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CAPTURE EFFICIENCY OF INTEGRAL FUME EXTRACTION TORCHES FOR GMA WELDING

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ABSTRACT

The Econweld Project identified the development of a lightweight and ergonomic fume extraction GMAW torch as a high priority research need. This report has been completed in response to this need.

At source capture is the most efficient method to eliminate welding fumes from the metal working environment, particularly from the breathing zone of the welder. Worker productivity can increase up to 20% when an integral suction torch is installed in a welding fabrication shop, owing to less sick leave among welders and improved employee morale. Moreover, significant energy savings can be achieved when source capture is used compared to general ventilation methods.

The state of art of existing fume extraction torches and requirements for improved torch performance have been analysed considering the weight, flexibility, and fume extraction capability, with particular emphasis on the integral extraction torch adopted by the EC funded Econweld Project

Through an historical survey of the evolution of integral suction torches, the recent methods for evaluating their capture efficiency have been analysed, the early developments of fume extraction torches have been reviewed and the more effective improvements of commercial torches have been investigated both for their increasing efficiency and enhanced ergonomic assessment.

The modern Computational Fluid Dynamics (CFD) approach has been briefly described, in order to model the fume plume dispersal and capture efficiency, with the validation of results performed by prestigious scientific institutions.

KEYWORDS

Fume, capture efficiency, GMAW, LEV, plume, on-gun extraction, on-torch extraction, welding fume, suction, isokinetic sampling, extraction devices, tracer gas, CFD, particulate matter, FER.

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CONTENT

1 INTRODUCTION

In order to assure welder's comfort and adhere to workplace safety and environmental regulations, the EC funded Econweld Project *[Ref. 1]* is exploring the use of integral fume extraction torches. These devices incorporate fume capture capability within the handheld welding tool, reducing the need for separate local exhaust equipments (LEV) or the use of personal respirators (RPE) by welders. As a result, workers are more productive because they do not have to transport and reposition extraction equipment each time they work in a new location.

Earlier fume exhaust welding torches had limited flexibility and were bulky to handle, when compared to conventional hand held tools. The new generation of fume extraction torches should improve the workplace environment, while their manipulation by welder should be more comfortable for extended periods of time.

The EC funded Econweld Project *[Ref. 2]* identified the development of a lightweight and ergonomic fume extraction GMAW torch as a high priority research need. This report has been completed in response to this need.

2 WELDING FUME EXTRACTION TORCHES

Literature on fume extracting welding torches has been collected and reviewed in relation to design, application, efficiency of extraction, and potential effects on gas shielding and weld quality. The state of art of existing fume extraction torches and requirements for improved torch performance have been analysed considering the weight, flexibility, and fume extraction performance, with particular emphasis on the integral extraction torch adopted by the Econweld Project *[Ref. 1]*.

A prototype, lightweight torch has been developed by Aspirmig *[Ref. 9]* during this research project and the evaluation of the new, improved torch is currently under investigation both in laboratory tests and workshop trials performed at Partner's premises *[Ref. 10-11]*.

2.1 Fume capture at source

At source capture is the most efficient method to eliminate welding fumes from the metal working environment, particularly in the breathing zone of the welder, since the volume of the particulate fumes to be removed increases rapidly as the fume removal device moves away from the welding spot because of the dilution of the fume plume *[Ref. 8]*. Worker productivity can increase up to 20% when at source capture welding fume extraction is installed in a welding fabrication shop, owing to less sick leave among welders and improved employee morale. Moreover, significant energy savings can be achieved when source capture is used compared to general ventilation methods.

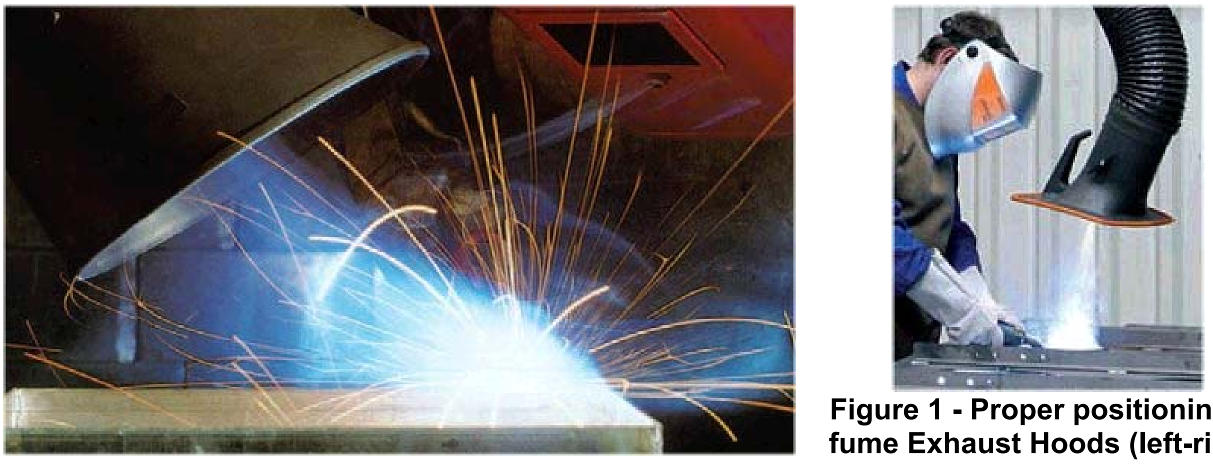


Figure 1 - Proper positioning of fume Exhaust Hoods (left-right)

In order to capture a plume of fumes (**Figure 1**), the hood should be positioned somewhat above the weld opposite the welder. This positioning allows ample room for the operator to work while protecting him from harmful gases *[Ref. 3]*.

It is commonly recommended to achieve an air velocity in the range of **0.5 m/s** (100 ft./min.) across the welding zone (arc point): higher velocities may affect the gas shielding that surrounds the weld metal. If the airflow field $u(x, y, z)$ in front of an exhaust opening is known, one can dimension an exhaust hood using the capture velocity method.

The capture velocity is defined as:

The air velocity at any point in front of the hood necessary to overcome the opposing airflows and to capture the contaminated air by causing it to flow into the exhaust hood [Ref. 5].

The values for necessary capture velocities are empirical.

Some general guidelines for capture velocities and examples of corresponding processes or operations are given in **Table 1**, adapted from Brandt [*Ref. 6]*.

Table 1 – Minimum capture velocities recommended to achieve a sufficient capture efficiency [ACGIH, 1995, *Ref. 5***].**

Condition of dispersion of contaminants	Example of process or operations	Necessary capture velocity [m/s]
Released with practically no velocity into still air	Evaporation from open vessels	0.25 ÷ 0,5
Released at low velocity into moderately still air	Spray booths; welding; plating	0.5 ÷ 1.0
Released with considerable velocity or into zone of rapid air motion	Spray painting in shallow booths; barrel filling	1.0 ÷ 2.5
Released at high initial velocity or into zone of very rapid air motion	Grinding; abrasive blasting; surfacing operations on rock	2.5 ÷ 10

After choosing an appropriate capture velocity for the process, the required exhaust airflow needed as well as the opening size can be specified. Volume flow rate and hood size depend on the wanted distance between contaminant source and exhaust opening - the capture distance.

Even with an efficient hood design, extractor arm hoods must be positioned approximately 30 cm to 40 cm from the weld to be fully effective *[Ref. 3]*.

In summary, the necessary components to achieve proper source capture of welding fumes are an easily positioned fume extractor with a well-designed hood, a right airflow through the fume extractor and a conscientious welder who will position the hood (**Table 2**) in a manner that will draw hazardous fumes away and continuously from his breathing zone.

Table 2 - Typical air flow rates and capture distances for LEV equipment

Air Flow Q (m^3/min)	Air Flow Q (m^3/h)	Hose/Duct Diameter (mm)	Hose/Duct Capture Distance (mm)	Weld Length Before Repositioning (cm)
High Vacuum, Low Volume				
1.5	90	38÷51	51÷76	10 ÷ 15 for duct 20 ÷ 30 with flange
2.5	150	38÷51	51÷76	10 ÷ 15 for duct 20 ÷ 30 with flange
3.0	180	51	76	10. ÷ 15 for duct 20 ÷ 30 with flange
4.5	270	76	127 ÷ 152	23 ÷ 30
Low Vacuum, High Volume				
14÷17	840 ÷ 1,042	100 ÷ 150	150 ÷ 230	30 ÷ 46
23÷28	1,300 ÷ 1,700	150 ÷ 200	230 ÷ 300	46 ÷ 60

Table 3 - Local extraction ventilation for welding

System type	Typical airflow	Comments
Welding torch with integral fume extraction	50 ÷ 100 m^3/h	Extracts fumes at the weld zone through GMAW and FCAW torches
High vacuum source capture nozzle	150 ÷ 300 m^3/h	Capture fumes with High Velocity Low Volume extraction nozzles, positioned by the welder
Flexible fume extraction arm	900 ÷ 1,400 m^3/h	Draws higher air volume and is easily positioned & repositioned by welder

On-torch extraction uses high vacuum technology (**Table 3 and 4**), i.e. high speed extraction and low air volumes to extract the fumes.

Table 4 - High and low vacuum technology

	Low Vacuum	High Vacuum
Air volume, m^3/h	600 ÷ 1,800	150 ÷ 250
Removal velocity, m/s	0.5 ÷ 5.0	15 ÷ 18
Transport velocity, m/s	6.0 ÷ 14.0	18 ÷ 25

Most of LEV is mounted on the wall and working distances are limited. The collection arms of these devices must be repositioned frequently, which is not done in practice.

The position of the suction nozzle is very important for the welding quality in high-vacuum systems. The nozzle must be positioned a certain distance away from the welding point so that the suction flow does not disturb the shielding gas distribution on the welding pool. Therefore, the major challenge in this system is to maintain the welding quality. If the suction flow rate through the nozzle is high, it disturbs the shielding gas distribution and deteriorates the welding quality. Therefore, it is required that the welder fine-tunes the exhaust flow rate for each set up.

2.2 Basic principles of fume extraction torches

Fume extraction torches are capturing at source tools formed as an integral part of the torch assembly. Their physical configuration is similar to the conventional welding torches, integrated with some suction basic openings (rim, edges, slots, multiple holes) placed around a surface (typically the torch nozzle at the lower end of handle) for capturing the fume plume (**Figure 2**) *[Ref. 4]*.

The exhaust openings are very small, with high air velocity (greater than 10 m/s) and with low flow rate (mostly less than 100 m^3/h), placed very close to or around a fume source with small dimensions.

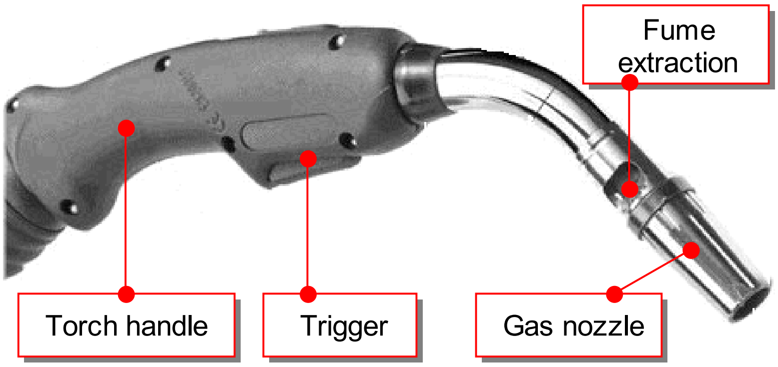


Figure 2 – GMAW torch with fume extraction adopted by Econweld Project

The suction flow rich of the captured fumes is connected through a flexible conduit to the extraction system (<u>exhaust unit or aspirator</u> – **Figure 3**), able to supply the required extraction flow rate, at a constant pressure. Typically the modern exhaust units are provided with start-stop devices enslaved to the arc ignition and stop, thus assuring the extraction flow only when required.

Antiwear materials nowadays guarantee the protection of cable and pipes connecting the torch handle to the aspirator.

Cooling of the conduit and fumes include mixing sufficient ambient air with the welding fumes. This ambient air, in combination with the positioning of the fumes extracting orifice on the nozzle (but away from the area of the weld) allows the temperature of the handle to be maintained within acceptable limits. Under such circumstances, small variations of the torch attitude in relation to the work can make substantial differences to the flow profiles of gas and extract air.

From the literature describing these systems it is clear that the work being welded is important to the balance by turning the downward flowing gas into the upward/inward flowing extracted air.

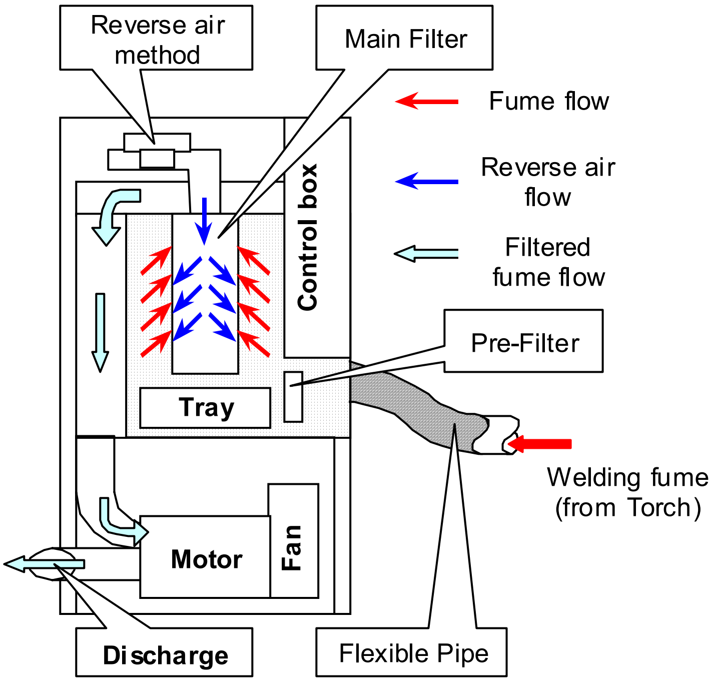


Figure 3 – Schematic layout of welding fume collector

Finally, it is useful to mention that the <u>noise</u> induced by the suction flow of the air at high speed through the exhaust openings of extraction torches must be maintained well below the actual limits.

Effective welding fume capture is only achieved when <u>the velocity</u> of the extracted air exceeds 0,3 m/s, the average velocity at which a fume plume rises. Therefore, a velocity of **0.4 m/s** is normally selected *[Ref. 12-13-14]* as being sufficient to ensure capture of fume and gases at any given point. For a particular extraction device, this capture velocity can only be achieved by applying a <u>minimum volume air flow rate</u>, which is dependent upon the aspect ratio and cross sectional area of the opening ports. Consequently, extraction devices need to be used with exhaust systems that provide, at least, the minimum air volume flow rate.

