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# The Development of Fume Extractor for a Welding Booth

Babalola Philip Olufemi<sup>1</sup>, Oriyomi Moses Oluwayimika<sup>1</sup>

<sup>1</sup>Department of Mechanical Engineering, Covenant University, Km. 10, Idiroko Road, P.M.B 1023, Canaan land, Ota, Nigeria.

E-mail address: phillip.babalola@covenantuniversity.edu.ng; +2348034843286

**Abstract.** In our society today, there are several welding activities in the manufacturing establishments, production factories and metal fabrications on our streets daily. During this welding processes, welders are exposed to welding fume that are dangerous to their health. This can be prevented. The aim of the work is to develop a system that remove welding fume from the breathing zone of welder and leave the surrounding safe for other personnel. The system was designed using American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard among others. The booth volume, hood size, hood location, duct size and fan size were designed, selected and fabricated. The designed static pressure of the system is 164.412 Pa and the design volumetric flow is 6.126 m<sup>3</sup>/min. The ventilation system was tested by using thermo anemometer, thermometer and a measuring tape. Volumetric flow test on the flexible duct shows that at 150 mm extension, maximum air flow of 4.217 m<sup>3</sup>/min is achievable with this system while at full extension, 5.376 m<sup>3</sup>/min is achievable. Results, shows that welding at 0 mm to 100 mm from the hood extract smoke from the source whilst between 200 mm to 400 mm distance from the hood were significant lagged in extracting the smoke but at 500 mm, smoke reaches the welder's breathing zone.

Keywords: welding, fume, airflow, anemometer, extraction

## 1. Introduction

Most everyday construction processes in our society today engaged at least one welding operation <sup>[1]</sup>. Welding is an operation in which two or more parts are united by means of heat or pressure or both in such a way that there is continuity in the material (metal) between these parts (Figure 1). A filler metal, whose melting temperature is of the same order as that of the parent material, may or may not be used. There are various types of welding: shielded metal arc welding (SMAW); gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG); gas metal arc welding (GMAW), commonly termed metal inert gas (MIG); flux-cored arc welding (FCAW); submerged arc welding (SAW); electro-slag welding (ESW); electric resistance welding (ERW), which included spot welding and seam welding; plasma arc welding; aluminothermic welding; electron beam welding (EBW); diffusion welding (DFW); friction welding (FRW); ultrasonic welding (USW); and oxyfuel gas welding (OFW). All these produce welding fume in form of gas or vapor that smell strongly and dangerous to inhale.

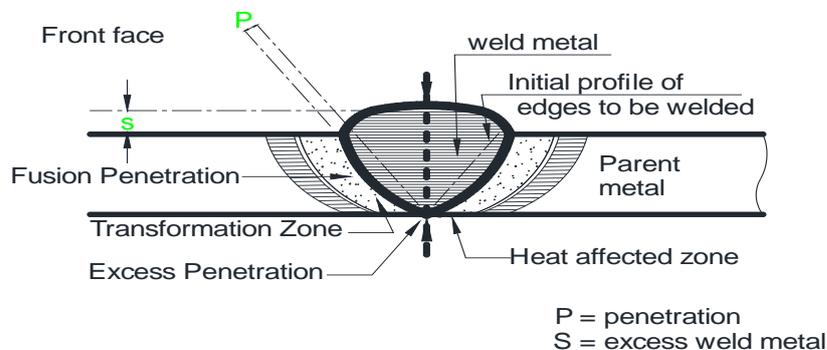


Fig. 1 Butt joint weld <sup>[2]</sup>



With increase in technological advancements and industrialization during the last few years, there are greater risk of human contact with harmful gases and fumes. Sustainable development must be environment and human friendly with very low emission indexes. Unfortunately, welding operations release harmful gases into the environment due to high energy requirement and hazardous fumes <sup>[3]</sup>.

Welding gases are produced from condensed metal particles and oxides that are volatile due to enormous temperature of the arc <sup>[4]</sup>. This harmful to the health of individuals around it. For healthier and safe working conditions, this gaseous emission must be reduced to the barest minimum. The working welder is the most vulnerable to this hazard and work on associated risk around the breathing zone is needed <sup>[4]</sup>. Welding fume impose various health challenges such as cancer, metal fume fever, pneumonia, occupational asthma, irritation of throat and lungs, and temporary reduced lung function.

