Original Article

Evaluation of the Performance of Two Types of Low Volume High Velocity Ventilation Systems for the CO_2 Welding Process

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Abstract

Aim: Millions of workers worldwide are exposed to the complications of fumes and gases welding process. This study aimed to evaluate the performance of two types of hoods installed on CO_2 welding torch in a low volume high velocity (LVHV) ventilation system to control its pollutants. **Materials and Methods:** Two designs of slots and bell-shaped hoods were designed with an inner diameter of 46 and 37 mm, respectively. To determine the efficiency of the studied hoods, personal sampling at the source of pollutant production (at a distance of 15 cm from the tip of the torch), was performed by the National Institute of Occupational Safety and Health Method No. 7302. The concentration of iron metals, manganese, and total chromium was measured and analyzed when the LVHV ventilation system was on and off. **Results:** The two designed hoods, showed different efficiencies against the studied metals. The highest efficiency obtained was related to manganese metal in the bell-shaped hood with an average of 84.92%, and the lowest efficiency was related to chromium metal in the slot hood with an average of 13.39%. Optimal exhaust flow rate ventilation obtained for low volume – high-velocity ventilation system was 14 m^3/h. **Conclusion:** In general, the bell-shaped hood with 75.34% efficiency had better performance in eliminating welding fumes than the slot-shaped hood, which is due to the physical form of the hood. Therefore, the shape of the hood, distance of the hood from the point of electric arc and exhaust flow rate at the hood opening, are important factors in the design and efficiency of a low volume - high-velocity ventilation system.

Keywords: Destructive and nondestructive tests, gas metal arc welding, low volume-high velocity ventilation, on-gun extraction

INTRODUCTION

Welding is one of the main processes in the industry for bonding between metals. In 1988, the US National Institute for Occupational Safety and Health reported a list of more than 80 different types of welding.[1,2] Some various types of welding include shielded metal arc welding (SMAW) with the coated manual electrode, submerged-arc welding, gas tungsten arc welding, plasma arc welding, and gas metal arc welding (GMAW). GMAW is also known as CO_2 welding since CO_2 is used in this type of welding. The advantages of this type of welding include high efficiency due to using a continuously fed wire, having no slag, and low contamination. The welding wire chosen is based on the base metal and is usually made of copper because copper has good heat transfer.[3,4] Millions of daily workers worldwide are exposed to welding fumes[4,5] in industrialized countries. Up to/2%–2% of the total workforce are engaged in welding jobs, most of which are in the shipbuilding, construction, building,… industries.[6,7] Of these, approximately 400,000 workers worked full-time as welders in the United States in 2014,[8] while this figure is more than 2 million worldwide.[9]

Welding fumes can contain oxides, fluorides, silicates, chromates, and at least 13 metals, including manganese, cadmium, chromium, iron, lead, and nickel.[10,11] Welding fumes have previously been classified by the International Agency for Research on Cancer as potentially carcinogenic to humans (Group 2B). However, recently, welding fumes

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and their metals (Cr [VI], Be, Cd) have also been classified as carcinogenic in humans (Group 1).[12,13] This fume has numerous harmful effects on humans, such as causing cancer, neurotoxicity of metals,[8] changes in the mononuclear blood cells DNA,[6] damage to the lungs and kidneys, and sleep disorders of welders.[14] Besides, welders are also at increased risk of cardiac ischemia and changes in systolic and diastolic pressure.[15,16] Hexavalent chromium in welding fumes is known to be responsible for lung cancer,[17] skin allergies,[18] and spontaneous abortion.[19]

Due to the wide application of welding in production methods and the risks of chemical agents in the welding process, and to provide a healthy and safe environment for employees and protect products and equipment in small and large industrial factories, it is of utmost importance to reduce gases and toxic particles in the workplace to below acceptable levels. Various methods, including general and local ventilation with local ventilation priority, have been recommended to control welding fumes.[20-22]

Two ventilation systems, namely portable and mobile, were investigated for electric welding in the study of Zaidi *et al*. The results showed an efficiency of 63% for the portable system and 88% efficiency for the mobile system in reduction of manganese concentration.[23]