A general classification of fume extraction torches (**Figure 4**) must take into account the following characteristics:

1. <u>suction field (velocity)</u> – Three-dimensional field (space) in front of the entry plane of the extraction port. The air velocity in the suction field must be greater than the air velocity in the surrounding air. The size and the shape of the suction field can be described by a three-dimensional flow profile having the same air velocity; the suction field pattern depends upon the geometry of the extraction device, air movement, surrounding surfaces and the flow rate of the extracted air;
2. <u>capture zone (range flow)</u> - Part of the suction field in which the air velocity is equal to or greater than the minimum air velocity required for effective capture of welding fume (0.4 m/s);
3. <u>exhaust device tool</u> – The suction basic openings can be integrated on a new designed torch or can be mounted on an existing torch as a separate add-on device.

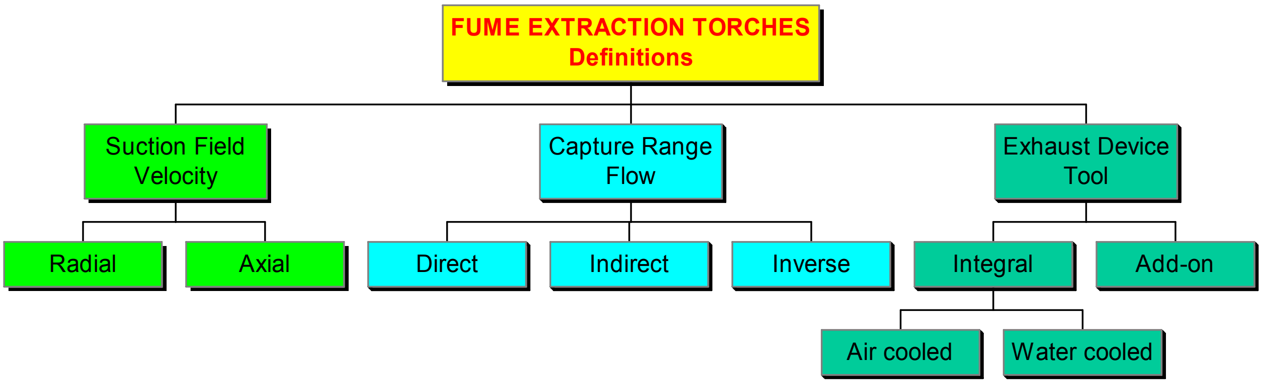


Figure 4 – Fume extraction torches – General classification

2.2.1 Axial vs. Radial Suction Field

The suction field is created through proper designed openings placed symmetrically around the lower front end of the torch axis, shown schematically in vertical position (**Figures 5.a, 5.b, 5.c**). The suction field can be symmetrically aligned with the torch axis (<u>axial pattern</u>) or can be symmetrically oriented with an angle variable from 45 to 90 degrees towards the torch axis (<u>radial pattern</u>).

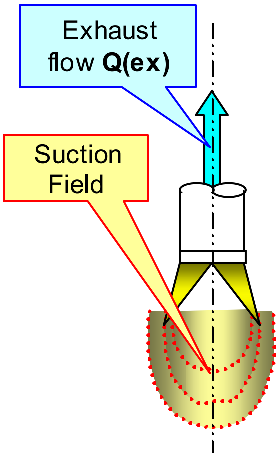
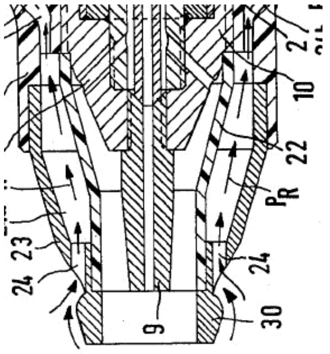


Figure 5.a - Axial suction field - Schematic (top) – Patent (bottom) *[Ref. 15]*



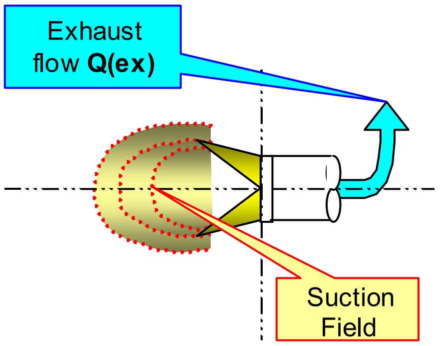
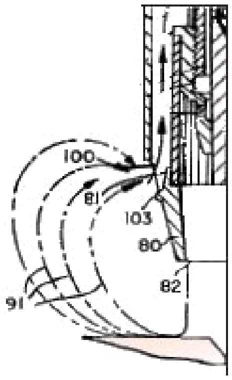


Figure 5.b - Radial suction field (90°) - Schematic (top) – Patent (bottom) *[Ref. 16]*



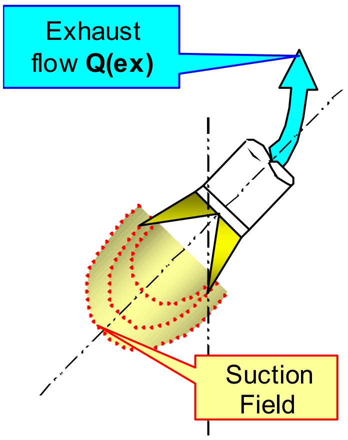
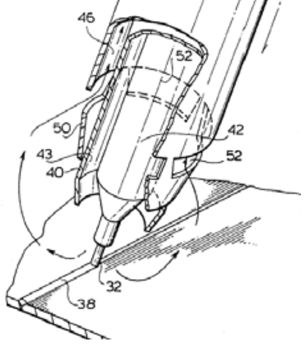


Figure 5.c - Radial suction field (45°) - Schematic (top) – Patent (bottom) *[Ref. 17]*



2.2.2 Direct vs. Indirect Capture Range

The suction basic openings are placed around a surface for capturing the fume plume, typically the torch nozzle at the lower end of handle for a direct capture (**Figure 6.a**) or the torch body far away from the distal end of the nozzle for an indirect capture (**Figure 6.b**).

The introduction of fume extraction openings close to the arc point (direct capture) must satisfy conflicting requirements. On one hand, the downward flow of shielding gas must be non-turbulent, on the other, an upward and inward flow of hot fume must be drawn back into the torch head by the exhaust system.

The balance that must be struck between these opposing forces to ensure maximum extraction efficiency without loss of weld quality because of reduced or disturbed gas flow is in practice very fine. Furthermore, this balance must be maintained under conditions where miniaturization and low extraction volumes accentuate the characteristically rapid decrease in suction velocity with increasing distance from an exhaust opening.

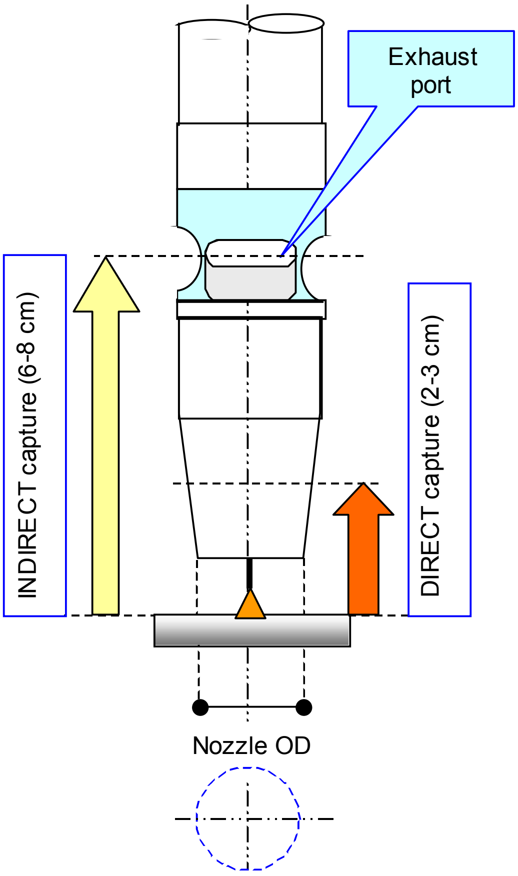


Figure 6 - Direct vs. Indirect capture range (schematic)

- Direct capture path in the radial wall jet by means of extraction ports around the torch nozzle has been shown to be strongly influenced by the exhaust flow rate of the aspirating unit.
- The location of the extraction port is generally too close to the axis of the torch and too far from the work surface to capture either the fume-laden wall jet or the rising plume.

Figure 6.a – Direct Capture Nozzle

- Indirect capture path by means of extraction ports located on the lateral surface, far away from the torch distal end, has been shown to be slightly influenced by the exhaust flow rate of the aspirating unit.

Figure 6.b - Indirect Capture Nozzle

2.2.3 Direct vs. Inverse Extraction

In the direct extraction torches, the welding fumes are captured near the source of emission through proper openings placed symmetrically on the distal end around its lateral surface (extraction ports). The shielding gas mixture, instead, is provided through an inner orifice placed on the torch nozzle, concentrically to the extraction ports, like any conventional GMAW torch (**Figure 7**).

A recent variation is disclosed in US Patent *[Ref. 18]* in which a fume extraction port surrounds the welding electrode and a concentric inert gas supply port surrounds the extraction port (**Figure 8**).

While this configuration (swapping positions of shielding gas and exhaust flows) assists in confining the bulk of the fume to a region close to the arc and therefore makes the task of extracting fume relatively easy compared to prior art devices, the configuration also dilutes the inert gas concentration to unacceptably low levels with ambient air in the vicinity of the arc and weld pool. This is irrespective of the relative flow rate of shielding gas and rate of fume extraction.

Some difficulties can arise in balancing the correct flow rates of shielding gas and exhaust gas, in particular when the value of the welding current exceeds 150 A. For this reason the quality of weld can be poor owing to porosities and irregularities in the bead shape.

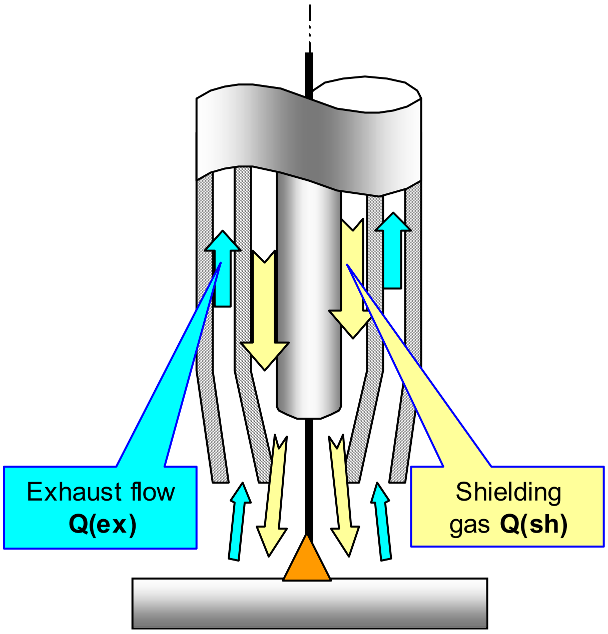


Figure 7 - Direct on-torch extraction with axial exhaust path (schematic)

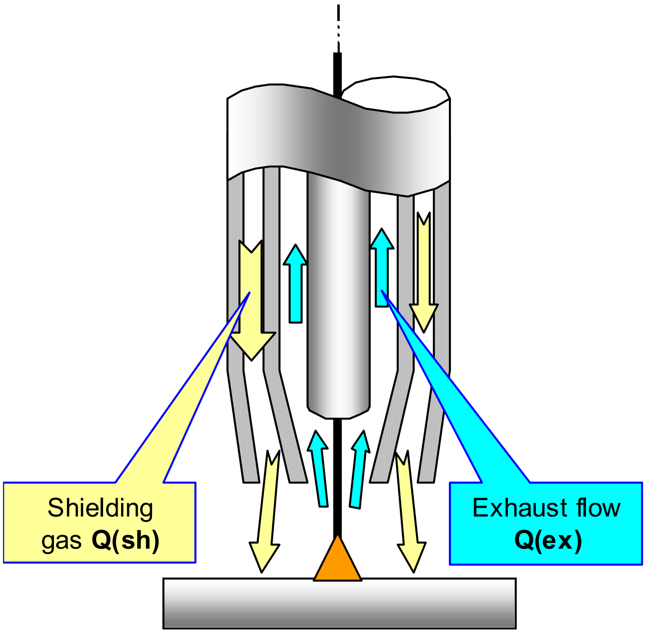


Figure 8 - Inverse on-torch extraction with axial exhaust path (schematic)

2.2.4 Direct vs. Indirect Extraction with Radial Exhaust Field

The position of the suction openings in the direct extraction torch (**Figure 9**) is very important for the welding quality when using high-vacuum systems. The openings are positioned at a short distance from the welding point, in such a way that the suction flow can disturb the shielding gas distribution on the welding pool. Therefore, the major challenge in the direct extraction is to maintain the weld quality by adjusting the suction flow rate according to the welding position. If the suction flow rate through the openings is too high, it can disturb the shielding gas distribution and deteriorate weld quality; on the contrary, if the suction flow rate is too low, the capture efficiency can be very poor.

Therefore, it is required that welder fine-tune the exhaust flow rate for each set up when using a direct capture extraction torch.

In the indirect extraction torch (**Figure 10**), the welding fumes are captured near the source of emission through proper openings placed symmetrically around its lateral surface (extraction ports), but far away from the torch nozzle, where the buoyant fumes are less aggressive after completing (partially or totally) the condensation process. The plume velocity and its thermal gradient are considerably reduced near the suction openings and the shielding gas distribution is marginally affected by the suction flow rate and the opening position relative to the welding pool.

Therefore, welder is not required to adjust the exhaust flow rate for each set up when using the indirect capture extraction torch, in both the variants of axial and radial suction field.

