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ORIGINAL ARTICLE

Evaluation of Ventilation Performance Parameters for an On-Gun Welding Prototype

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ABSTRACT
Reported exposures to hazardous fumes and gases from the welding process indicate the importance of using effective ventilation systems to control these emissions. This study was designated to control the welding contaminants and to utilize the performance of a prototype on-gun system in bench scale. The study evaluated ventilation parameters including exhaust flow rate, capture velocity, and lastly, duct and face velocities for the system of interest. Hood operation was tested at 34.06 standard cubic feet per minute (SCFM). ISO 10882-1 (part 1) method, the gravimetric method, was used to determine the total particle concentration and hood efficiency. The study found that, in general, when the hood face was located at 2 cm from the gas nozzle, capture velocity in arc point reached 140 fpm. By increasing the distance to 4-6 cm, the capture velocity decreased to 100 and 60 fpm, respectively. We concluded that the distance of the hood face from nozzle had a direct effect on capture efficiency. The evaluated hood could reduce exposure risk of welding fumes with a capture efficiency of 77.73% in the hood distance of 2 cm from the nozzle.

KEYWORDS: *Exhaust Hood, Fume Exhaust Gun, Industrial Ventilation, On Gun Welding, Welding Fume*

INTRODUCTION
Welding is a common industrial process, so that up to 2% of the working population in the industrialized countries is a type of welding [1]. During the welding process, toxic fumes and gases are often produced and released [2]. Welding fumes are a complex mixture of different metals [3], which pose serious health risks to welders [4]. Therefore, evaluation and control of toxic particulates and gases in a workplace to achieve the acceptable limit are important to provide a safe and healthy work environment [5-6]. Fume control by ventilation and local extraction is often used to good effect in an industry, but can be misused [7]. Several procedures including general and local exhaust ventilation are proposed to decrease the above-mentioned hazards [8]. Due to the welder's general proximity to the arc and emission source, local exhaust ventilation (LEV) and ventilation strategies for confined spaces can be assigned to improve welders and work environment [9-10].In this context, one commonly used system is movable exhaust hoods. However, for a hood to provide efficient capture, it must locate close to the emission source. With a local ventilation hood (LEV hood), it may be difficult for a welder to reposition the hood as necessary for it to be close to the emission source [11-13]. Another method in order to reduce the level of contamination is the use of a low volume, high velocity system (LVHV),

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which when installed on a welding torch, can be designed as an add-on arrangement or an integral part of torch. This system is known as on-gun exhaust. The main advantage of this system is that it remains close to the contamination source while capturing less air volume when compared to movable hoods. The one of the challenges of this method is that it increases the probability of removing shielding gas and thus decreases the quality of the weld in high velocity [14]. Some modern companies are producing and marketing various models of LVHV systems. There are, however, many problems in the import, purchase, maintenance and repair costs of these systems especially for small welding workshops in developing countries [15]. Such countries may need access to inexpensive procedures to maintain the health and safety of employees as an imperative subject. In this study, we evaluated the performance of a prototype of the on-gun system in bench-scale investigated parameters, such as exhaust flow rate, capture velocity, duct and face velocities, and finally looked at the effect of hood face distance from the contaminant source in three different heights. The study focused on the high of the hood face from torch nozzle, the height at which despite capture velocity was in the recommended range for the capture of welding fume while not decreasing the quality of the weld. This height was selected as the optimal height [16].

MATERIAL AND METHODS

Design of hood: The fume exhaust gun system was designed as an elbow shape with a rotation angle of 165 degrees and applied as an adaptor (Fig. 1). It was installed around the torch and fixed onto the upper part of the torch neck (inner diameter of the duct inlet and outlet was 32 and 25 mm, respectively). Pipes of aluminum (with an inner diameter of 32 mm and thickness of 1 mm) were connected to the end of adaptor inlet to act as an exhaust hood with a circular opening. Adjusting the distance of the hood opening from the torch nozzle for each step of the test was carried out by changing the length of the pipes [16]. The adaptor outlet was connected to an exhaust fan by a flexible duct with an inner diameter of 32 mm and length of 3 mm. Tests were carried out on a table with dimensions 80×130 cm. Evaluated parameters were exhaust flow rate, duct and face velocities, and capture velocity for the system of interest. The symbolic and real-time images of bench-scale model are shown in Fig. 1.