Amid welding processes, shielded metal arc welding (SMAW) and manual metal arc welding (MMAW) are the most versatile. This is mitigated by enclosing the welding operations, use extractor fan to remove emissions with integral respiratory protective equipment (RPE) by the operator. Furthermore, process parameters such as voltage, current and shielding gas composition may be modified. This is however a compromise on welding production and quality.

Meeker et al. <sup>[5]</sup> did extensive work on both experimental and field evaluations of a commercially available handy LEV unit. He used an equipment with a small bell-shaped hood and that operated at approximately 103–110 cfm (0.049–0.050 m<sup>3</sup>/s). The efficiency of the filter was 99.97. Another investigator, Smargiassi et al. <sup>[6]</sup> examined the exposure rate of welders working on heavy excavation equipment. The system used GMAW with AIRMIG model 520, and Henlex gun having extractor fan of 70–80 cfm (0.03–0.04 m<sup>3</sup>/s) flow rate.

## **2. Material and Methods**

In this work, fume extractor is designed for a welding booth to capture the unwanted gases at the point of production, hence clearing the breathing zone of the worker. The main objective is to keep the welder's breathing area as clean as possible. Welding smoke consists of gases and fine particles, which disperse at relatively low speed from welding point and are best arrested at the source.

### **2.1 Functional requirement**

A welding booth has some functions its meet for welder to properly work and perform optimally as recommended by American Welding Society (AWS). A working space that allows easy manoeuvring within the work or training space. This was met with standard booth sizes of 1,524 mm (5 ft.) x 1,524 mm (5 ft.) x 2,438 mm (8 ft.) according to AWS guidelines for booth width and depth. Inside the booth, is a platform for workpiece that allows operator to be as comfortable as possible while welding. A platform of 1,200 mm x 600 mm x 950 mm (H) is adopted for this purpose. Mechanical ventilation is employed to ventilate the booth. This is discussed later.

The welding booth is made up of main enclosure, work table, hood, duct, air cleaner, air mover, and exhaust stack. Sheet metal for hood, duct and exhaust stack is G-60 coated galvanised steel of lock forming grade as specified by Sheet Metal and Air Conditioning Contractors National Association, Inc. (SMACNA) <sup>[7]</sup>. This conformed to American Society of Mechanical Engineers (ASTM) A653 and A924 standards. Minimum yield strength for steel sheet and reinforcement is 207 kPa.

### **2.2 Design approach**

For optimum design as recommended by ASHRAE <sup>[8]</sup> these principles are followed:

- Hood location shall be as close as possible to the source of contamination.

- The hood opening shall be positioned so that it causes the contaminant to deviate the least from its natural path.
- The hood shall be located so that the contaminant is drawn away from the operator's breathing zone.
- Hood size shall be larger than the cross section of flow entering the hood.

### 2.3 Required volume

Ventilation rate procedure (VRP) is adopted for calculating the required volume. According to Chartered Institution of Building Services Engineers (CIBSE) guide, between 15 to 30 air changes per hour is recommended for welding shops. 30 air changes per hour is selected for the welding booth.

Where:

$$\begin{aligned} \text{Booth volume flow rate (Q}_b\text{)} &= \text{Booth volume (V}_b\text{)} \times \text{Air changes per hour} \\ \text{Q}_b &= (\text{V}_b) \times \text{Air changes per hour} \end{aligned} \quad (1)$$

### 2.4 Duct sizing

Constant velocity method is used for sizing duct that convey particles as recommended by ASHRAE<sup>[9]</sup>. From American Conference of Governmental Industrial Hygienists (ACGIH)<sup>[10]</sup>, it recommended 10 to 13 m/s minimum transport velocity for welding fume. For this work, 13 m/s was selected.

For duct; using continuity equation,

$$Q = A \times V \quad (2)$$

$$A = Q/V \quad (3)$$

Q = Fume flow rate

A = Area of the duct

V = Fume velocity

For round duct

$$A = \pi \frac{d^2}{4} \quad (4)$$

$$d = \sqrt{\frac{4A}{\pi}} \quad (5)$$

### 2.5 Hood

Side draft hoods was used to draw contaminant away from the operator's breathing zone. ASHRAE Handbook - HVAC Applications, recommended that face area of hood must have at least twice the area of the duct<sup>[9]</sup>. Hence, the minimum area of hood ( $A_h$ ) = 2 x Area of Duct ( $A_d$ )

$$A_h = 2 \times \pi \times \frac{d^2}{4} \quad (6)$$

### 2.6 Fan sizing

Welding booth developed is shown in Figure 2 and the exhaust system is as shown in Figure 3. The airflow rate was calculated using continuity equation.