In the study by Meeker *et al*., the local exhaust ventilation (LEV) was tested for shielding gas welding. Finally, the LEV reduced the exposure to manganese and total particle exposure by 53% and 10% respectively.[24]

Investigation of the effect of ventilation on the exposure to flux-cored arc welding fumes was studied in Marjorie Wallace's study, showed that using ventilation reduces the exposure by almost half ventilation is on.[25]

In a study of two types of hoods conducted by David Yapp, both hoods selected from the welding gun design phase were integrated on the gun. For both types of guns, the efficiency range was between 30% and 70%. The efficiency variance was also due to the position of the produced fume relative to the suction nozzle.[26]

Previous studies reveal that a common method in controlling welding fumes in industries is using LEV. However, to achieve proper suction, the hood must be located close to the source of contamination, which requires repeated adjustment of the hood by the operator. It can be difficult in practice and maybe forgotten by the worker, and ultimately, it cannot have the desired performance.[27,28] Using a low volume high velocity ventilation system is the right way to overcome these problems. This system can be placed additionally on the welding torch (add-on) or made as an integral part of the torch (an integral part of the torch), which is called an on-gun extraction system.[24]

Since there are many welding guns are used without hoods, so using LEV installed on existing torches was investigated in the present study. Accordingly, two types of bell and slot-shaped hoods were made suitable for a CO$_2$ welding torch, and their performances were evaluated with two indicators of welding quality and pollution collection efficiency.

MATERIALS AND METHODS

This study is an experimental study carried out in one of the Isfahan machinery manufacturing companies. The type of welding used was GMAW with CO$_2$ shielding gas, and SB500New torch and ER70S-6 welding wire were also used in this study. In this research, based on the shape and dimensions of the welding torch, two types of bell and slot-shaped hoods with diameters of 46 and 37 mm, respectively, were made of copper and installed on the welding torch. As shown in Figure 1a and b, which is a scheme of the designed system, the hood used is installed at a distance of 2 cm from the tip of the welding torch nozzle and was connected to the suction by a flexible silicone hose with an inner diameter of 13 mm. Besides, to apply the pressure drop due to the length of the hose, this length was considered 3 m to affect the pressure drop [Figure 2].

The optimal exhaust airflow in the workplace was determined by first adjusting the fan at a specific flow rate by a flow meter without a valve. The welder was then asked to comment on the health of the welding in that flow rate while performing the welding. Furthermore, the amount of suction by the installed hood was observed visually, and finally, by increasing and decreasing the flow rate and ensuring the proper welding and suction, the optimal exhaust flow rate was obtained, which was 14 CFM. As a result, sampling was performed with this flow rate for both bell and slot-shaped hoods when the ventilation system was on. The exhaust system used was a single-phase blower with a power of 1.1 kW, a flow rate of 150 CFM, and a maximum pressure of 23 kPa.

The type of welding in this study was fillet weld. To take a sample of its fumes according to the method 7302 of the American National Institute of Occupational Safety and Health, MCE filter with a diameter of 37 mm and a pores size of 0.8 µm and 224-44TX air sampling pump (SKC Ltd.) were used. Sampling pumps were calibrated before and after use with a soap bubble set (flow meter) according to the pump manufacturer's instructions. It should be noted that the flow rate and suitable time for sampling were obtained by pre-test and based on Ojima's study, which was 4 l/min and 5 min,[29] respectively. To equalize the environmental conditions of

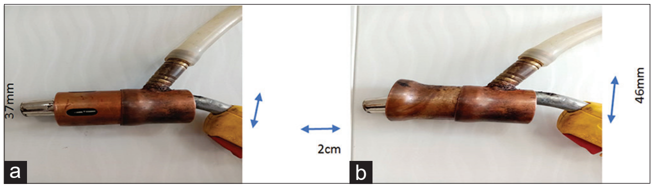

Figure 1: Images of the designed system: (a) Slot-shaped hood; (b) Bell-shaped hood