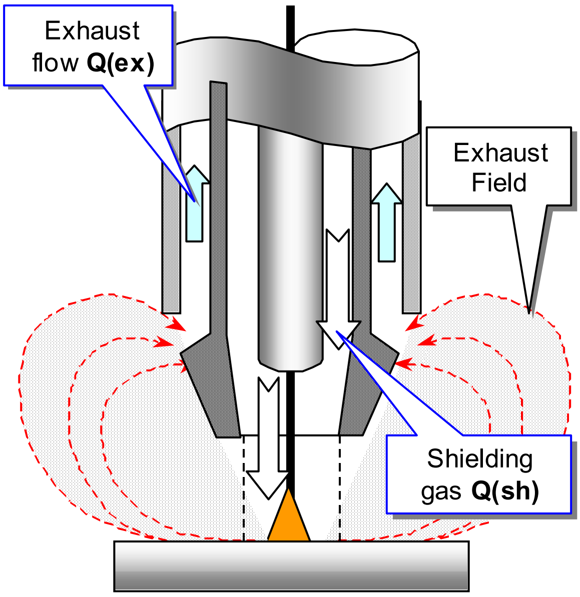


Figure 9 - Direct on-torch extraction with radial exhaust path (schematic)

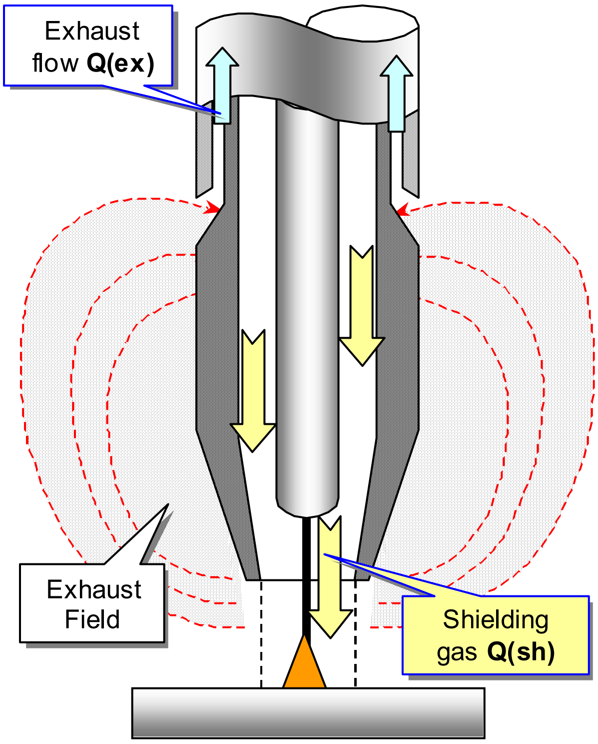


Figure 10- Indirect on-torch extraction with radial exhaust path (schematic)

2.2.5 Direct Extraction with Radial Supply Jet

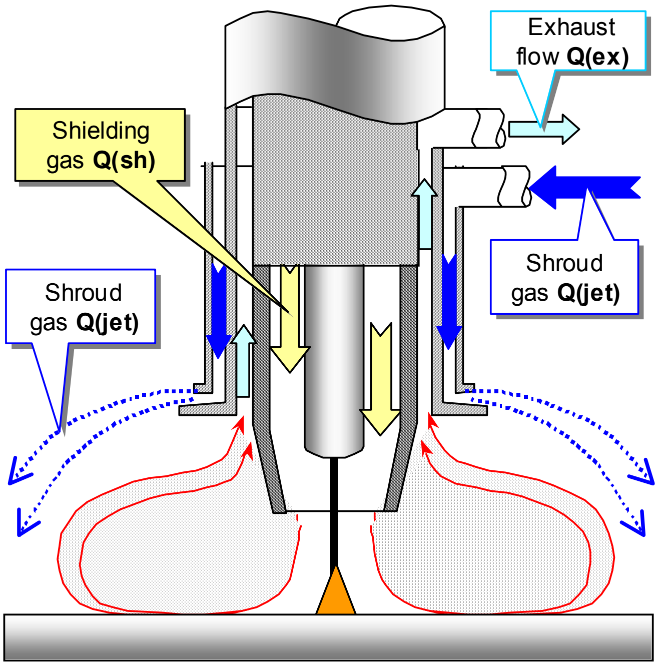


Figure 11 - Schematic extraction nozzle with radially directed shroud gas jet *[Ref. 19]*

A more recent International Patent *[Ref. 19]* discloses an invention, which provides an arc welding torch (**Figure 11**) and a method of extracting fumes from a welding site.

- The torch is composed by a consumable metal electrode and one shield gas port adapted to direct a shield gas curtain with flowrate **Q(sh)** around the electrode and the welding pool, as in conventional GMAW torch.
- One shroud gas port is spaced radially outward from the shield gas port and accommodated to confer a radially outward component of velocity to the shroud gas exiting with flowrate **Q(jet)**.
- Fume gas is extracted by means of an aspirator with flowrate **Q(ex)** from a position radially intermediate the shield gas and the shroud gas curtain; the latter tends to form an aerodynamic flange around the torch and the welding pool, thus isolating the fume rich region from the surroundings and allowing the fume to be captured from the envelope.

2.2.6 Integral vs. Add-on Extraction Torches

The suction basic openings are integrated on a new designed torch embodiment (integral extraction torch - **Figure 12**), where a proper fume extracting nozzle is arranged to capture the fume plume with a direct or indirect suction path. Two are the main ergonomic/size requirements for a handheld torch with integrated fume extraction capability: the tool must be light to handle (lightweight) and not bulky, thus allowing welder a correct line of sight on welding pool.

The add-on arrangement (**Figure 13**) can be designed as an integral part of a standard semi-automatic welding torch, or more frequently an exhaust hood or a fume nozzle can be easily fitted as an add-on improvement to an existing equipment for automatic applications.

Figure 12 – Integral extraction torch

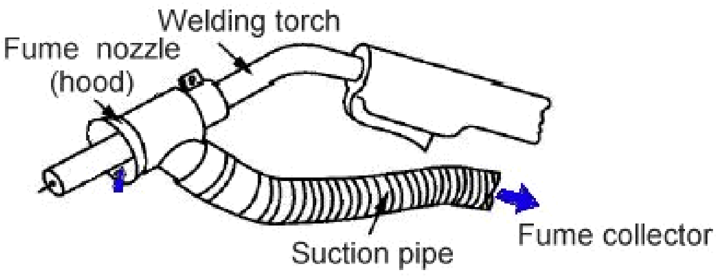


Figure 13 – Add-on extraction torch

2.3 Evaluation of Capture Efficiency of Fume Extraction Torches

Fume capture efficiency is the decisive criterion for evaluating the performance of welding fume extraction torches. It is currently measured by a number of widely differing methods. Experimental studies have been conducted in order to determine whether a uniform assessment of capture elements is possible when different test methods are employed *[Ref. 13 - 14]*.

Requirements for extraction devices have been set out in standards valid throughout the European Union in the course of harmonization. The available draft standard governing extraction devices for welding fumes contains four different methods for testing capture efficiency *[Ref. 20]*.

Manufacturers and users may in future employ two simple methods requiring no major measurement resources. Two further methods are suitable for use with all extraction devices (including on torch extraction systems) but they require more involved measure equipments, as they measure the capture efficiency in percentage terms.

Indication of capture efficiency by the manufacturer enables the user to select the most suitable extraction device.

The capture efficiency **η** of a local exhaust ventilation system is defined as:

"The ratio of the directly captured contaminant to the amount of totally generated contaminant (DIN-EN1093/3, 1996)".

This definition is valid for a specific test set up which is described in the mentioned standardization. The capture efficiency is the most meaningful number to assess different local ventilation systems in their capability to solve a specific ventilation task *[Ref. 4]*.

2.3.1 Evaluation Methods

Four principal methods of evaluating the capture efficiency of fume extracting torches have been developed in the past:

1. Use of photography - This method allows only a qualitative evaluation of efficiency. It was used by early workers and is still employed in marketing literature to graphically illustrate the effect of fume extracting torches.
2. Total particulate fume - In this technique, the total fume emitted is collected, first powering on the extraction system and then switching off the extraction system. This technique is relatively simple and widely used, but its accuracy is low (about 20-25% of inaccuracy).
3. Breathing zone measurements - Standard techniques for measuring the fume in the welder's breathing zone are used, with and without operation of the fume extraction system. This method has the advantage that it directly measures the quantity of most interest, the fume exposure of the welder. However, breathing zone measurements tend to be subject to large variations due to the size and position of welder, general environment, and position of weldments.
4. Tracer techniques - Use of a tracer gas such as Helium has been employed in order to make continuous and recordable measurements. This method requires a mass spectrometer to measure the tracer gas concentration.

In theory it should be possible to calculate the capture efficiency without measurements by using modern Computational Fluid Dynamics (CFD) approach, but any CFD simulation is only as good as the mathematical models that are supplied as input to the solving software, so it is always necessary to validate CFD results against physical experiments.

A method has been developed by the Institut National de Recherche et de Sécurité (INRS), France, for measuring the efficiency of fume exhaust devices on GMA welding torches *[Ref. 21-22]*. Applicable both in laboratory and on site, it is based on the use of a tracer gas (Helium), which may be a component of the welding gas or be mixed with it.

Some boundaries have been defined in order to develop a standard procedure for measuring the capture efficiency of welding fume, namely:

- the method must be implemented both in laboratory conditions and welding workshops;
- the method must be friendly to use and must assure wide circulation;
- the method must have high sensitivity and assure fast response to transitory welding phases.

Two welding torches, provided with integral fume extraction nozzles from commercial supplier, have been used at INRS to fine-tune the experimental procedures.

The improvements arising from the evaluation procedure should assure a large acceptance criterion from the end user, who normally requires the product efficiency as well as a method to check the tool performance and quality.

2.3.2 Balance Method

The balance method defines the capture efficiency (η) of the extraction system as the ratio between the mass captured by the extraction ports **m**(c) and the fume mass emitted during the welding process **m**(e):

$$\eta = \mathbf{m}(c) / \mathbf{m}(e) \times 100\ [\%] \qquad (1)$$

The method is based on the following statement:
the sum of the fume mass captured by the suction torch **m**(c) and the fume mass which is not captured by the suction torch **m**(nc) must be equal to the fume mass emitted during the welding process **m**(e), being all the masses expressed in [mg/s].

This hypothesis can be expressed as:

$$\mathbf{m}(e) = \mathbf{m}(c) + \mathbf{m}(nc)\quad [mg/s] \qquad (2)$$

Replacing the relationship (1) with the value given by (2), we obtain:

$$\eta = \mathbf{m}(c) / \mathbf{m}(e) \times 100\ [\%] = (1-\mathbf{m}(nc) / \mathbf{m}(e)) \times 100\ [\%] \qquad (3)$$

The evaluation procedure consists in measuring **m**(c) through an isokinetic sampling of the captured fume inside the extraction tube on the torch hosing (**Figure 14**), while **m**(nc) is measured trough an isokinetic sampling of the air and plume surrounding the suction torch.

This second collection is performed through an exhaust hood containing the suction torch, and connected to a collecting device.

Experimental trials have shown that the exhaust hood slightly modifies the normal airflow path near the suction torch, thus affecting the torch capturing performance. Moreover, the bulk size of the hood is incompatible with some operative welding conditions and makes the balance method partially unsuitable for on site evaluation.

For these reasons, the balance method has been changed to a relative method.

2.3.3 Total Particulate Method

This relative method allows to determine the ratio between the mass of fume really captured by the torch and the mass of fume extracted when the ideal efficiency is supposed to be η=100%.

The choice of a standard sample procedure must be done within the particulate fume and a tracer gas (generally Helium) introduced into the arc point. Welds must be performed in order to be perfectly reproduced, thus requiring:

- an isokinetic sampling within the suction conduit of a constant fraction of welding fume captured by the suction torch;
- a capture of this constant fraction on a filter, collecting the particulate matter.

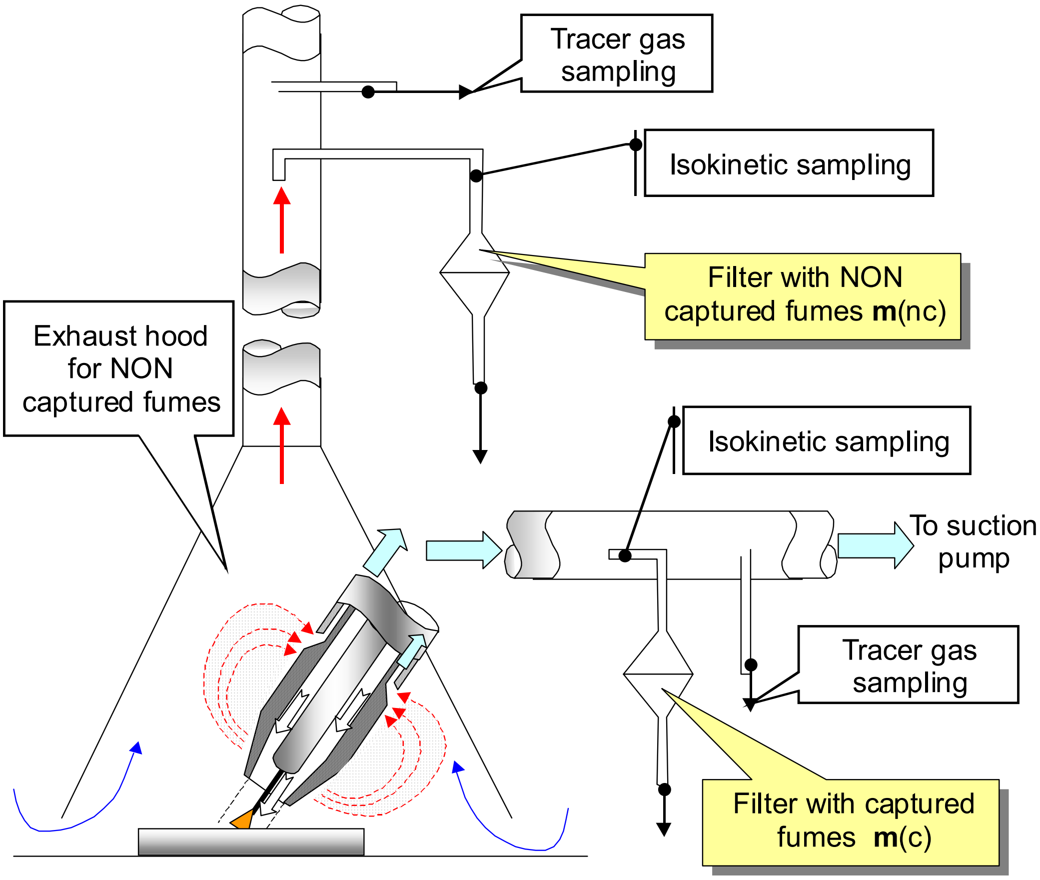


Figure 14 - Schematic layout of Balance Method

By weighting the filter before and after the testing procedure, the collected particulate is measured. Some cautions must be taken during the sampling procedure:

- the suction flow rate to the torch must be kept constant during the sampling period;
- the sampling location must be far away from the torch conduit in order to get an homogeneous concentration of the particulate matter;
- the suction velocity at sampling location must be closely equal to the velocity inside the conduit, in order to achieve an isokinetic sampling representative of the particle sizes.