Quantification of the system

Measurement of velocity pressure in a duct: In order to measure duct velocity pressure within the evaluated system, a traverse point method for circular ducts of 6 inches and smaller were used per ACGIH (American Conference of Governmental Industrial Hygienists) standard method [17]. The instrument used in this measurement was a pitot tube and an inclined monometer. For the determination of airflow rate in system, six traverse points were used. Averaged duct velocity is a function of velocity pressure (in.w.G) according to Eq. 1 [18]. Velocity pressure is calculated using the traverse points method. The flow rate was calculated based on ACGIH standard method, which is shown as Eq. 2 [19].

Equation 1:

$$V = 4000 \times \sqrt{VP}$$

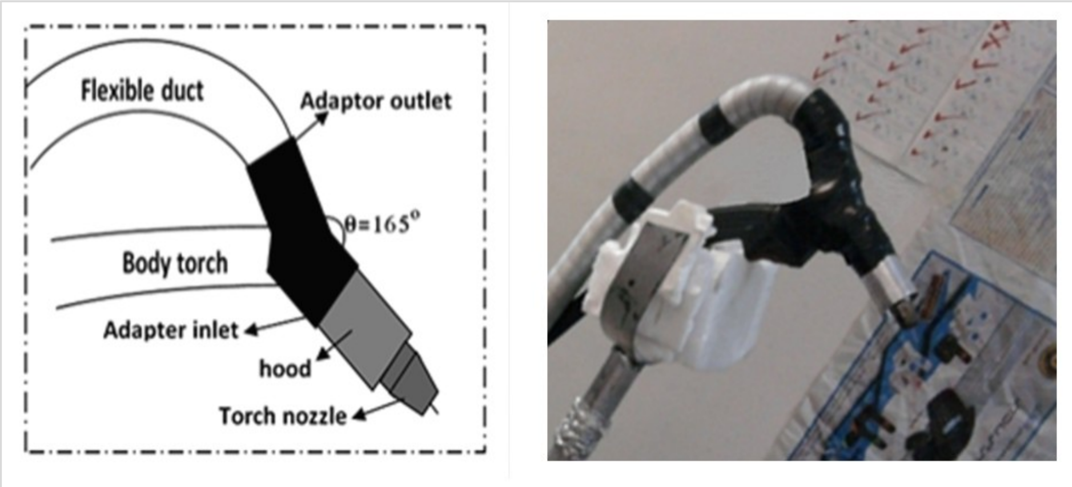
Equation 2:

$$Q = A \times V$$

Upstream velocity measurement: Measurements of capture velocity around the hood opening were performed by a thermos-anemometer (KIMO INSTRUCTEUR-VT50) in relation to the assumptive arc point without welding operations. The hood was placed perpendicular to the work piece and above the assumptive arc point. Measurements were performed at 7 points at horizontal distances (0, 31, 50, 75, 100, 150 and 200% of hood face diameter (D_h)) and each point in four vertical distances from the work piece (0, 31, 63 and 94% of hood face diameter). This was expressed as a percentage of hood face diameter (X/D). Note that D is considered the sum of useful and non-useful diameter of the hood opening, and due to proximity of hood with work surface, and thus the thermal sensor was unable to measure exactly on the surface. The farthest vertically point from the hood was selected in 94% of face diameter. Then, the measured velocities used to draw out the velocity contours by the assistance of Microsoft excel and Tec plot software.