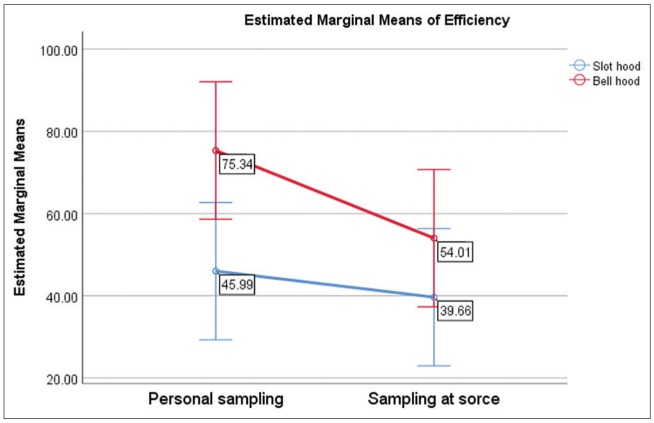

Figure 2: Average efficiency in both personal and at the source sampling when the metal is only iron

welding in terms of temperature, humidity, airflow, and nonperformance of other industrial activities (welding or grinding adjacent to the examination area), a fixed place was considered such that three sides were enclosed. The same welder performed the welding operation with 25 years of experience during the entire test period, and the necessary monitoring was performed to ensure that the welding speed, welding angle, welder's body position, and other factors related to the welder stay the same. Fillet weld was the type of welding used in this study.

Finally, to test the quality of the weld and ensure that the studied ventilation system does not negatively affect the shielding CO_2 gas, according to ISO standards, the non-destructive method and checklist completed by expert welders were used. It should be noted that none of the expert welders knew which welding was done with or without ventilation, and finally, the average scores were used to judge the quality of welding.

Determining of the hoods efficiency

Source sampling and personal sampling were used to determine the efficiency of the designed system. In the first scenario, personal sampling was performed in the worker's breathing area while the ventilation system was off and welding was performed. In the second scenario, personal sampling was performed when the ventilation system was on, the bell hood was installed on the welding torch, and the welding operation was performed. In the third scenario, as in the previous step, personal sampling was performed while the ventilation system was on, but this time the slot hood was installed on the welding torch instead of the bell-shaped hood, and then, welding operation was performed.

Source sampling was done in all three scenarios mentioned in personal sampling, with the difference that the sampling holder was placed on the welding torch and at a distance of 15 cm from the tip of the torch. Thus, sampling was performed at the source of pollutant production when the ventilation system was off, the ventilation system was on with the bell-shaped hood, and the ventilation system was on with the slot hood. It should be noted that welding was repeated five times for each of the above steps,[24] and each time, a personal sampling and a sampling at the source were done so that a total of 30 samples were obtained to determine the efficiency of the ventilation system. An interval of 5–10 min was observed between each sampling step to dilute the contaminant produced in the previous sampling stage.

The obtained samples were analyzed by ICP LIBERTY-RL inductively coupled plasma device made by Varian company in Australia to determine the concentration of ferrous metals, manganese, and chromium fumes during welding when the ventilation system is on and off. The values obtained from the concentration of metals were placed in the following equation and the efficiency of the two types of bell and slot-shaped hoods designed in this study, were determined. One-way ANOVA test was to analyze the data using SPSS software version 16. Equation 1 was used to calculate the efficiency.

$$Efficiency(\%) = \frac{C_{off} - C_{on}}{C_{off}} \times 100 \qquad (1)$$

C_{off} is Concentration of pollutants when the ventilation system is off, and C_{on} is Concentration of pollutants when the ventilation system is on.

RESULTS

In the personal sampling, the performance of each ventilation system was investigated concerning iron, manganese, and chromium metals. The results are shown in Table 1 in terms of mg/m^3 and the percentage of each metal as an average and standard deviation. The concentration of total metals is also presented in the table. Both bell and slot-shaped approaches have a statistically significant difference in the efficiency and reduction of the three metals concentrations, namely iron, manganese, and chromium ($P < 0.001$). pairwise comparison of these metals in both ventilation approaches was performed.