By defining:

M1 = mass of the particulate matter collected by the filter during the welding time (mg), **Figure 15**;
t = welding time (s);
M2 = mass of the particulate matter collected by another filter within the same extraction conditions, but without welding, during the same time t (mg), **Figure 16**.
The total mass of the particulate matter collected by the two filters is expressed by:

$$\mathbf{M} = (\mathbf{M}1 - \mathbf{M}2) / t \quad [\text{mg/s}] \qquad (4)$$

Performing a third test while welding using ideal suction conditions, for instance using an extraction flow rate higher than the normal set, we can expect to collect on a third filter a particulate mass **M**(max) corresponding to a capture efficiency of 100% and then:

$$\eta = \mathbf{M} / \mathbf{M}(\text{max}) \times 100\ [\%] \qquad (5)$$

Three remarks on the procedure are important:

1. **M**(max) is only postulated;
2. the method evaluates an average efficiency, weighted during the welding period, thus ignoring possible variations in the suction conduit during the trials;
3. **M**1 and **M**2 are not measured during the same period.

The second remark requires a deep survey. By measuring the difference (M1 – M2), only the particulate matter produced during welding is evaluated, thus excluding all other contaminant sources.

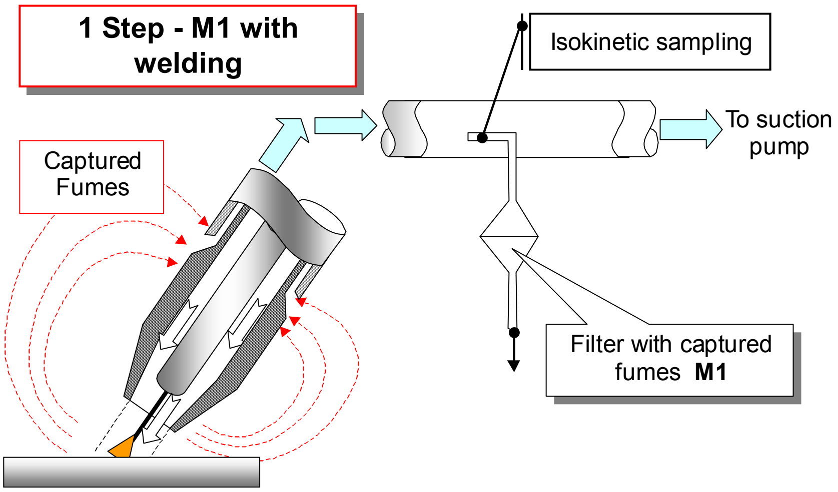


Figure 15 - Layout of Particulate Method – 1st Step

This is equivalent to detract from the measure a background noise, presumed to be constant, and this is real, because M2 is well lower than M1. The internal roughness of the evacuating conduits can pick up some particulate matter from the fume, or in opposite case, occasional movements of the hoses can draw away some particulate matter by the exhaust air. These alternating and random phases of particulate deposition and collection can alter and misrepresent the measured values M1 and M2, thus giving capture efficiency with uncertainty range lower than about 25%.

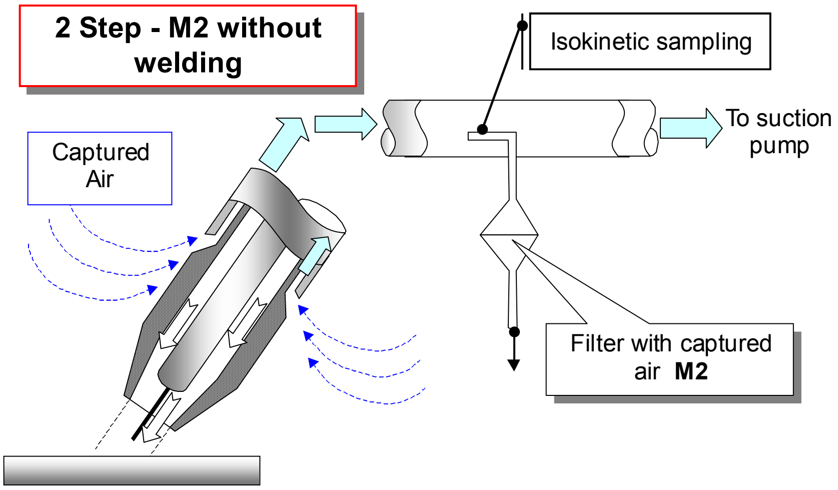


Figure 16 - Layout of Particulate Method – 2nd Step

2.3.4 Tracer Gas (Helium) Method

Basically, the evaluation of capture efficiency of a suction torch is performed using a tracer gas with the same behavior of the welding fume. The choice of tracer gas is done under some general requirements:

1. absence of toxicity;
2. chemical stability;
3. no interference with the fume plume;
4. easy to be measured, even at low concentrations;
5. low cost.

Helium is the best choice as a tracer gas, fulfilling these stringent. The use of Helium well simulates the emission behaviour of fumes having an aerodynamic diameter up to 5 μm, while fume emission diameters are lower than 1 μm.

The evaluation procedure can be summarized in three measurements of the tracer gas, performed with a constant extraction flow rate supplied to the torch, namely:

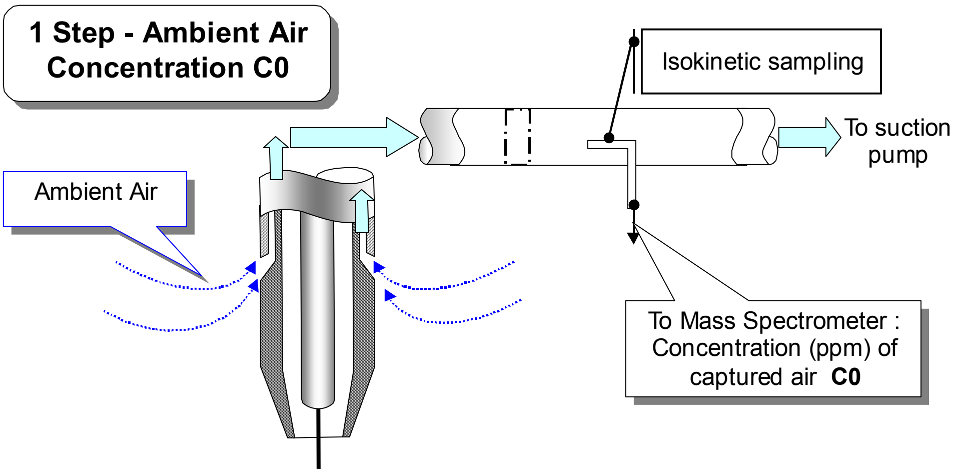


Figure 17 – Tracer Gas Method - 1st Step: Determination of C0

- **C**0, ambient air concentration (ppm), measured without tracer gas (**Figure 17**);
- **C**1, gas concentration (ppm), measured supplying the torch with the shield gas mixed with the tracer gas (Helium in the proportion of about 1%), both present in the suction ports of the torch without welding (**Figure 18**);
- **C**2, gas concentration (ppm), measured under standard welding conditions, supplying the torch with the shield gas mixed with the tracer gas in the emission zone of the fumes, using the same suction flow rate (**Figure 19**).

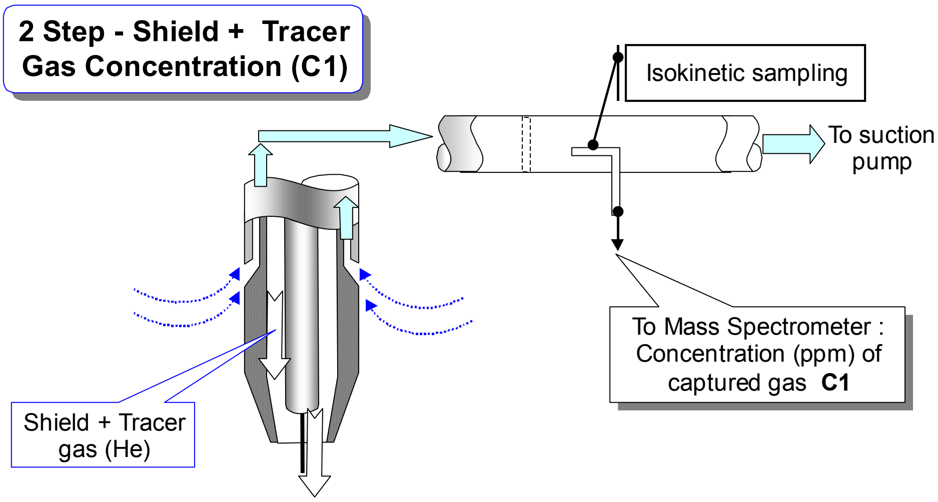


Figure 18 – Tracer Gas Method - 2nd Step: Determination of C1

All gas concentrations are measured using a mass spectrometer calibrated on the employed tracer gas. The suction conduit of the torch is the location area of the isokinetic sampling (constant and homogeneous concentration) of the tracer gas (Helium): a 2.5 m distance from the torch body is a good, recommended value.

The capture efficiency of the suction torch under test can be evaluated using the relationship:

$$\eta = (\mathbf{C}2 - \mathbf{C}0) / (\mathbf{C}1 - \mathbf{C}0) \times 100\ [\%] \qquad (6)$$

The statistical interpretation of the test results can be performed by means of informatics tools, i.e.:

- estimation of the mean capture efficiency during the total time of the welding test (%);
- estimation of the standard deviation of the capture efficiency (%);
- confidence interval for the mean.

The main advantages of the procedure, when compared to both the balance and total particulate methods, can be summarized as follows:

- the maximum capture efficiency can be evaluated (η=100%);
- pick-up or release of particulate inside the evacuating conduits do not influence the results;
- the welding post can be separated from the environment during on site tests;
- it is easy to use;
- capture efficiency can be recorded (**Figure 20**) with written evidence;
- possible random variations during the welding process can be evaluated.

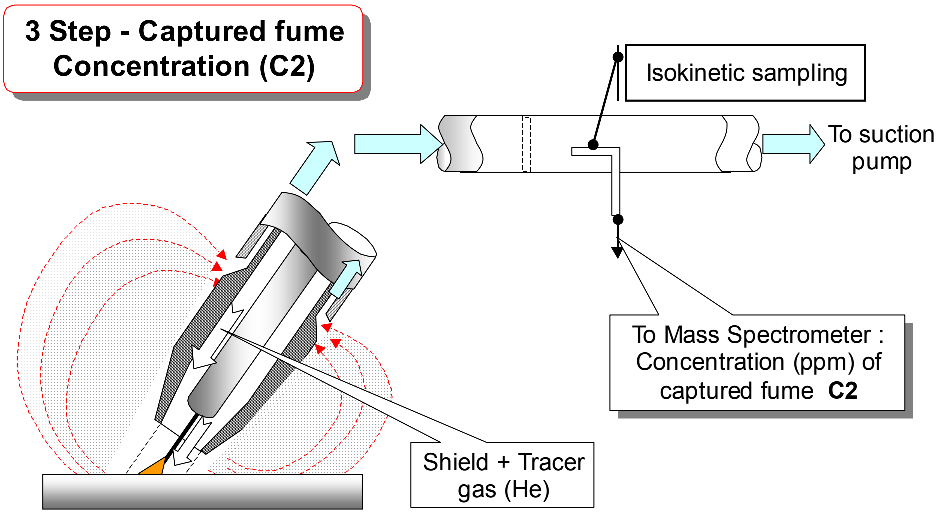


Figure 19 – Tracer Gas Method - 3rd Step: Determination of C2

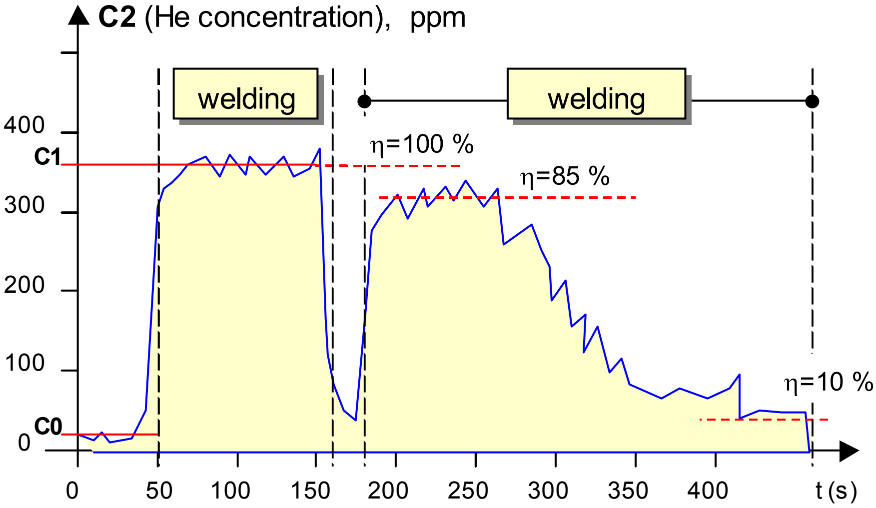


Figure 20 – Spectrometer recording of capture efficiency evaluated by Tracer Gas Method (Torch angle: variable) *[Ref. 22]*

3 CAPTURE EFFICIENCY OF FUME EXTRACTION TORCHES

3.1 Early Developments of Fume Extraction Torches (1968 – 1974)

Earlier fume exhaust welding torches had limited flexibility and were bulky to handle, when compared to conventional handheld tools. Moreover, the integrated suction capability raised severe restrictions on both the head nozzle and handle cooling, together with a great emphasis on minimizing the negative effect on weld quality arising from the suction flow path influencing the shield gas envelope.

As a matter of fact, the introduction of fume extraction openings close to the arc point must satisfy conflicting requirements. On one hand, the downward flow of shielding gas must be non-turbulent, on the other, an upward and inward flow of hot fume must be drawn back into the torch head by the exhaust system.

The balance that must be struck between these opposing forces to ensure maximum extraction efficiency (without loss of weld quality because of reduced or disturbed gas flow) has been in practice the main, concurrent task of the early designed torches.

3.1.1 Literature survey

Several companies in North America and Europe developed concurrently fume extraction torches in the late 1960's and early 1970's.

Wildenthaler and Cary *[Ref. 16, 23]* describe the development of an add-on nozzle to remove fumes (**Figure 21**). Capture efficiency was evaluated by photographing the fume plume.

Wiehe, Cary, and Wildenthaler *[Ref. 24]*, reported of a system that uses an outward tapering cone around the gas nozzle (**Figure 22**). A blower rated at 60.0 m3/h and pressure equivalent to 20 kPa provided the extraction. Breathing zone measurements gave an estimated 85% capture efficiency.