Sampling and the efficiency of the system: In order to determine the total particle concentration, ISO 10882-1 (part 1) method was applied [20]. Sampling was performed by a closed-face 37-mm glass fiber filter. The sampling flow rate was set on 1.2 l/min for 15 minutes. Sampling was also performed at 30 cm above arc point (equal to breathing zone of welders) [18].Furthermore, sampling was carried out during the welding operation and in two steps: active and inactive hood performance (off and on the hood).

In each set, four samples were collected and the testing was performed in triplicate. The adjusted welding conditions are shown in Table 1. Welding type was Gas Metal Arc Welding with CO_2 shielding gas. The torch nozzle tip inner diameter and nozzle outer diameter were 12 mm and 18 mm, respectively.



A **B**

Fig. 1. A symbolic image and B-bench scale image of the designed experimental micro hood

RESULTS

Duct velocity pressure, exhaust flow rate and face velocity: Ventilation parameters were calculated by using obtained results of measured velocity pressures in the duct. In this case, the hood face area was first calculated. Since the hood was encircled by the nozzle of torch, the shape of hood cross-section was annular.

The hood opening area was obtained from Eq. 3. The hood and torch nozzle dimensions are shown in Table 2.

Equation 3:

$$A_f = \pi (r_{out}^2 - r_{int}^2)$$

Where,
A_f: annular face area
r_{out}: outer radius of nozzle
r_{int}: inner radius of hood

The equal mean velocity pressure (VP_e) using Eq. 4 was obtained, 2.9 in.w.G, and then used to calculate the minimum duct velocity (V_{duct}), exhaust flow rate (Q_{ex}) and face velocity (V_{face}) respectively using Eqs. 5-7.

The ambient temperature range was measured between 24 and 26 ° C (average 25 °C) and the standard temperature is 27 °C. Therefore, the density factor (degree of freedom, df) was considered to be approximately 1.

Equation 4:

$$VP_e = VP_m/df$$

Equations 5:

$$V_{duct} = 4005 \times \sqrt{VP_e}$$

Equation 6:

$$Q_{ex} = 4005 \times A_{duct}\sqrt{VP_e}$$

Equation 7:

$$V_{face} = Q_{ex}/A_f$$

df: density factor
VP_e: equal or corrected velocity pressure (in.w.G)
A_{duct}: duct area (ft^2)
V_{duct}: minimum duct velocity (fpm, feet per minute)
Q_{ex}: Exhaust flow rate (cfm)
A_f: hood face area (ft^2)
V_{face}: hood face velocity (fpm)

Capture velocity: Table 4 shows the results of capture velocity measurements in closed Arc point and without a performed welding process in order to evaluate the performance of the system of interest. All measurements were obtained at a constant flow rate of 34.06 SCFM (standard cubic feet per minute). As determined in Table 4, when the hood face is located at a distance of 2 cm from the gas nozzle, the capture velocity in the arc point is 140 fpm and with an increased distance to 4 and 6 cm capture velocity, the arc point decreases to 100 and 60 fpm, respectively [21]. The coefficient of variation is recommended as a repeatability and reproducibility indicator for the measurement and accuracy controlling in laboratory equipment [22-23]. According to the importance of velocity magnitude in the arc point, velocity was measured near this point [24], assessed the relationship between shielding gas flow rate and velocity in the arc point, and introduced the boundary in which welding defects occur, as summarized in Fig. 2.

Velocity contours: After measurements of capture velocities in specified points were collected, velocity contours were analyzed using Tecplot 360 software. Fig. 3 shows the velocity contours in a flow rate of 34.06 CFM at a hood position of 2 cm from the nozzle. This profile confirms that the velocity at upstream of the hood is decreased.