In the sampling at the source, 15 samples were taken and only the iron metal concentration was determined. The results in Table 2 show a significant difference between the three scenarios ($P = 0.001$).

Figure 2 shows the average efficiency of iron metal concentration in the two ventilation approaches studied, in two modes of personal and at the source sampling.

Figure 3 indicates the concentration and efficiency of iron metal in both personal and source sampling modes. As can be seen, the total efficiency in personal sampling is higher than the total efficiency at source sampling.

DISCUSSION

Analysis of the results of the measured metals

Table 1 shows the average concentrations of iron, manganese, and chromium in mg/m^3 when the ventilation system is off. The highest concentrations are related to iron and manganese metals with values of 7.81, and 0.67 mg/m^3, respectively, and chromium metal is in the next rank in terms

Table 1: Mean concentration and standard deviation of metals concentrations measured in two ventilation approaches with bell and slot-shaped hoods in the personal sampling

Ventilation approaches	Parameter	The concentration of total metals (Fe, MN, Cr)	Chromium	Manganese	Iron	*P*
Without any ventilation (*n*=5)	MC±SD (mg/m³)	2.833±3.99	0.0212±0.005	0.67±0.43	7.81±2.97	>0.001
Ventilation with bell-shaped hood (*n*=5)	MC±SD (mg/m³)	0.681±0.946	0.017±0.002	0.1±0.03	1.92±0.48	>0.001
	Average efficiency±SD (%)	75.34	16.83±6.65	84.92±4.64	75.36±6.19	>0.001
Ventilation with slot-shaped hood (*n*=5)	MC±SD (mg/m³)	1.5±2.77	0.018±0.006	0.29±−0.15	4.21±1.8	>0.001
	Average efficiency±SD (%)	45.99	13.39±17.43	56.56±23.06	46.017±23.06	0.691

MC: Mean concentration, SD: Standard deviation

Table 2: Mean concentration and standard deviation of iron metal concentration in two ventilation approaches with bell and slot-shaped hood in sampling at the source

Ventilation approaches	*P*	Mean	Minimum	Maximum	SD
Without ventilation (*n*=5)	>0.001	24.92 (mg/m³)	20.93	26.8	2.51
Ventilation with bell-shaped hood (*n*=5)		11.46 (mg/m³) 54.01 (%)	7.24	17.73	4.1
Ventilation with slot-shaped hood (*n*=5)		15.03 (mg/m³) 39.65 (%)	11.17	22.92	4.98

SD: Standard deviation

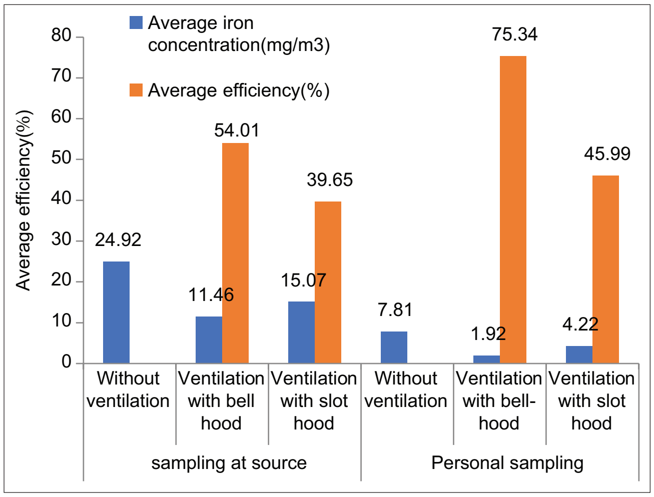

Figure 3: Mean concentration (mg/m³) and efficiency (%) of iron metal concentration in personal and at source sampling

of concentration (0.0122 mg/m³). Welding wire used in this study was of ER70S-6 type, the percentage of manganese used in this welding wire, which is the highest amount and in the range of 1.4-1.85%, and the base metal of iron, confirms the obtained values. These results are in line with the results of Jafari's study (7.13 mg/m³). The highest concentrations of metals obtained in welding fumes in Shokrolahi *et al*.'s study[30] were related to iron, manganese, zinc (without chromium), respectively.