$$Q = A \times V \quad (2)$$

Q = Fume flow rate

A = Area of the duct

V = Fume velocity

Given:

V = 13 m/s

For round duct of  $d=0.1\text{m}$ ,

$$A = \pi r^2 = \pi \frac{d^2}{4} \tag{4}$$

$$A = 0.007854 \text{ m}^2$$

Therefore,

$$Q = 0.007854 \times 13 = 0.102102 \text{ m}^3/\text{s} = \mathbf{6.126 \text{ m}^3/\text{min}}$$

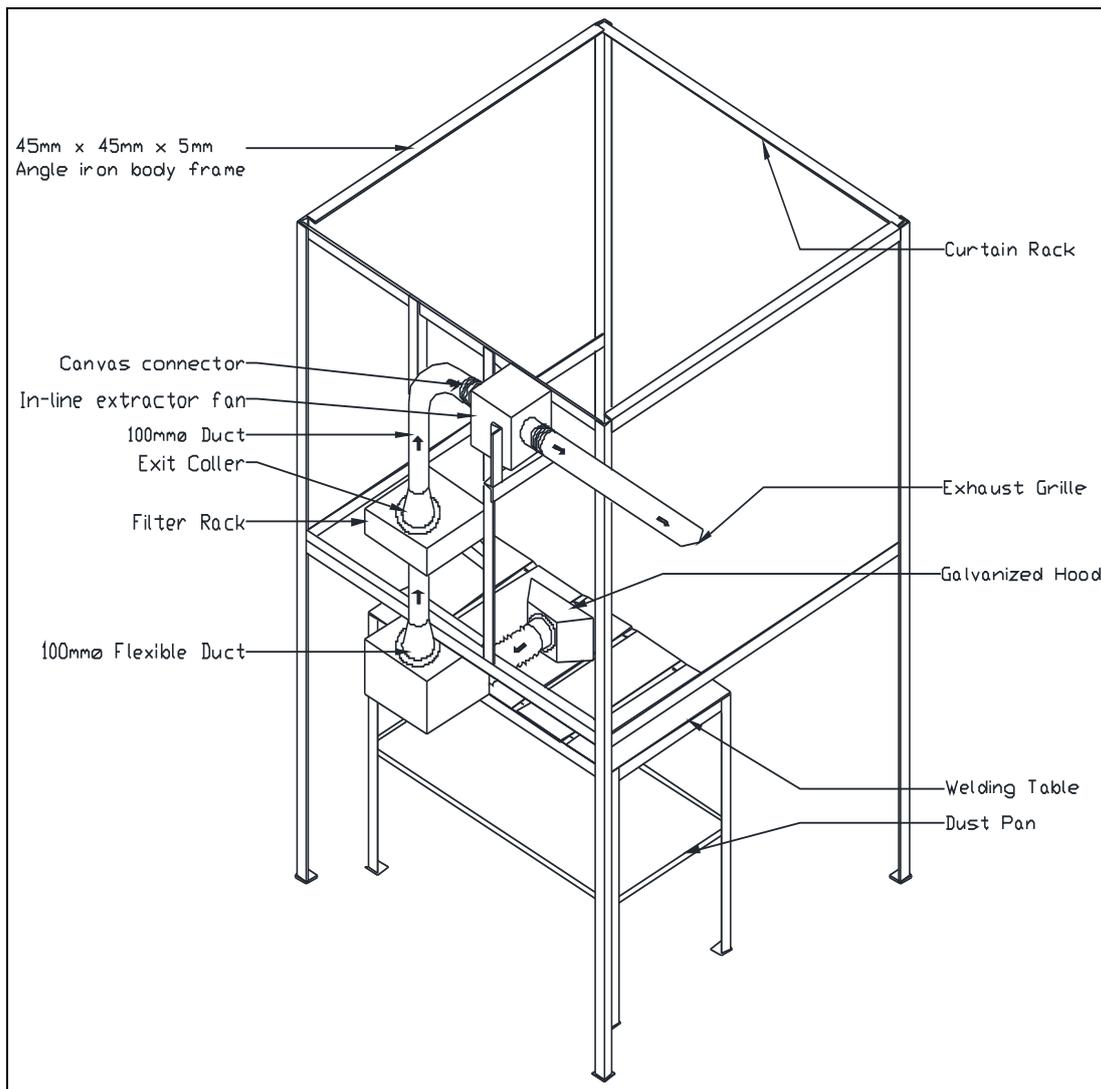
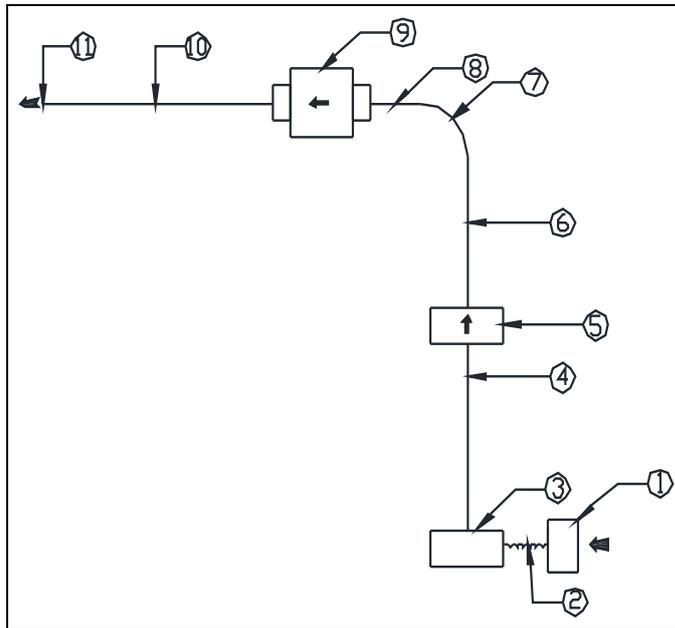