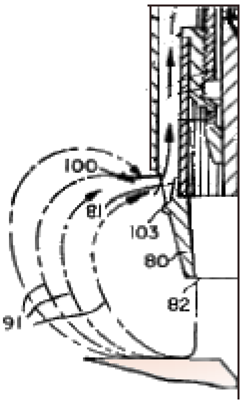


Figure 21 – Patent nozzle details *[Ref. 16]*

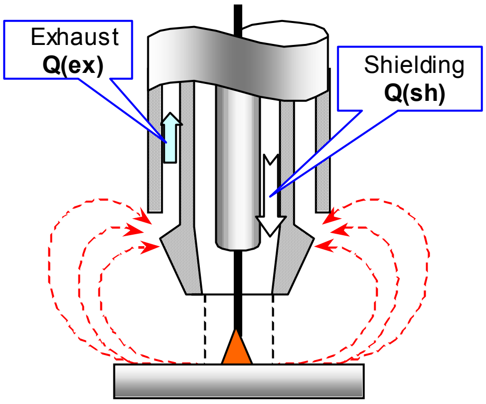


Figure 22 – Fume exhaust nozzle *[Ref. 24]*

Kollman *[Ref. 25]* describes the development of a fume extracting torch in his 1973 paper. In order to minimize size, a centrifugal blower pump was chosen. This unit had a working range of 54.0 to 60.6 m^3/h flow at a pressure of 13 to 18 kPa.

Kollman experimented several designs of fume nozzles and used a hybrid design with a flared annular sleeve with peripheral holes (**Figure 23**). In addition, holes were provided in the flow line that could be blocked or left open by the welder to adjust the extraction airflow. Kollman found that lower flow rates were required when welding in a deep V-groove or when welding a fillet into a corner, in order to avoid disturbing the gas stream.

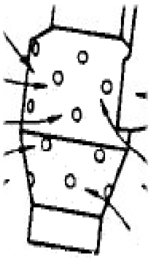


Figure 23 – Flared annular sleeve with holes

Other two articles in 1972 *[Ref. 26, 27]* describe the development of a fume extraction torch with a lightweight chamber that fits over the standard gas nozzle, about 19 mm above the nozzle outlet, and extracts 100 m^3/h. The fume suction is reported not to interfere with the gas shield and not to obstruct the operator's view; moreover, the additional cooling that is provided by the extracted air flow permits higher welding currents without raising torch handle temperatures.

Head *[Ref. 28]* describes in great details the factors affecting the operation of fume extracting torches. He defines two basic types of exhaust nozzles, which are concentric with the torch head to promote uniform extraction flow field in all welding positions.

- In the first type (**Figure 24.a**) extraction is via an <u>annular exhaust slot</u> or bell shaped skirt located about 12 mm behind the gas nozzle (direct suction).
- In the second type (**Figure 24.b**) an extraction chamber is used, having a number of <u>small holes</u> distributed over the surface, spreading the suction zone over a greater area (indirect suction).

Both arrangements can be designed as an integral part of the standard semi-automatic welding torch, but the exhaust chamber type b) can be easily fitted as an add-on improvement to an existing equipment.

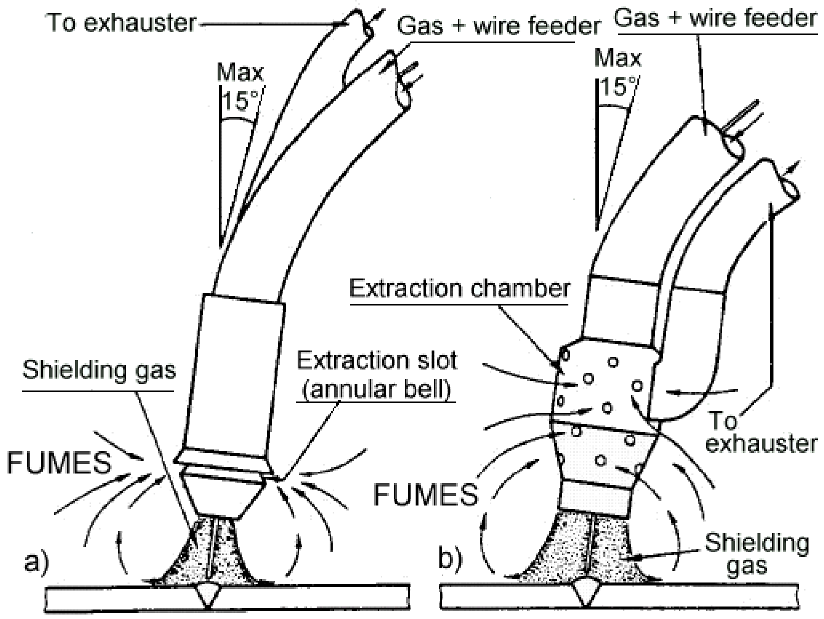


Figure 24 - Welding torches with integral fume extraction – a) Annular slot type; b) Multi-hole chamber *[Ref. 28].*

Exhaust flow rates are not very great, ranging from about <u>60 to 100 m^3/h</u>, according to type and design. Extraction hoses that carry fumes away from the torch are typically between <u>25 to 38 mm</u> inside diameter. The vacuum fan or blower used to draw air through the nozzle must provide the required flow at a static pressure which may be <u>12 to 20 kPa</u> measured at the torch inlet.

Most recommended practice is that the welding torch must be used as far as possible perpendicular to the workpiece, or no more than a few degrees (5°) from the perpendicular, thus preserving some degree of uniform and symmetric capture flow path.

In practice, the joint configuration and position will vary these conditions considerably, for example:

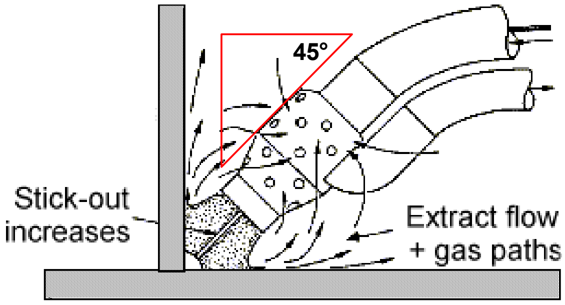


Figure 25 - Fillet weld – Torch angle=45° for best capture *[Ref. 28]*

- Flat Bead on Plate Weld (**Figure 24**) – The PA position is the configuration for which the torch is designed, achieving good capture efficiency.
- Fillet Weld (**Figure 25**) – The 1F-2F positions has a concentrating effect on gas and extract flows, increasing velocity. The fume control is generally satisfactory, unless torch angle deviates from a line bisecting the weld (45°). Difficult access may require increased electrode stick-out, increasing the distance between the extraction holes and the arc and thus decreasing capture efficiency.
- Confined Box Section – The conflicting forces of shield gas flow and extract flow act in a complex

and unpredictable manner. Fume may swirl away out of the capture zone, possibly dispersed by the concentrated gas flow, but control may also be good because of concentrated extraction flow paths.

- Open Corner Weld (**Figure 26**) – The shielding gas is not turned back to the extraction flow path and fumes escape from the capture zone.
- Vertical Weld – In the PG-PF positions, the axis of the torch head is almost horizontal, and the vertical rise of the fume plume through thermal lift exceeds the capture condition. In these positions, fume capture may be poor.
- Welding Complex Assemblies – The torch angle may be dictated by the relative positions of workpiece and the need to keep the arc within the vision of the operator. With excessive deviation from the most favourable torch attitude, the balance may be altered as described and fume capture efficiency can be very poor.
- Operator Fatigue – The torch angle may deviate from the perpendicular because of fatigue. Welding methods, aids, manipulators, torch supports, etc. should be introduced to compensate discomfort where possible.

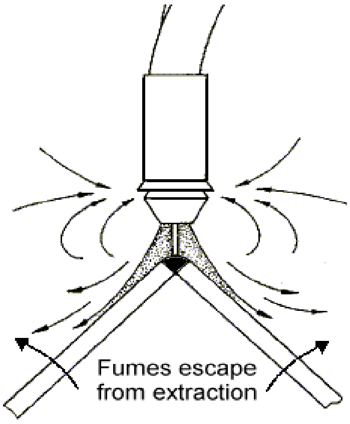


Figure 26 - Open corner weld

3.2 Improvements of Fume Extraction Torches (1975-2002)

The new generation of commercial extraction torches must both improve the workplace environment and enhance their ergonomic assessment, in order to be easily manipulated by welders for extended periods of time.

3.2.1 Research at Danish Welding Institute

Aastrup *[Ref. 29]* used a system similar to the standard AWS total fume box to measure the efficiency of fume extraction torches. He measured a 96.5% reduction in fume using a fume extraction torch. His experiments were conducted with 1.6 mm diameter flux cored electrodes, using 100% CO_2 shielding gas and welding on mild steel in the flat position (PA).

3.2.2 National Institute for Occupational Safety and Health (NIOSH)

Wangenen *[Ref. 30]* studied several aspects of welding fume, including the use of fume extraction torches.

The model tested had a finger activated trigger, which permitted quick shifting of normal suction flow of 21 to 24 L/min and then down to 17 L/min.

Wangenen reported that, since at least a 1:1 ratio of shielding gas flow to suction flow is required for weld quality, the normal shielding gas flow of 14 to 17 L/min had to be increased to 24 to 26 L/min. While these flows maintained quality in flat position welding, satisfactory welds in angles and shapes required reducing suction flow to 17 L/min while maintaining shielding gas flow at 24 L/min. When welding with 1.6 mm diameter wire, at 85 mm/s, and 98% Ar+2%O_2, the overall reduction of fumes in the welder's breathing zone was 78%.

It was reported that the fume exhaust torch appeared to provide a major improvement in fume control on flat surface welding, but was less successful when suction flow had to be reduced from 24 to 17 L/min for welding in angle sections and corners.

Wangenen concluded that that the fume exhaust torch is the most practical and effective means of local exhaust ventilation for welding of galvanized or stainless steels.

3.2.3 *Research at The Welding Institute*

Wright *[Ref. 31]* describes the development of a fume extracting nozzle that could be used with different torches. The nozzle is coaxial with the torch and a variety of nozzle designs were evaluated (**Figure 27**).

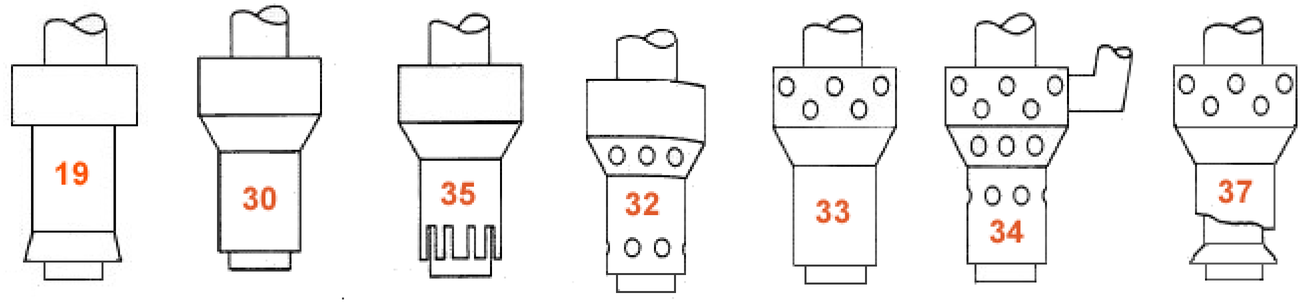


Figure 27 - Evaluation of different fume extraction nozzles (in red are shown the maximum extraction flow rates in m^3/h, before suction flow affects shield gas coverage *[Ref. 31]*

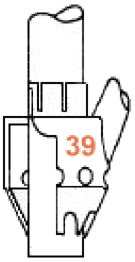


Figure 28 - Nozzle shape

A design with an inward tapering nozzle with both slots and holes and an outlet diameter of 22 mm has been selected (**Figure 28**) for testing fume capture efficiency.
A fume collector with a maximum extraction rate of <u>60 m^3/h</u> was used, with a 2.8 m extraction hose.
Wright tested this system both by taking breathing zone measurements and by measuring fume not collected by the extraction torch. Overall, the extraction nozzle removed 90% of fumes. Fairly consistent results were obtained both from total fume and breathing zone measurements. The results are summarized in the **Table 5** and **Figure 29**.

Table 5 - Capture nozzle efficiency – Wright *[Ref. 31]*

Electrode	**Welding Position AWS (EN)**	**Shielding Gas**	**Current** (A)	**Total Fume Q(ex)=OFF** (g/min)	**Total Fume Q(ex)=39 m^3/h** (g/min)	**Capture Efficiency**
Solid wire	1F (PA)	CO_2	360	0.58	0.06	90%
Basic cored	1F (PA)	CO_2	360	0.92	0.06	94%
Basic cored	1F (PA)	CO_2	450	1.74	0.09	95%
Basic cored	1F (PA)	Argoshield 20	460	0.99	0.17	83%
Basic cored, Curved neck	1F (PA)	CO_2	460	1.79	0.22	88%
Cored	1F (PA)	Argoshield 5	410	0.76	0.05	83%
Low alloy	1F (PA)	CO_2	350	1.49	0.12	92%
Low alloy	1F (PA)	CO_2	400	1.37	0.21	75%
Rutile cored	1F (PA)	CO_2	400	80	8	90%
Rutile cored	2F (PB)	CO_2	400	30	5	84%
Basic cored	2F (PB)	CO_2	450	80	10	75%
Hardfacing, Curved neck	1G (PA)	None	400	2.51	0.45	82%
Hardfacing, Straight neck	1G (PA)	None	400	1.59	0.01	99%

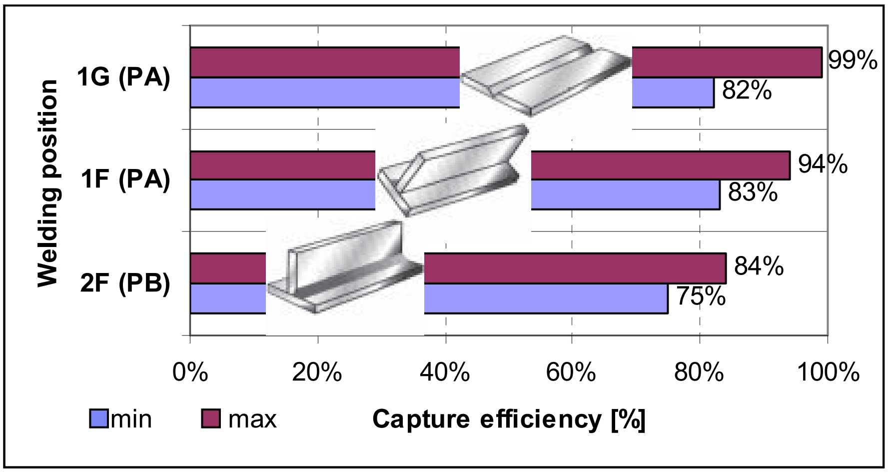


Figure 29 – Capture efficiency Wright tests: min- max ranges

3.2.4 Research at Institut National de Reserche et de Sécurité (INRS)

Cornu *[Ref. 22]* devised a method to measure fume capture efficiency using Helium as a tracer gas. The Helium was mixed with the shielding gas, with a proportion of about 1%. Concentration of Helium can easily be measured using a mass spectrometer. Cornu used a range of suction flow rates from 40 to 90 m^3/h to compare the performance of two fume extraction torches from French manufacturers (Torch A and B). The welding process was FCAW using an argon+CO_2 gas mixture to which Helium was added as the tracer.