Table 1. Welding conditions

Parameter	Values
Welding position	Flat
Welding current (A)	200
Arc voltage (V)	57
CO_2 flow rate(L/min)	15
Electrode diameter (mm)	0.7
Wire protrusion length (mm)	10-15

Table 2. Dimensions of designed hood

Dimension	Values	
Duct inner diameter	0.083 ft	25.3 mm
Duct area (A_d)	0.0054 ft^2	0.0005 m^2
Inner hood face diameter (total diameter)	0.105 ft	32 mm
Outer torch nozzle diameter	0.054 ft	18 mm
Useful- hood face diameter	0.046 ft	14 mm
Face area (A_f)	0.0059 ft^2	0.00055 m^2

Table 3. Average of calculated aerodynamic parameters

Parameters	Number of sample	$\bar{X}$	±SD	CV%
Duct Velocity (fpm)	3	6296.64	92.50±	1.469
Exhaust Flow rate (scfm)	3	34.06	0.50±	1.468
Face Velocity (fpm)	3	5763.93	84.67±	1.469

Table 4. Capture velocity in close of arc zone (Q_{ex} = 34.06 sCFM) and without welding process, for three hood face distance from gas nozzle tip.

Hood face distance from gas nozzle (cm)	Number of sample	$V_c$in arc point (fpm)	±SD	CV%
2	4	140	8.718	6.23
4	4	100	12.6	12.6
6	4	60	9.8	16.33

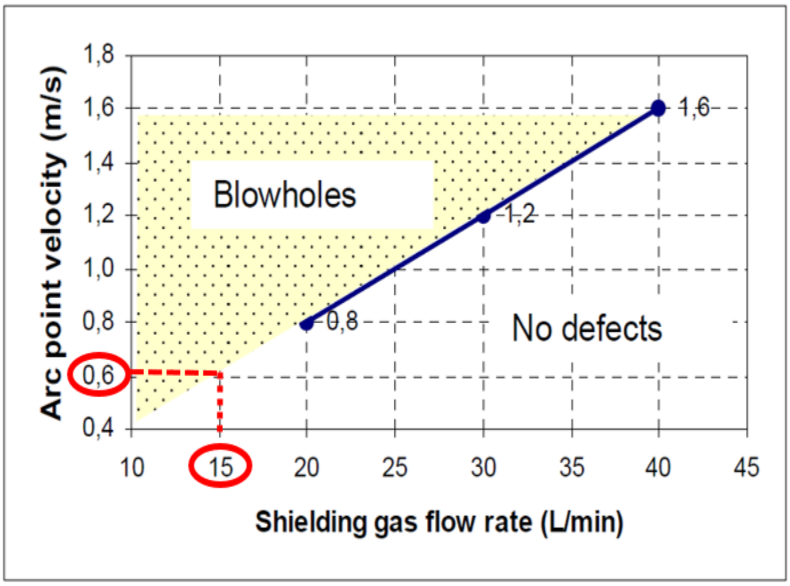


Fig. 2. Arc point velocity vs. shield gas flow rates the boundary at which welding defects occur [24].