Fig. 2 Exposed welding booth isometric



Parts List		
S/No	Description	Material
1	Hood	Stainless Steel
2	Flexible Duct	PVC/Aluminium
3	Plenum Box	Galvanized Iron
4	Duct	Galvanized Iron
5	Filter	G.I. / Aluminium
6	Duct	Galvanized Iron
7	Elbow	Galvanized Iron
8	Duct	Galvanized Iron
9	Extractor Fan	Galvanized Iron
10	Duct	PVC/ Aluminium
11	Exhaust Grille	Stainless Steel

Fig. 3 Welding booth extractor system schematic

Duct friction factor and pressure loss were calculated by using Darcy and Colebrook equations.

Darcy equations:

$$\Delta p_f = \frac{1000fL}{D_h} \times \frac{\rho V^2}{2} \tag{7}$$

where,

$\Delta p_f$  = friction losses in terms of total pressure, Pa

$f$  = friction factor, dimensionless

$L$  = duct length, m

$D_h$  = hydraulic diameter, mm

$V$  = velocity, m/s

$\rho$  = density, kg/m<sup>3</sup>

Colebrook equations:

$$\frac{1}{\sqrt{f}} = -2 \log \left( \frac{\epsilon}{3.7D_h} + \frac{2.51}{Re\sqrt{f}} \right) \tag{8}$$

where,

$\epsilon$  = material absolute roughness factor, mm

Re = Reynolds number.

$$P_t = \sum_{i \in F_{up}} \Delta P_{t_i} + \sum_{i \in F_{dn}} \Delta P_{t_i} \quad \text{for } i = 1, 2, \dots, n_{up} + n_{dn} \tag{9}$$

Where,

$F_{up}$  and  $F_{dn}$  = sets of duct sections upstream and downstream of fan

$P_t$  = fan total pressure, Pa

$\epsilon$  = symbol that ties duct sections into system paths from exhaust/return air terminals to supply terminals

Also, total pressure is the sum of static pressure and velocity pressure:

$$P_t = P_s + \frac{\rho V^2}{2} \tag{10}$$

Or

$$P_t = P_s + P_v \quad (11)$$

where,

$P_t$  = total pressure, Pa

$P_s$  = static pressure, Pa

$P_v$  = Velocity pressure, Pa

$\rho$  = density of air or gas in duct, kg/m<sup>3</sup>

$V$  = fluid mean velocity, m/s

For air at standard conditions ( $\rho = 1.204$  kg/m<sup>3</sup>),

Therefore,

$$P_v = 0.602V^2 \quad (12)$$

Fan static pressure,

$$P_s = P_t - P_v \quad (13)$$

$$P_s = \mathbf{164.412Pa}$$

### 3. Airflow and Air Velocity Test

The effect of compressing and extending the flexible duct on the air flowrate and air velocity were investigated. Also, the efficacy of fume extraction from various distances away from the hood entrance were examined. The air flowrate and air velocity were measured using Extech (AN 100 Model) Thermo Anemometer together along with digital multi-meter (DT9205A), thermometer and measuring tape.