Cornu's results of trials on Torch A are summarized in the **Table 6** and **Figure 30** (curve 1-2-3). The welding parameters and conditions for Torch A are listed as follows:

- Welding current: 250 A
- Welding voltage: 33 V
- Welding technique: FCAW with flux cored wire Φ =1.6 mm
- Filler wire speed: 48 cm/min
- Welding speed: 13.8 cm/min
- Shielding gas type: Ar=82%, CO_2=13%, He=5%
- Shielding gas flow rate: 10 L/min and 30 L/min

Table 6 – Capture efficiency – Torch A – Cornu *[Ref. 22]*

Torch	**Curve** f[Q(ex)]	**Shield Gas Q(sh)** (L/min)	**Welding position AWS(EN)**	**Capture Efficiency at** Q(ex)=40 m^3/h	**Capture Efficiency at** Q(ex)=90 m^3/h
A	**1**	10	1G(PA) - Torch 90°	80%	98%
A	**2 (*)**	10	1G(PA) - Torch 90°	62%	88%
A	**3**	30	1G(PA) - Torch 90°	38%	96%
(*) Horizontal air draft with 0.5 m/s velocity measured at torch head level.					

The behaviour of Torch A shows (**Figure 30** - curve 1) that the average capture efficiency enhances when increasing the exhaust flow rate up to the value of Q(ex)=90 m^3/h.

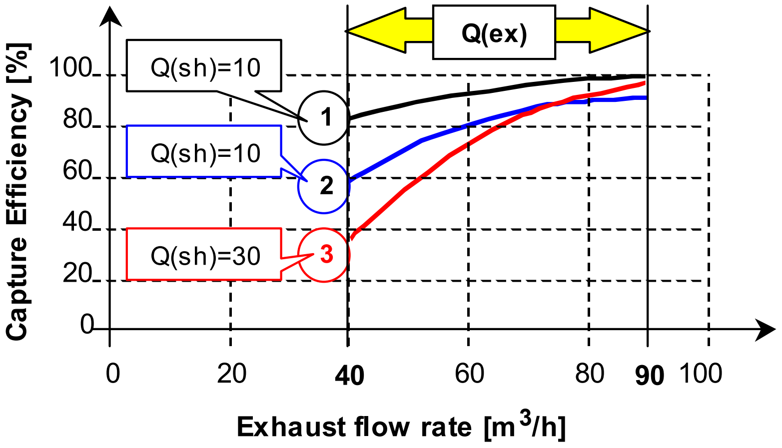


Figure 30 – Capture efficiency Torch A - Cornu Tests

The torch vertical position is ideal for the best capture performance, because the exhaust orifices are symmetrically placed around the fusion bath and the fume plume. When an air draft at 0.5 m/s is imposed (**Figure 30** - curve 2), the capture efficiency is lower and the loss becomes more significant when decreasing the exhaust flow rate. A high shield gas flow rate (**curve 3**) has the consequence to spread part of the fume plume away from the suction field of the exhaust orifices. This effect is moderate when Q(ex) is large (80-90 m^3/h), while decreasing the suction flow rate a large amount of fumes escape from the exhaust field, thus lowering the torch capture efficiency.

Cornu tested a second model of suction torch (Torch B) both in manual and automatic welding (**Figure 31** – welding positions 4-5-6).

Cornu's results of trials on Torch B are summarized in the **Table 7** and **Figure 32** (curve 4-5-6). The welding parameters and conditions for Torch B are the same used for Torch A, with the exception of absence of air draft and the shield gas flow rate set at 16 L/min in all the trials.

Table 7 Capture efficiency – Torch B – Cornu *[Ref. 22]*

Torch	**Curve** f[Q(ex)]	**Shield Gas Q(sh)** (L/min)	**Welding position AWS(EN)**	**Capture Efficiency at** Q(ex)=40 m^3/h	**Capture Efficiency** at Q(ex)=90 m^3/h
B	**4**	16	1G(PA) - Torch 90°	88%	90%
B	**5**	16	2F(PB) - Torch 90°	72%	80%
B	**6**	16	1G(PA) pipe - Torch 60°	38%	78%
B	**7**	16	5G(PF) up pipe - Torch 80°		84%
Note: All tests are performed in still air environment (no cross draft).					

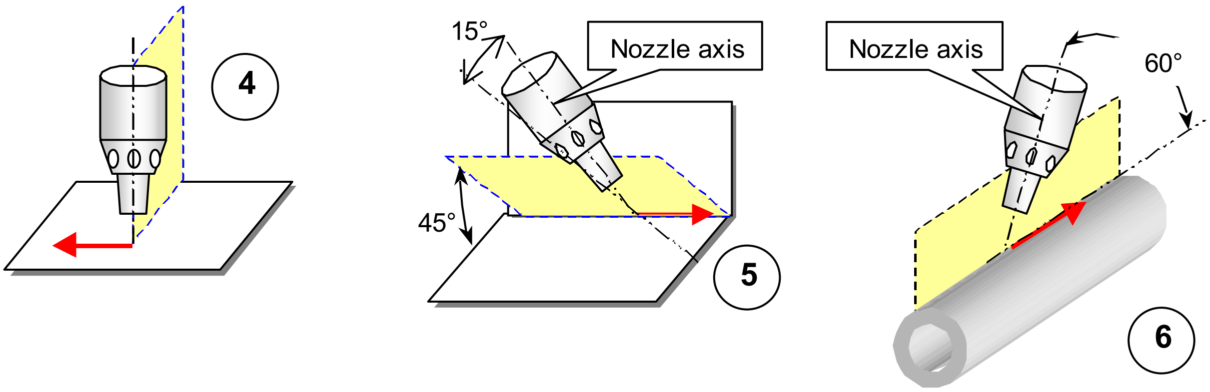


Figure 31 – Welding positions for Torch B from Cornu Tests

Figure 32 shows the results for Torch B. The **curve 4** is related to an automatic welding on flat position (position PA) and shows that the average capture efficiency is quite independent from the exhaust flow rate Q(ex).

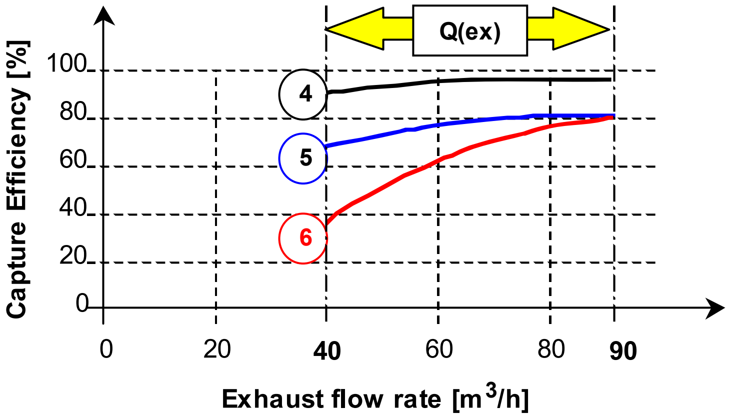


Figure 32 – Capture efficiency - Torch B - Cornu Tests

The manual welds (**Figure 32** - curve 5 and 6) has been performed in configuration which cannot be realized on a bench test, in order to investigate the effect of joint configuration on the welding area and the relative position of exhaust openings in respect to the fume plume.

Two joint configuration have been studied:

- Horizontal welding bead inside a fillet weld (welding position 2F-PB curve 5)
- Welding bead on the upper contour of a cylinder with Φ=115 mm (welding position 1G-PA curve 6)

The **curve 6** shows that the capture efficiency of torch B is less than that measured on flat position (**curve 4**) and horizontal position (**curve 5**). The behaviour of **curve 5** can be ascribed to the positive influence of confinement between the fillet walls which is more important than the negative effect of the torch inclination in comparison with the arising fume plume. On the contrary, **curve 6** shows that both the absence of confinement and the torch inclination has a very important and negative effect on the poor capture efficiency.

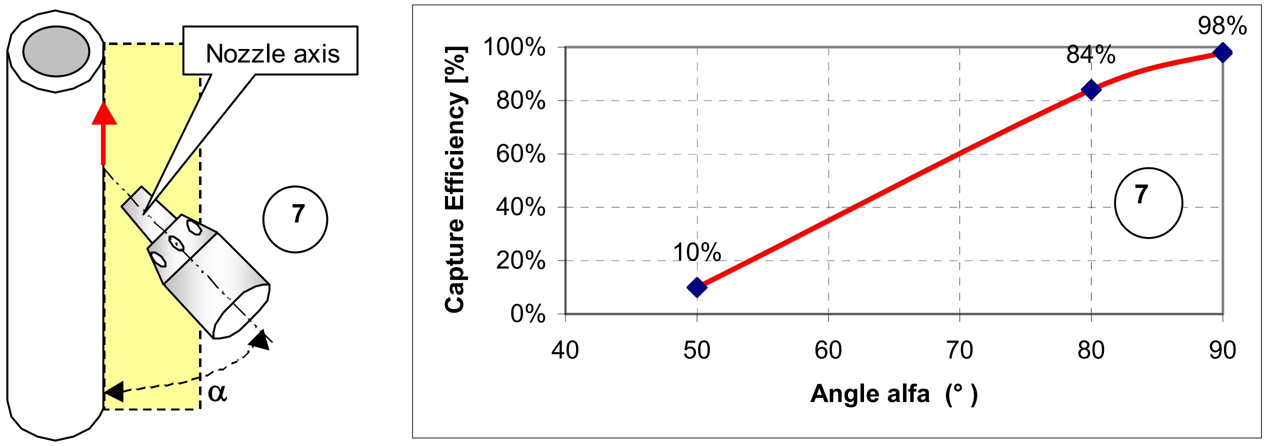


Figure 33 – Capture efficiency for Torch B from Cornu Tests (position 5G-PF)

Cornu tested the same Torch B (**Figure 33**) in welding trials performed on vertical up position (welding position 5G-PF) on the lateral contour of a cylinder with Φ=115 mm (**curve 7**).

During the ascending path, the welder forearm position has been continuously modified and the torch inclination angle has been changed from 80° to 50°.The capture efficiency is shown rapidly decreasing while the suction openings depart from the ascending fume plume.

Cornu concluded that there were some differences in performance between the two torches and that capture efficiency is affected directly by suction flow rate. Measurements on flat plate always gave higher efficiency. Both welding position and shape of part have a significant affect on capture efficiency. The **Figure 34** summarizes the results of min-max capture efficiency ranges investigated at the French Institute.

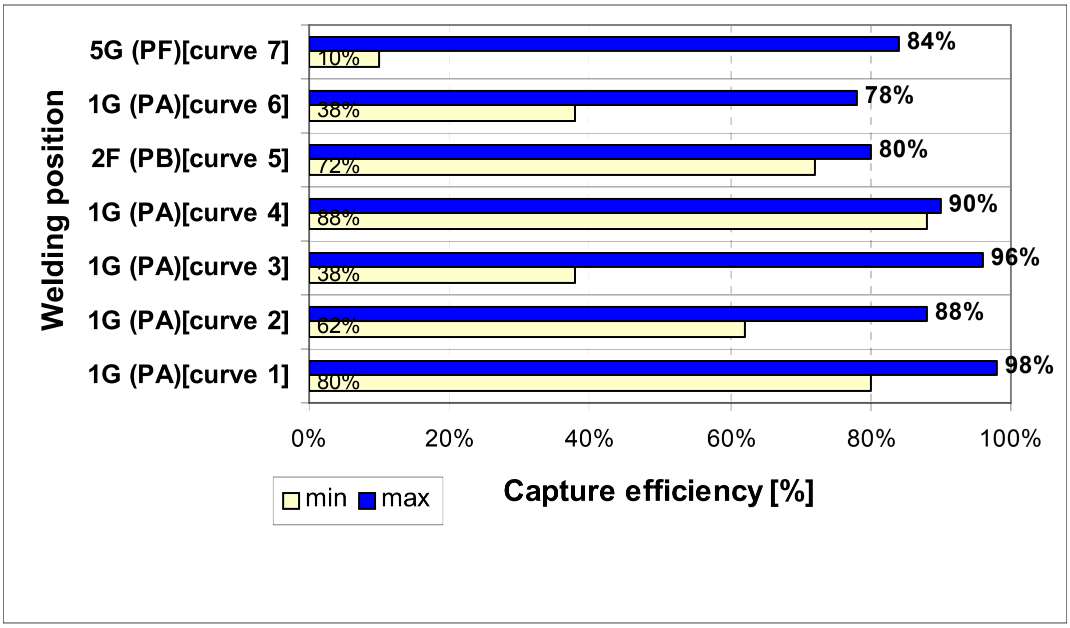


Figure 34 – Capture efficiency: min max ranges from Cornu tests

3.2.5 Research at Institut de Recherche en Santé et en Sécurité du Travail (IRSST)

Perrault et al. *[Ref. 32]* carried out a study to compare the fume collection rates of commercial suction torches in the laboratory and in industry with a fume collector which is comparable to the generation rate of the measuring system. An ergonomic study was also carried out to briefly explore first the muscular load imposed on the shoulder, elbow and wrist in relation to the type of suction torch, and second a few indices of the subjective acceptability of the welding tools by welders *[Ref. 33]*.

The tests were performed under standard welding conditions, as follows:

- Solid wire: E71T-1, Φ=1.6 mm
- Shielding gas type: 100 % CO_2
- DC electrode positive, with a constant potential power source
- Contact tip-to-work distance: 19 mm
- Sampling time: 2 minutes
- Welding Parameters: approximately 300 A and 26 V

Welding fume generation rates were measured in a fume chamber of the type already described in the technical literature *[Ref. 34]*. A professional welder carried out all the welding tests. During the preliminary tests at the start of each series of tests, the welder checked that the welding equipment was operating properly, and the exhaust flow rate did not cause any defects or porosities on the weld bead. This suction flow was maintained for the entire operation.

The welding position was maintained with an angle of 30° to the vertical (bead on plate, position PA, **Figure 35**).

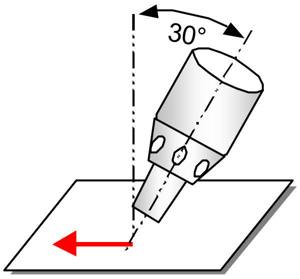


Figure 35 – Welding position – Flat bead on plate – IRSST Tests

When the fume collection rate was measured with the exhaust ON, the shield gas flow rate was increased to maintain the weld quality.

The collection rates for the total fumes emitted by the suction torches operating under standardized laboratory conditions are given in **Table 8**.