In the study of Mehrifar *et al*., the highest concentrations of metals were related to iron, aluminum, manganese, and chromium, respectively.[31] It should be noted that about 90% of the contaminants in the welding fume come from the welding wire or welding electrode, and about 10% originate from the base metal.[30] Therefore, the difference in the concentration of metal oxides in the welding fume in this study compared to other studies is probably due to differences in the electrode used and the type of welding (E7018 electrode and SMAW welding versus ER70S-6 electrode and GMAW welding).

The effect of the designed ventilation system on the concentration of total metals

The total concentration of metals (including total metals of iron, chromium, and manganese) in the condition without ventilation is 2.83 mg/m³, in the case of using the ventilation approach with a bell-shaped hood, it is 0.68 mg/m³, and in the case of using the ventilation approach with slot-shaped hood, it is 1.5 mg/m³. Pairwise comparisons of both ventilation approaches revealed that both slot hood ($P = 0.004$) and bell-shaped hood ($P < 0.001$) could significantly reduce the total concentration of metals compared to the condition without ventilation so that the ventilation approach with a bell-shaped hood reduces the total concentration metals (iron, manganese, and chromium) by 2.15 mg/m³ and the ventilation approach with slot hood by 1.32 mg/m³ comparing to the condition without ventilation. However, the comparison of two ventilation approaches with slot and bell-shaped hoods showed that although the ventilation performance with bell-shaped hood was better than the slot hood, this difference was not statistically significant at the level of 5% ($P = 0.063$). The ventilation performance with a bell-shaped hood was 0.82 mg/m³ better than the ventilation performance with a slot-shaped hood.

Changes in the concentration of metal fumes in the two ventilation approaches studied

The performance of each ventilation approach on the three studied metals can be seen as the average concentration of metals in milligrams per cubic meter (mg/m^3) and percentage (%) in Table 1. The reduction rate of iron metal in the condition of using ventilation with bell-shaped hood and in the condition of using ventilation with slot hood was 75 and 46%, respectively, which is less than the reduction rate of this metal in the Jafari's study which was 79% at the best condition. The reason for the higher efficiency of iron metal ventilation in Jafari's study compared to the present study can be attributed to the simultaneous use of local and general ventilation in that study, because when the general ventilation was off, and the local ventilation was on, this efficiency was reduced to 72%. The reduction rate of manganese metal in the condition of ventilation with bell-shaped hood and the condition of ventilation with slot hood was equal to 84.92 and 56.5%, respectively, which was more than the study of Meeker *et al*., in which they could reduce the concentration of this metal by 75% in the laboratory using the ventilation system. However, it is less than the amount in the study of Zaid *et al*.; whether they use mobile ventilation system (with 88% manganese reduction) or portable ventilation system (with 63% manganese reduction).

As mentioned before, in the study of Zaid *et al*., portable and mobile local ventilation systems were used, so the welders must adjust the hood repeatedly due to changing the welding point and changing their location, which may be forgotten and leading to the fluctuation of the ventilation system's efficiency. However, in the present study's ventilation system, as the hood used has a fixed position and is always close to the welding fume production point, it has stability and the same efficiency. Besides, it can be ensured that this level of efficiency will always be constant during welding.

As shown in Table 1, the concentration of chromium metal has been decreased from 0.0212 mg/m^3 when the ventilation system is off to 0.017 mg/m^3 in the case of ventilation with the bell-shaped hood and 0.018 mg/m^3 in the case of ventilation with the slot hood which is equivalent to 16.83% and 13.39%, respectively.

The analysis results indicated that the reduction rate of concentration in the three studied metals in the two ventilation approaches with bell-shaped and slot hoods is statistically significant ($P < 0/001$). Pairwise comparing metals in the two mentioned ventilation approaches showed that in the ventilation with bell-shaped hood, the average ventilation rate of manganese metal was 9.56% and 68.08% higher than iron and chromium, respectively, and iron metal was 58.52% more ventilated than chromium metal. In the ventilation approach with a slot-shaped hood, manganese is more ventilated than iron and chromium.