#### 3.1 Volumetric flow through flexible duct

The volumetric flow test was conducted by mounting the ball bearing vane wheel of the anemometer on the hood, and then move the hood from 150 mm to 200 mm, 250 mm, 300 mm, 400 mm and 500 mm when the in-line extraction fan is in operation. The minimum and maximum values of airflow and air velocity were measured at each of the locations (Figure 4).



Fig. 4 Test bed showing flexible duct, hood, vane wheel, anemometer and measuring tape

#### 3.2 Welding point proximity to hood test

The efficacy of the extraction is put to test by measuring air flow rate and air velocity from distance to hood entrance during welding operations. Two scenarios were evaluated. One, with the flexible duct un-stretched and the other with the flexible duct fully stretched out. In each case, the thermo

anemometer ball bearing vane is placed at varied distances between 20 mm to 120 mm as shown in Figure 5.



Fig. 5 Exhaust hood, anemometer vane wheel, and measuring tape during welding operation

## 4. Results and Discussion

### 4.1 Volumetric flow through flexible duct

This test shows the significant impact of flexible duct used in relation to the extension of the duct. The total length achievable was 500 mm and minimum contraction was 150 mm. The result of the test is showed in Figure 6. It is observed that, the degree of extension of flexible duct have impact on the flow of the fluid due to friction introduced by the duct surface. At 150 mm extension, maximum air flow achievable was 4.217 m<sup>3</sup>/min and at full extension, the flow increased to 5.376 m<sup>3</sup>/min. When the duct is not fully extended, the zig-zag surface increased the surface roughness which led to increased in friction and reduction in airflow and velocity. With the full extension of the duct, it approximates a smooth circular pipe with reduced surface roughness and subsequent increase in airflow and velocity as observed.

### 4.2 Welding point proximity to hood test

The efficacy of the extraction is put to test by measuring air flow rate and air velocity from distance to hood entrance during welding operations. Two scenarios were evaluated. One, with the flexible duct un-stretched and the other with the flexible duct fully stretched out. In each case, the thermo anemometer ball bearing vane is placed at varied distances between 20 mm to 120 mm as shown in Figure 5.

The results of extraction airflow rate and air velocity from various distances to hood entrance during welding operations are shown in Figure 7 and Figure 8. While Figure 7 results were obtained when the duct was 30% extended, Figure 8 results were obtained when the duct was 100% extended. It was observed that, at distance 20 mm away from the hood, airflow rate and air velocity were of the same value irrespective of the extension rate of the flexible duct. Also, at 120 mm away from the hood, the Thermo Anemometer were unable to read the airflow rate and velocity of air.