Table 8 - Capture efficiency under laboratory conditions – IRSST *[Ref. 32]*

Torch	**Shielding Gas**	**Current (A)**	**Average Total Fume Q(ex)=OFF**			**Average Total Fume Q(ex)=ON**			**Capture Efficiency**
			G/kg	S.D.	Tests	g/kg	S.D.	Tests	
1	CO_2	300	12.9	0.9	30	12.1	2.8	30	94%
2	CO_2	300	11.6	0.8	30	11.9	1.4	14	100%
3	CO_2	300	12.1	0.9	29	12.5	2.6	30	100%
S.D. = Standard Deviation - Capture efficiency under laboratory conditions – IRSST									

The results indicate no statistically significant difference between the generation rates without suction and the collection rates with suction measured in the laboratory. Under standardized welding conditions, the extraction systems at source for the 3 welding torches collect the same quantity of fume during welding inside a hood. Assuming that the initiation of suction at source has no effect on the generation rate value, it can be concluded that these suction systems collect all of the fumes emitted. However, the standard deviations for the collection rates are generally higher than those for the generation rates. The necessary increase in the shielding gas flow rates, to maintain the weld quality during extraction at source, may have produced turbulence near the welding torch, which results in a slight dispersion of the results of each test.

During field trials in industrial workshops, an identical procedure was proposed to the welders on the premises who were carrying out their usual task. The position of the electrode in relation to the pieces to be welded varied with the job requirements.

Table 9 - Capture efficiency in two industrial sites – IRSST *[Ref. 32]*

Torch	**Site**	**Shielding Gas**	**Current (A)**	**Average Total Fume Q(ex)=ON**			**Capture Efficiency**
				g/kg	S.D.	Tests	
1	**A**	CO_2	300	7.0	2.6	25	54%
	B	CO_2	300	6.9	1.2	29	53%
2	**A**	CO_2	300	10.9	3.1	28	94%
	B	CO_2	300	10.1	2.0	30	87%
3	**A**	CO_2	300	11.5	3.0	29	95%
	B	CO_2	300	9.5	2.2	29	78%
S.D. = Standard Deviation - Capture efficiency in 2 industrial sites – IRSST							

Table 9 indicates the collection results in two different industries (Site A and B). The results indicate that the differences in the collection rates are not statistically significant. In addition, the standard deviation is of the same order as in laboratory with aspiration at source. The normal operating conditions in these two industries did not change the distribution of the results.

Under these experimental conditions, the aspirating systems of the welding torches gave a lower collection rates in industry than under standardized operating conditions in the laboratory, namely 54% for Torch 1, 87% for torch 2 and 78% for torch 3. The differences in performance between the welding torches result from the welding equipment and not from the facilities or the modes of operation (**Figure 36**).

It can be concluded that the capture efficiency of the welding torches is excellent (approximately 100%, accurate to within the experimental errors). The collection rates measured in 2 industrial sites were 12 to 46% below the generation rates in laboratory, and this requires an accurate measurement of the generation rate in industry. However, the decreased efficiency was reproduced in two different industries with different welders.

The biomechanical evaluations do not reveal any contraindication regarding the use of any of the welding torches under investigation.

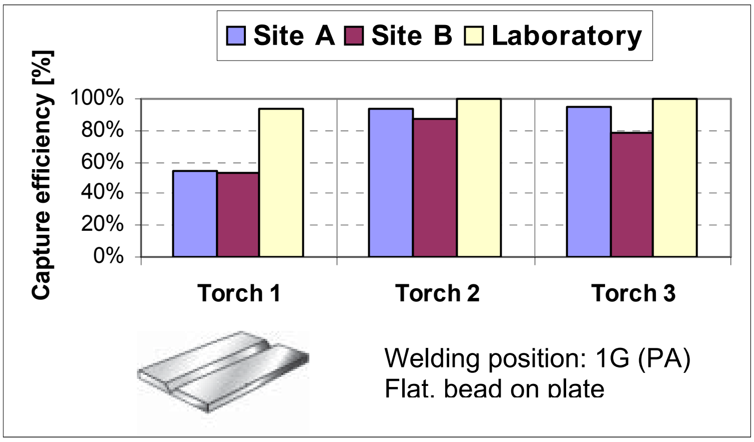


Figure 36 – Capture efficiency ranges - IRSST tests

3.2.6 Research at Edison Welding Institute (EWI)

Under the National Shipbuilding Research Program, Advanced Shipbuilding Enterprise (ASE), a project has been undertaken for Welding Panel to develop a lightweight fume extraction welding torch for shipyard use.

The Edison Welding Institute, with participation of five mayor shipyards, two welding equipment manufacturers, and several other organizations, evaluated five fume extraction welding torches of commercial production, developed a prototype torch which incorporates ergonomic engineering to improve usability, and evaluated this experimental torch during shipyard trials *[Ref. 35]*.

Five fume extraction torches were obtained from three manufacturers for usability evaluation and compared to five conventional torches for a range of ergonomic factors. Three of the fume extraction torches also were evaluated for fume capture efficiency (**Figure 37**).

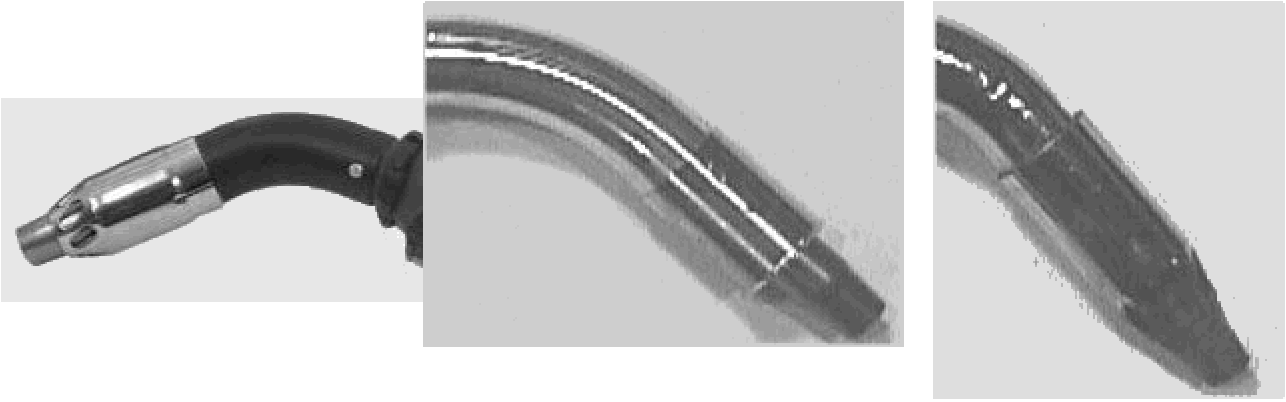


Figure 37 – Capture nozzle of three torches evaluated by EWI *[Ref. 35]*

The technique adopted for determining the capture efficiency was the measurement of total fume using the standard AWS fume generation rate test *[Ref 36]*. The test chamber was calibrated by making welds at 24, 26, 28 arc volts. The measured results should be within 10% of the standard calibration values to confirm that the fume chamber is operating correctly.

The conical test chamber is built so that the welding torch may be positioned to weld in the flat position. An air gap of 13 to 19 mm was maintained between the base of the chamber and the surface on which it rests.

Welding fume was drawn through the filter by an air pump rated at 42 to 60 m^3/h, and a pressure differential of 0.74 to 1.24 kPa. The filter was placed in an oven set between 93 and 107ºC. The filters were removed from the oven and weighed prior to starting the fume test. Immediately after the test the filter was weighed again.

The amount of fume captured in the filter is equal to the difference in weight of the filter before and after the test. Dividing the fume collected by the welding time gives the fume emission rate (FER) in grams per minute (g/min).

The fume emission rate of the process was measured using each of the three fume extraction torches tested with no vacuum flow to establish the baseline FER. Then each torch was tested using the low setting of the fume extractor and finally using the high setting on the fume extractor. The vacuum pump used for the tests with all three torches had two settings, low and high, and with a maximum rating of 84 m^3/h at a pressure of 15.0 kPa .

As the performance of fume extraction torch depends strongly on welding position, the AWS chamber test was modified slightly to determine the effect of welding position. The flat position test was performed on the surface of the plate. A tube (Φ=102 mm) was tacked on the square plate.

A horizontal fillet weld was made between the plate and the tube, and an overhead fillet weld was made by turning the specimen upside down. Finally, a horizontal bead-on-plate weld could be made on the cylindrical surface of the tube. This welding position simulated vertical welding.

One series of test welds were made at the standard AWS welding conditions (wire feed speed 760 cm/min, approximately 225 A and 26 V). These parameters produce a weld bead size that was too large for the out-of-position tests so the parameters were reduced until the current was approximately 125 A. These parameters were maintained for all subsequent tests.

Three tests were performed for each combination of welding torch, welding position, and vacuum setting and the results averaged to obtain the fume emission rate. It is apparent from comparing the tests that no significant changes in torch capture efficiency can be attributed to the change of current.

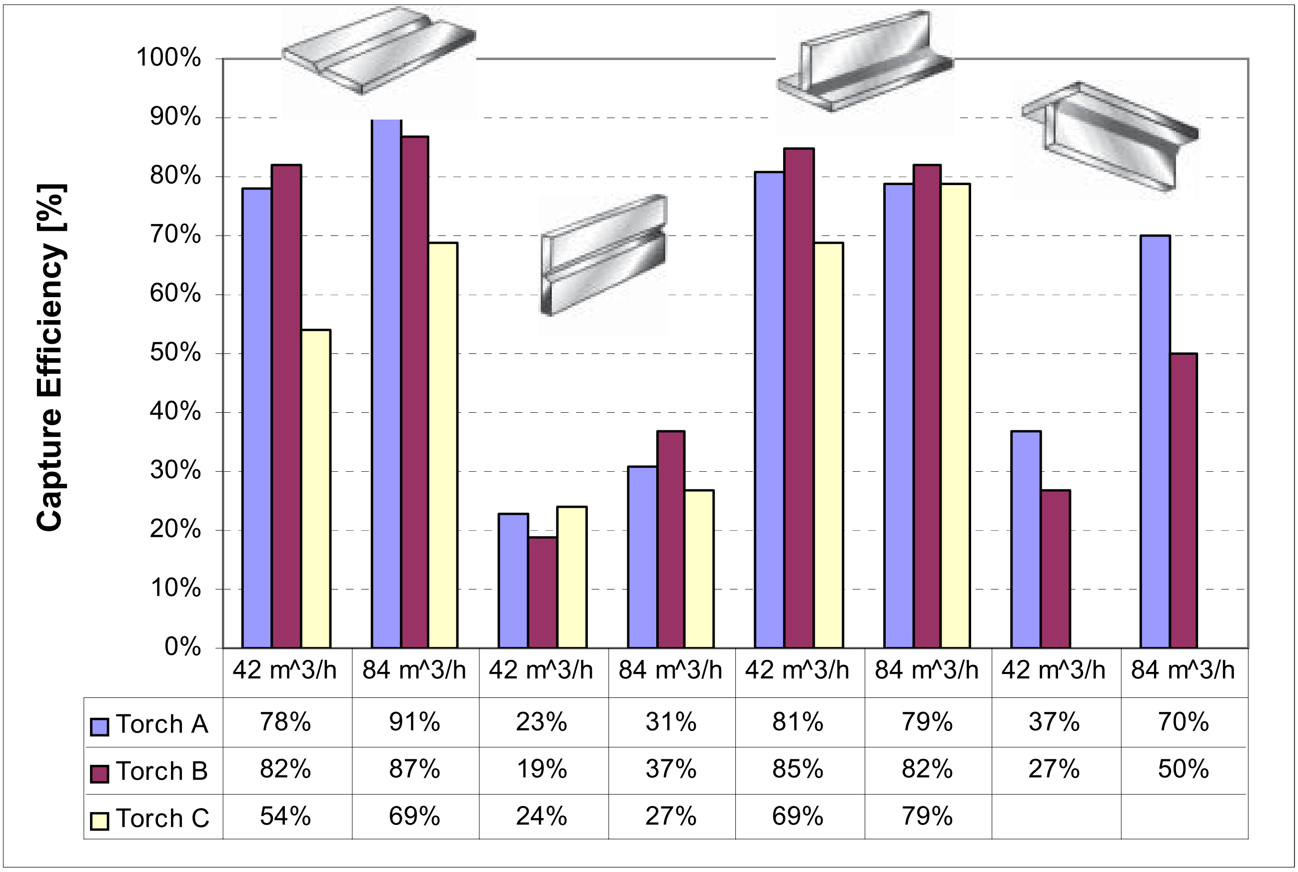
The results of capture efficiency of the three fume extraction torches are presented in **Table 10** and in **Figure 38**.

Table 10 - Capture efficiency tests – EWI *[Ref. 35]*

Torch	Welding position AWS(EN)	Capture Efficiency at Q(ex)=42 m^3/h	Capture Efficiency at Q(ex)=84 m^3/h	Test Conditions
A	1G(PA)	71%	83%	AWS conditions (I ≈ 225 A)
A	2F(PB)	77%	84%	AWS conditions (I ≈ 225 A)
A	2F(PB)	81%	79%	Lower current (I ≈ 125 A)
A	2G(PC)	23%	31%	Lower current (I ≈ 125 A)
A	1G(PA)	78%	91%	Lower current (I ≈ 125 A)
A	4F(PD)	37%	70%	Lower current (I ≈ 125 A)
B	4F(PD)	27%	50%	Lower current (I ≈ 125 A)
B	1G(PA)	86%	87%	Lower current (I ≈ 125 A)
B	1G(PA)	77%	-	Lower current (I ≈ 125 A)
B	2F(PB)	85%	82%	Lower current (I ≈ 125 A)
B	2G(PC)	19%	37%	Lower current (I ≈ 125 A)
C	2F(PB)	69%	79%	Lower current (I ≈ 125 A)
C	1G(PA)	54%	69%	Lower current (I ≈ 125 A)
C	2G(PC)	24%	27%	Lower current (I ≈ 125 A)
Capture efficiency for 3 models of commercial torches – EWI				

From these tests it was concluded that:

1. Average fume extraction efficiencies of about 80% were obtained for torches A and B in the flat and horizontal fillet weld positions (PA and PB). Torch C produced somewhat lower capture rates. The overhead fillet weld (PD) gave the next best results, with efficiencies in the range 30 to 70%. Here the low and high vacuum settings produced different results. The worst performance was in the horizontal bead-on-plate position (PC), which also represents vertical welding, where the average capture efficiency was between 20% and 30%.
2. The variation in capture efficiency is clearly due to relative position of the fumes and the extraction nozzle. In the flat and horizontal fillet positions, the fume plume tends to rise towards the extraction system, where most of it is captured. In the horizontal bead-on-plate position (also representing vertical welds) the fume plume rises and escapes from the torch suction region before it can be captured by the extraction nozzle. In the overhead fillet position, some fume escapes, but more than half is captured when the extraction system is on its high setting.
3. Slightly higher capture efficiencies were generally obtained for the high vacuum setting of the fume extractor compared to the low setting.



