilation parameters

	V <sub>d</sub> , mea m/s	Q, mea m <sup>3</sup> /s	V <sub>f</sub> , mea m/s	Q, req m <sup>3</sup> /s	V <sub>f</sub> , lim m/s	Vent %
Min	5.54	401.0	1.25	1283	7.62	23.1
Max	13.9	1006	12.3	3552	7.62	59.5
Mean	9.02	652.7	7.36	1998	7.62	34.7
Std dev	2.38	172.6	3.63	695.0	0.00	10.7
N	132	132	88	-	-	-

**Table 3.** The comparison of the results in different studies

Study	Year	Iron Oxide mg/m <sup>3</sup>	Res Dust mg/m <sup>3</sup>	Ozone ppm	CO ppm	
1	NIOSH	2006	4.00	-	>TLV	<TLV
2	Ashby	2002	13.00	-	-	-
3	NIOSH	1996	-	-	0.04-5.01	-
4	Korczynski	1993	16.3	-	0.6	5
5	Hiterbrink	1992	0.08	-	0.010	-
6	Evans	1979	>TLV	<TLV	-	<TLV
7	Present study	2009	2.17-10.4	3.53-20.9	0.01-0.07	7.45-27.0

standard methods such as US OSHA-ID 121 method used in the present study suggests an air flow rate of 2 l/min. This may lead to different results. The slot type hoods were used in Hiterbrink's study while the types of 9 hoods used in the present study had a plain opening and only 2 of them were slot type hoods [14]. In this type of slot hoods the air pollutant has a greater chance to be captured before it leaves the capturing space but in plain opening ducts the pollutant has less chance to be captured due to a smaller capturing space. The welder also needs to adjust the plain opening hood for each welding point. This is not an easy action and usually is ignored by the welder leading to a greater release of pollutant to the breathing zone. More studies should be carried out in order to find out which type of hood can be more effective for controlling welding fume.

Welding in a confined space with a ventilation capacity of 1.08 – 1.8 m<sup>3</sup>/min (0.40-0.67 air room changes per minute) could lead to a high concentration levels of iron oxide (e. g. 83.55 mg/m<sup>3</sup>), which was much higher than the maximum concentration levels experienced in the present study with both ventilation systems being off [21]. It seems that the natural ventilation and a larger welding space in the present study (compared to a confined space) diluted the concentrations of welding fumes to an average level of 10.4±2.49 mg/m<sup>3</sup>.

**Ozone:** The threshold limit value of ozone recommended by the ACGIH for heavy works such as those in the present work is 0.05 ppm. The results show that only with both general and local exhaust ventilation systems set to off position, the average concentration of ozone was 0.05 ppm. In other ventilation settings it was less than TLV. The results of the present study agree with another study [20]. The ozone levels measured in other studies, as reviewed in Table 3, are more than TLV. The method used to measure the ozone in the present study is the same as the method earlier [20].

**Respirable dust:** The results revealed that only when the local exhaust ventilation system was on, the average concentration level of the respirable dust was less than TLV of 5 mg/m<sup>3</sup> recommended by ACGIH (2005). The results from the present study for two cases of having local and general ventilations set to on position agree with the results from Evans et al. study [24] (Table 3).

With both, the local and general exhaust ventilation system set to off position, the average respirable dust exposure will go up to 4 times the TLV. In the same ventilation scenario, the respirable dust exposure in some welding stations was even higher, almost 10 times the TLV.

The results show that the general ventilation system can reduce the average respirable dust concentration by 47% while the same ventilation capacity is not able to reduce the other air pollutants to the same extent. This is mainly because smaller particles remain suspended for longer time having a higher chance of being exhausted by the general ventilation.

Size and geometrical distribution of the particles depend on the composition of the welding base metal alloy and it may vary from one welding operation to the other one [22]. The statistical tests showed that with  $p < 0.05$ , there was a significant difference between the average respirable dust concentrations in different ventilation operating settings. The results obtained from the present study for respirable dust is within the range of Saito et al. study [23].

**Carbon monoxide:** The results show that only when both the ventilation systems were set to off position, the exposure level to carbon monoxide exceeded the TLV of 25 ppm as recommended by ACGIH (2005). The results also revealed that when the general was on and the local exhaust ventilation was off, the average concentration of carbon monoxide was below TLV. Statistical analysis showed that with  $p < 0.05$ , there was a significant difference between CO average concentration levels with different ventilation operating set up.

Earlier studies, showed that the concentration of carbon monoxide in welding operations were below TLV [24]. The results of the present study (with both the local and exhaust ventilation system on) well agree with the results obtained earlier [17, 24]. The average concentration of CO obtained from the present study was also much higher than CO concentrations obtained by Korczynski [25].

During welding in confined space with ventilation rate at 1.08-1.8 m<sup>3</sup>/min (0.4-0.67 room air change per min), the CO concentration may go up to 60 ppm, which is much higher than the CO concentration in the present study with the both ventilation systems set to off position [21].

**General ventilation:** The industrial ventilation committee of ACGIH suggested a general ventilation system for welding shops when the local exhaust can not be used. According to the ventilation standard recommended by ACGIH (e.g. VS-90-01 in [14]), if the present welding shop is supposed to be ventilated with only general exhaust system, its ventilation capacity should be 59745.7 m<sup>3</sup>/h or 35165 cfm according to the following calculation:

$$Q = 800 * 1.8 * 2.22 * 11 = 35164.8 \text{ cfm} = 59745.7 \text{ m}^3 / \text{h}$$

In present study, the measured general ventilation capacity ( $18884.5\text{m}^3/\text{h}$ ) is much lower than the standard ventilation capacity ( $59745.7\text{m}^3/\text{h}$ ). The low ventilation capacity is the main reason that it can not dilute the welding fumes down to the acceptable levels. The existing general ventilation is able to dilute the iron fume by 31.5%, the respirable dust by 47%, the ozone by 64.3% and the carbon monoxide by almost 30%.

**Local exhaust ventilation:** In 2 welding stations, slot hoods (e.g. VS-90-01 in [14]) were used. The plain opening hoods (e.g. VS-90-02 in [14]) were applied to the remaining 9 stations. The required exhaust ventilation rate for each hood was calculated according to the ACGIH recommendations. The measured ventilation air flow rate of each hood was divided by the standard ventilation rate to obtain the percentage of the ventilation capacity. The results showed that the minimum ventilation capacity is equal to 25.1%, the maximum ventilation capacity is 59.5% and the average ventilation percentage is  $34.7\pm 10.7\%$ . The implemented local exhaust ventilation rate is far from the standard level. This could be the main reason for its lack of ability in reducing the welding fumes to an acceptable level. The local exhaust ventilation system's relative effectiveness in the present study may be justified by the low activity of the welding shop. The welding air pollutants are expected to go much higher in this shop, if they do work at their maximum capacity

Even local exhaust ventilation, based on ACGIH recommendations may fail to control high toxic air pollutants in some industrial processes, thus, the evaluation of the occupational exposure to welding fumes with an extremely low TLVs are strongly recommended [26].

## CONCLUSION

General exhaust ventilation failed to control the welding fumes to an acceptable level at the welding stations. Local exhaust ventilation and the combination of it with general exhaust ventilation were able to control the welding fumes to an acceptable level at the welding stations.

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