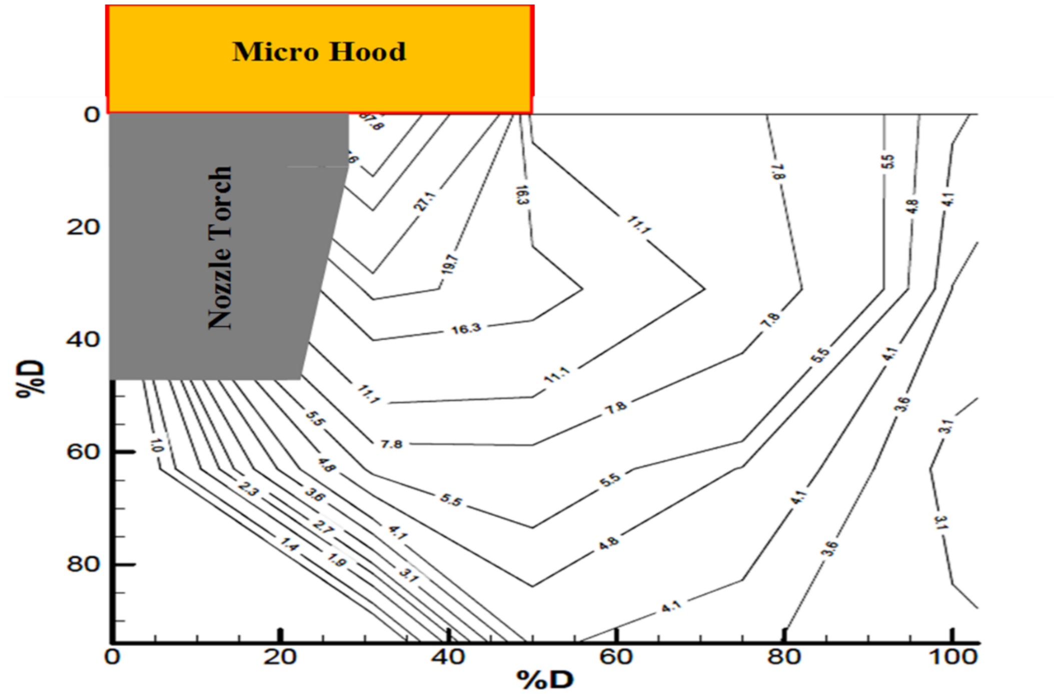


Fig. 3. Velocity contours in flow rate of 34.06 sCFM at hood position of 2 cm from nozzle

Table 5. LEV system effects (OFF-ON) on the total particles effective capture

Exhaust hood	Hood distance from nozzle (cm)	Test number	Distance from work piece (cm)	Con. total particles (X±SD), (mg/m^3)	CV (%)	Capture Efficiency (%)
OFF	--------	3	30	75 ±7	9.33	---------
ON	2	3	30	16.7±4	23.95	77.73
ON	4	3	30	41.7±12	28.8	44.42
ON	6	3	30	58.3±17.45	29.93	21.47

Shielding gas flow rate = 15 lit/min , sampling zone in breathing zone assumed 30 cm from above the Arc, welding position was flat and hood was vertically above the welding zone.

Elimination efficiency on Total particles: Table 5 shows the results of total particles (T.P) sampling and capture efficiency of the interested system before and after the exhaust operation. All the sampling was performed with a constant exhaust flow rate of 33.44 CFM, and sampling points were placed at a distance of 30 cm above the arc point, that was equivalent to the welder's breathing zone.

Capture velocity: From the results listed in table 4, it can be concluded that an increased distance of hood from nozzle reduces capture efficiency, yet it may improve the welding operations on the fillets and corners. Moreover, it may provide the availability for V shape sections or narrow process. On the other hand, in spite of this method, it may reduce the interruption of the hood but it may be necessary to use more exhaust flow rates than the previous position. This problem can be solved by the use of higher exhaust flow rates. According to ACGIH recommendations, capture velocities above 100 to 200 fpm may lead to disorder in shielding gas and consequently decreased welded metal quality. However, some of studies reported that a smaller capture velocity could contribute to optimal capture efficiency [17].

Since the shielding gas flow rate of 15 l/min was used in this study, so based on the boundary specified in Fig. 2, in the velocity of 120 fpm (0.6 m/s) the blowholes or defects occur in welding. By comparing the measured velocities in the arc point, it can be found that velocity of 140 fpm for hood at position of 2 cm from arc point is higher than the mentioned boundary, thus, it is inappropriate and can lead to defects in welding. These velocities were measured without welding operation and considering that shielding gas decreases the exhaust flow rate, the velocities can be considered higher than the mentioned rates for without welding operation conditions. At the hood positions of 4 and 6 cm from arc point, velocity was obtained as 100 and 60 fpm, respectively which is located lower than the mentioned boundary and is not to produce defects in welding.

Since these velocities, especially in the position of 6 cm, are lower than the recommended limits for effective capture of welding fumes, it may not have enough efficiency.