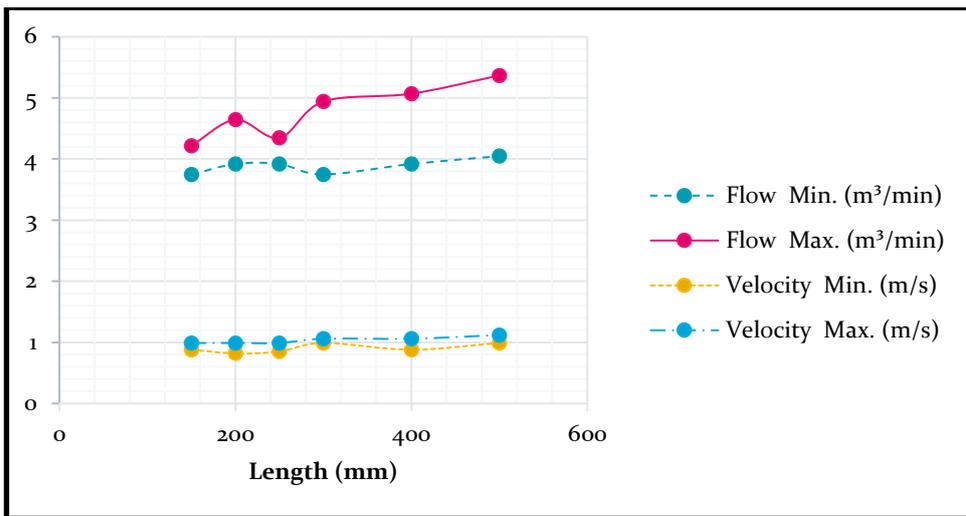


Fig. 6 Effects of flexible duct extension on airflow and air velocity

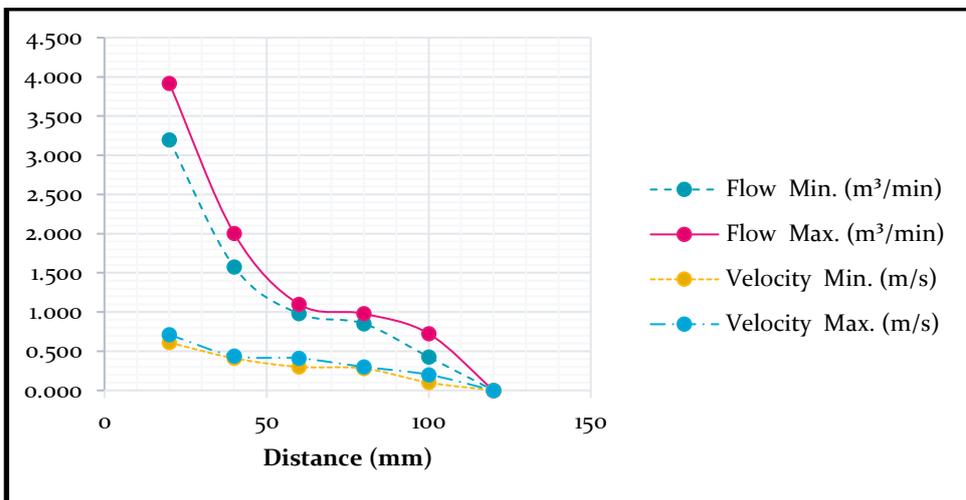


Fig. 7 Airflow and proximity to hood at 30% flexible duct extension

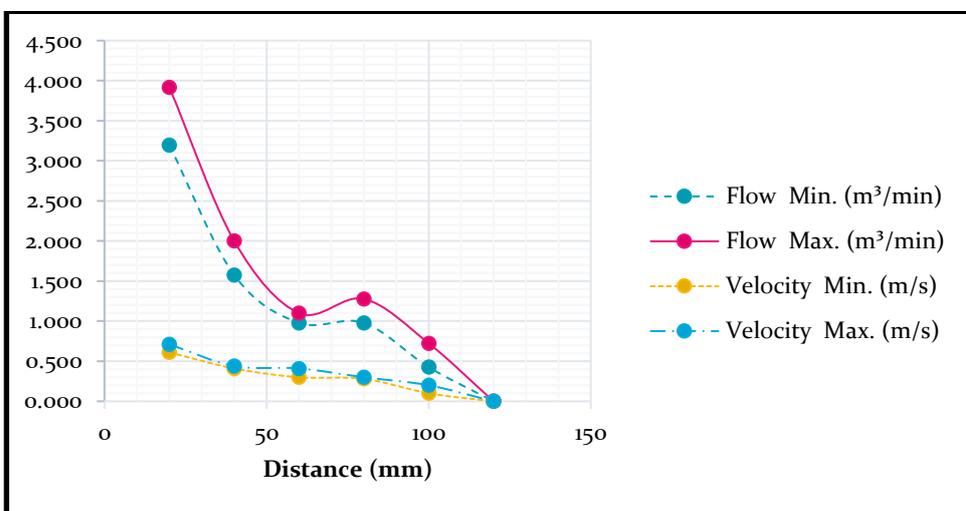


Fig. 8 Airflow and proximity to hood at 100% flexible duct extended

## 5. Conclusion

The ventilation system design and developed for the welding booth were tested and it showed that the use of flexible duct needed to be avoided where it is possible. This is due to the impart of the surface deformation as result of contraction and extension of flexible duct that increases the frictional force on the air flow thereby reducing the air quantity.

From experiment conducted on proximity of welding point, it was found that extracting hood work well at range between 20 mm to 100 mm irrespective of degree of extension of the flexible duct. Welding operation should be restricted to this range for best fume extraction, as this keeps welding smoke away from breathing zone of welder as from the adjoining welding area.

It was observed that confined welding area restricted gases and fumes from escaping to the environment due to the negative pressure provided by the ventilation system.

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