Due to the different performance of the two ventilation approaches on the studied metals, it can be said that if, for example, the pollutant in the workplace is only iron or manganese metal, ventilation with a bell-shaped hood and then with slot-shaped hood (with lower efficiency) can have a good performance in reducing the two metals. If we want to choose one of these two ventilation approaches to reduce these two metals, the ventilation approach with a bell-shaped hood is preferable to the slot-shaped hood. On the other hand, the two ventilation approaches investigated in this study could not significantly reduce chromium metal.

The standard deviation of different metals in the ventilation approach with a bell-shaped hood (with a standard deviation of 5.82%) is relatively less than the ventilation approach with a slot hood (with a standard deviation of 21.18%) [Table 1]. In other words, ventilation with a bell-shaped hood could ventilate metals with close-together efficiency. Therefore, it can be suggested to use the bell-shaped hood to the elimination of welding fumes, most of which are iron, manganese, and chromium.

Analysis of sampling results of iron fume in the production source

As mentioned, only the iron metal was quantified in sampling at the source, and the results are shown in Table 2. The analysis results explain that the average ventilation rate of the three ventilation approaches is significantly different from each other ($P = 0.001$). The amount of iron metal in the condition without ventilation is 24.92 while using ventilation with a bell-shaped hood, which is 11.46, and in the case of using ventilation with a slot hood, this amount is 15.03 mg/m3. Pairwise comparison of these groups showed that both ventilation approaches with slot hood ($P = 0.002$) and bell-shaped hood ($P < 0.001$) significantly reduced the concentrations of iron metal in welding fumes compared to the condition without any ventilation. This reduction rate, which is equal to 54.1% and 39.65%, respectively, indicates that the bell-shaped hood is more efficient than the slot hood in iron fume ventilation.

Comparing the efficiency of the two ventilation systems studied based on changes in iron concentration in the personal and at the source sampling

To compare the efficiency of two designed ventilation systems (bell-shaped and slot-shaped) in personal and at the source sampling, the average concentration of iron metal was compared in these two conditions. As shown in Figure 2, the average efficiency of ventilation with bell-shaped and slot hood for the iron metal in personal sampling is 75.3 and 46%, respectively, and at source sampling, it is 54 and 39.7%, respectively.

In general, the average efficiency of the bell-shaped hood (64.67%) and slot hood (42.82%) had a statistically significant difference ($P = 0.014$), which indicates that the efficiency of the bell-shaped hood is higher than the slot hood in iron metal ventilation. In other words, the bell-shaped hood has ventilated iron metal approximately 22% more than the slot hood. This result is probably due to the structure and bell shape of this hood that surrounds the welding torch in the welding fume production area and prevents contaminants from escaping. As shown in Figure 3, the mean concentration of iron in the condition without ventilation at source sampling (24.923 mg/m^3) was higher than the condition without ventilation in personal sampling (7.81 mg/m^3). but, the average efficiency of the bell-shaped hood was less in source sampling (54%) than in personal sampling (75.34%), revealing an inverse correlation between the concentration of the contaminant (iron metal) and the efficiency of the bell-shaped hood ($P = 0/014$, $r = -0/644$). When the amount of contaminant (iron metal) in the welding fume is higher, the efficiency of the ventilation system while using the bell-shaped hood is reduced, showing the effect of concentration on efficiency.

The most important limitations of the study were the presence of CO_2 gas as a shielding gas in CO_2 welding, how to provide the required high static pressure, and ergonomic problems related to the design of hoods.

CONCLUSION

The performance of the two ventilation approaches studied under controlled conditions was different in reducing the concentration of different metals, and the metals were not ventilated to the same extent. Two bell-shaped and slot-shaped hoods ventilated iron metals, manganese, and chromium with different efficiencies. In conclusion, the bell-shaped hood could ventilate the studied metals with higher efficiency due to its bell shape, which increases its capability to absorb welding fumes in the hood capture area.

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Ethics code

RESEARCH.REC.1398.763.

Conflicts of interest

There are no conflicts of interest

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