Velocity contours: As dedicated in Fig. 3, a drop in velocity along and around the centerline of hood is shown. The drop is related to the torch nozzle that acts as an obstacle. It passes through the hood and creates a gap in the contour shapes of the centreline area. One limitation of this study was a small diameter of the hood opening and its proximity to the work surfaces that led to confined measured space and consequently, reduced the number of measurement points. Based on ACGIH in distance equal to the hood face diameter, velocity will be reduced approximately to 10% of the face velocity [17].

As shown in Fig. 3, in a distance equal to the hood face diameter, the velocity drop is lower than 10% of the face velocity. This velocity drop is due to the annular shape of hood or crossing the gas nozzle (as an obstacle) through of the hood and along in front space of hood opening. This has led to the separation of the curves in this area. As a result, the plotted velocity contours are not exactly curvilinear, but these are located separately on both sides of the hood opening.

Elimination efficiency on Total particles: As is clear from Table 5, without the exhaust system, the mean T.P concentration is 75±7 and when the operation of the exhaust system was done for three positions of hood distances at 2, 4 and 6 cm, the mean T.P concentration were 16.7±4, 41.7±12 and 58.9±17.45 mg/m^3, respectively. The mean capture efficiency was obtained 77.73, 44.42 and 21.47% in the breathing zone of the welder, respectively. Obviously, because the exhaust flow rate was similar at all three positions, with increasing of hood distance from contaminant source, capture efficiency is reduced according to our findings. The maximum achieved efficiency was 77.73% when the hood distance from nozzle was 2 cm. Although, this position has higher efficiency, for reasons such as interference with welder vision, hood warming due to its proximity to the arc point, and unease of access to the groove sections for welding, this is not the best position for hood. While two of the other positions do not have the problems mentioned above, to achieve higher efficiency, it may be necessary to use higher flow rates and more powerful fans considerably increasing operating costs. Different studies have been done performed on the various types of on-gun systems. each of them depending on the test conditions (such as welding position, exhaust flow rate, shielding gas flow rate, welding type, dimensions and shape of the hood and power of fan) have possessed different efficiencies. Ojima, has reported in his study, capture efficiencies of 86.3 and 74.4% for flat and horizontal fillet welding positions, respectively in the breathing zone [25]. Zaidi et al. reported the containment efficiency of 63% for manganese fumes in breathing zone using a portable LEV [15]. Based upon maximum efficiency obtained in the present study is approximately near the efficiencies reported by the other similar studies. While the evaluated system in this study could not reduce fume exposure in breathing zone to below the acceptable occupational exposure limit ACGIH (5 mg/m^3), it did reduce fume concentration in breathing zone approximately 22% (from 75 mg/m^3 to 16.7 mg/m^3) at near position to arc point and also 55% (from 75 mg/m^3 to 41.7 mg/m^3) and 77.73% (from 75 mg/m^3 to 58.3 mg/m^3) at middle and far position from arc point, respectively.

CONCLUSION

The on-gun system used in this study was a prototype built with limited facilities and very low-cost materials. The obtained capture velocities near the arc point in distances of 2 and 4 cm from the hood opening of the torch nozzle, were 140 and 100 fpm, respectively. This is within the recommended range of ACGIH, determined to control welding fumes. Since the capture velocity near the arc point is smaller than the recommended velocity maximum by ACGIH (200 fpm), the possibility of removal of shielding gas was reduced. The evaluated hood in this study provides the ability to remove contaminants from the welding process and also reduces exposure risk of welding fumes with a capture efficiency of 77.73% in the hood distance of 2 cm from the nozzle. This system was designed in a bench scale. However, in industrial-scale design, it is requiring more facilities and financial supports. There would be fundamental modifications in design, the material used, as well as, more efforts to rectify study limitations. It is recommended to further experiment and field research to achieve higher efficiency.

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