	42 m^3/h	84 m^3/h	42 m^3/h	84 m^3/h	42 m^3/h	84 m^3/h	42 m^3/h	84 m^3/h
🟦 Torch A	78%	91%	23%	31%	81%	79%	37%	70%
🟪 Torch B	82%	87%	19%	37%	85%	82%	27%	50%
🟨 Torch C	54%	69%	24%	27%	69%	79%		

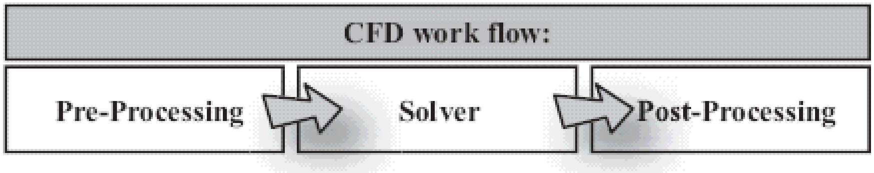
Figure 38 – Capture efficiency ranges from EWI tests

3.3 CFD Modelling: a New Approach to Fume Extraction Torches (2003 and after)

The Computational Fluid Dynamics (CFD) approach has been used to model many fluid flow situations including process plants and large-scale heating and ventilating systems *[Ref. 8]*.

The technique consists of first identifying a computational domain, which represents adequately the physical space in which the flow under examination takes place. The computational domain is then divided into a number of non overlapping sub-regions or cells. The differential equations for the conservation of mass, momentum and energy are integrated over each cell, and are converted into algebraic equations that can be solved numerically. The following flow chart well represents the three steps just described:

- Pre-processing: The first step of CFD analysis consists of several tasks. Defining the geometry of the region of interest, selecting the physical models to be considered, specifying fluid properties and boundary conditions, creating a mesh of control volumes.
- Solving: The main part of a CFD analysis is solving the governing equations. The partial differential equations for the flow quantities (velocity, pressure, energy, turbulent quantities and additional scalars such as contaminant concentration) - called the Navier Stokes equations - are integrated over the control volumes in the region of interest (flow domain). This is equivalent to applying a basic conservation law to each control volume. These integral equations are converted to a system of algebraic equations, which are solved iteratively.



- Post-processing: The third step of CFD analysis involves visualization of the results as e.g. vector plots, streamline plots or colored slices (maybe as animations) as well as quantitative analysis of the velocity or contaminant concentrations

Since any CFD simulation is only as good as the mathematical models that are supplied as input to the solver, it is always necessary to validate CFD results against physical experiments. The term "Validation" is often used for strongly differing things. Therefore, the definition of validation in the context of CFD simulations is given here as expressed by the AIAA 1 *[Ref. 37]*:

"The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model (AIAA, 1998)."

Validation has also been described as "solving the right equations". It is not possible to validate the entire CFD code. One can only validate the code for a specific range of applications for which experimental data are available. Thus one validates a model or a simulation. Applying the code to flows beyond the region of validity is termed "prediction". Validation examines if the conceptual models, computational models as implemented into the CFD code, and computational simulation agree with real world observations. The strategy is to identify and quantify errors and uncertainty through comparison of simulation results with experimental data. The accuracy required in the validation activities depends on the application, and so the validation should be flexible to allow various levels of accuracy.

3.3.1 National Institute of Industrial Health – Kawasaki – Japan - Ojima

Under the notification of general prevention of dust hazards issued by the Japanese Ministry of Health, Labour and Welfare (2003-2007), a fume exhaust torch system was recommended as an effective ventilation device for welding fume control. In addition, a fume exhaust torch is superior to the other ventilation systems in applicability. Unlike the fixed hood of a usual local exhaust ventilation system, a fume exhaust torch has a hood, which does not limit the size of the workpiece and welder's mobility because the hood is always close to the arc point and does not require laborious re-positioning or adjustments.

Ojima in a series of investigations for fume reduction in workplace *[Ref. 38, 39]* describes the development of an ordinary fume exhaust torch system *[Ref. 40]*, consisting of a welding torch integrated with a suction hood which exhausts the fume plume around the welding arc, a fume collector and a flexible duct connecting the hood to the collector (**Figure 39**).

The torch performance is affected by the geometry of the weld joint and the shielding gas flow rate.

In this study the author investigated the effects of welding position, elevation angle of weld line and shielding gas flow rate on fume capture performance.

The torch arrangement was an adapter type: the torch was arranged with a circular opening exhaust hood (42 mm diameter, 60° taper). A 26 mm diameter flexible exhaust duct was attached to the side of the hood.

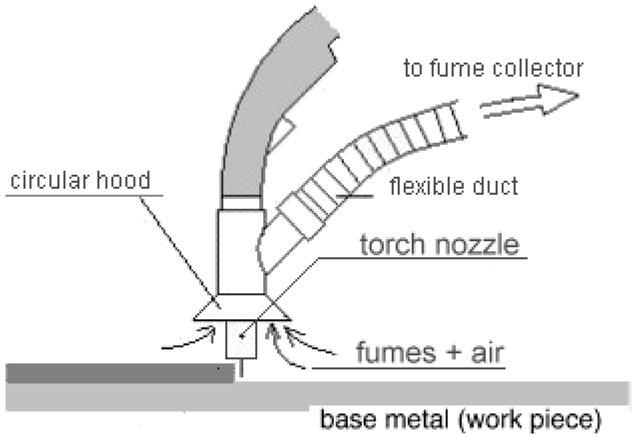


Figure 39 – Fume exhaust arrangement by Ojima *[Ref. 39]*

The fume collector system was characterized by:

- Static pressure: 19.6 kPa
- Face velocity at hood opening: 2.7 m/s
- Arc point velocity: 1,5 m/s
- Exhaust flow rate: 5.7 m^3/h

The test were performed in laboratory robotic CO_2 welding, with the main features:

- Wire filler: 1.2 mm solid wire (JIS Z 3312)
- Shielding Gas type: 100 % CO_2
- Shielding Gas flow rate: 20 L/min
- Welding speed: 20 cm/min
- Welding current : 100 A
- Arc on time for each sampling: 1 minute

Ojima investigated the following welding positions (**Figure 40**):

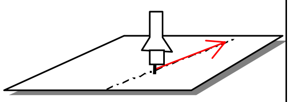
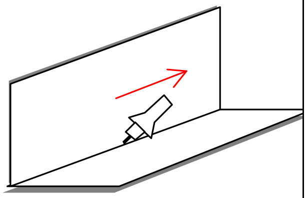
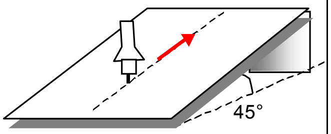
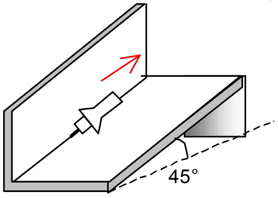
Flat, PA	Horizontal fillet, PB	Flat, PA up	Horizontal fillet, PB up
			
Code: PA (0°)	Code: PB (0°)	Code: PA (45°)	Code: PB (45°)

Figure 40 – Fume exhaust arrangement by Ojima *[Ref. 39]*

Table 11 - Capture efficiency at breathing zone (30 cm above arc point) – Ojima *[Ref. 39]*

Position Code	**Shielding Gas (*)**	**Current (A)**	**Average Total Fume Q(ex)=OFF**			**Average Total Fume Q(ex)= 5.7 m^3/h = ON**			**Capture Efficiency**
			mg/m^3	S.D.	Tests	mg/m^3	S.D.	Tests	
PA (0°)	CO_2	100	78.6	16.6	10	10.8	2.8	10	94%
PB (0°)	CO_2	100				20.1	5.2	10	100%
PA (45°)	CO_2	100				28.8	8.5	10	100%
PB (45°)	CO_2	100				29.1	4.1	10	100%

S.D. = Standard Deviation (*) Shielding gas flow rate = 20 L/min

The results (**Table 11**) show that the fume concentration at the breathing zone (30 cm above arc point) reached 78.6 mg/m^3, but a remarkable reduction could be obtained with the fume exhaust torch provided that the torch angle was set vertically. Although the torch could not achieve a personal exposure level below the OEL in Japan (1 mg/m^3), the respirable fume concentration was reduced to approximately 14% (10,8 mg/m^3) of the concentration of the non ventilation condition when the torch was applied to a horizontal (0°) weld line in the flat position (PA).

Comparing the results of layouts PA and PB (**Figure 41**), it became clear that the performance of the torch varied depending on the welding position. The capture efficiency was less in horizontal fillet position than in flat position. This means that the torch is more effective when it is angled vertically downwards. However, when the weld line was inclined at 45°, an obvious effect of welding position was not recognized since there was no significant difference in the fume levels between layouts PA(45°) and PB(45°).

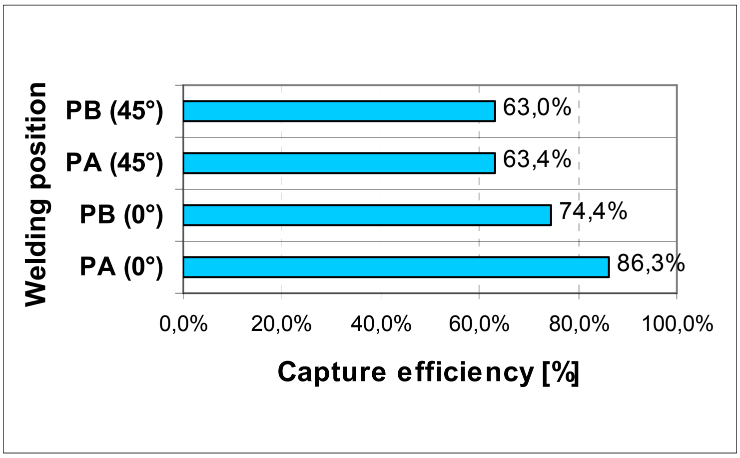


Figure 41 – Capture efficiency - Ojima *[Ref. 39]*

Comparing the results, an increase in the elevation angle of the weld line seemed to lower the torch performance. This is due to the fact that the fume plume tends to ascend along the base metal when the weld line is inclined and leaks out from the suction zone of the hood. Therefore, it could be concluded that the torch is most effective when the hood is centred directly over the arc point.

Figure 42 shows the relation between the shield gas flow rate and the fume concentration at the breathing zone. The fume level, when setting the layout PA(0°), was hardly affected by the fluctuations of the shield gas flow rate, provided that the flow rate was less than 30 L/min.

When the flow rate was over 30 L/min, the exhaustion was certainly impaired and the fume concentration rapidly increased with increase of the flow rate. In contrast, when the flow rate was reduced to 10 L/min, visible porosities were found on the surface of the weld metal due to the deficiency of the shield gas. Therefore, in order to avoid high level fume exposure and welding defects, the flow rate of the shield gas ought to be 15-25 L/min (16-26% of the exhaust flow rate) at a welding current of nearly 100 A.

The practical disadvantages of this system are its weight and bulkiness owing to the additional hood and flexible duct for exhaustion.

According to a questionnaire conducted by the Japan Welding Engineering Society, the fume exhaust system is still not widely used in Japanese industry because of its practical disadvantages. Suspending the torch by a mobile boom can take the weight off the torch, thus increasing welder's mobility and mitigate fatigue.

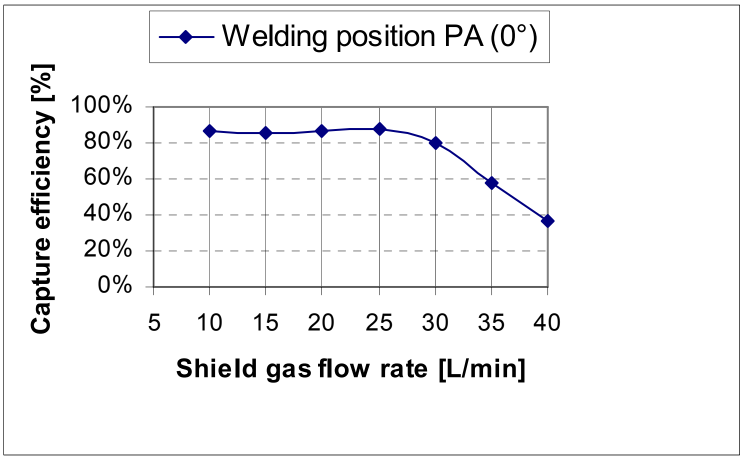
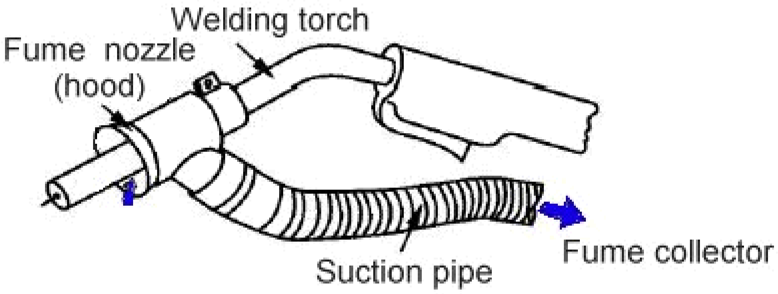


Figure 42 – Effect of shield gas flow rate on capture efficiency (PA position Torch = vertical)

3.3.2 National Institute of Industrial Health – Kawasaki – Japan - Iwasaki

Iwasaki *[Ref. 41]* describes the development of an ordinary fume exhaust system as described by Ojima, performing some investigations on capture efficiency by CFD modelling. The nozzle is coaxial with the torch and a variety of nozzle designs were evaluated. **Figure 43** shows the fume collecting torch with a plain bell mouth opening; by this kind of hood, almost all fumes near the welding torch can be captured.



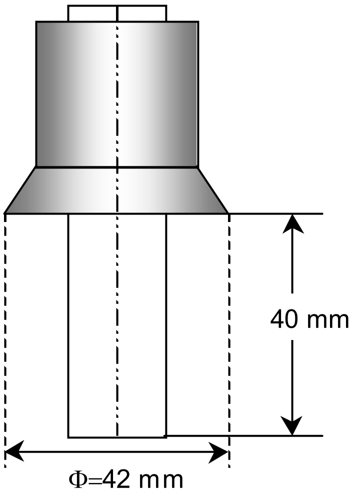


Figure 43 – Fume collecting torch (left) - Plain bell mouth extraction nozzle (right)

When operated with an exhaust air volume 120 m^3/h, the capture velocity near arc point was measured as about 0.5 m/s. **Figure 44** (left) shows the air velocity near the hood opening obtained by computational fluid dynamics (CFD) analysis based on the velocity measurements around a hood opening of the fume collecting torch.

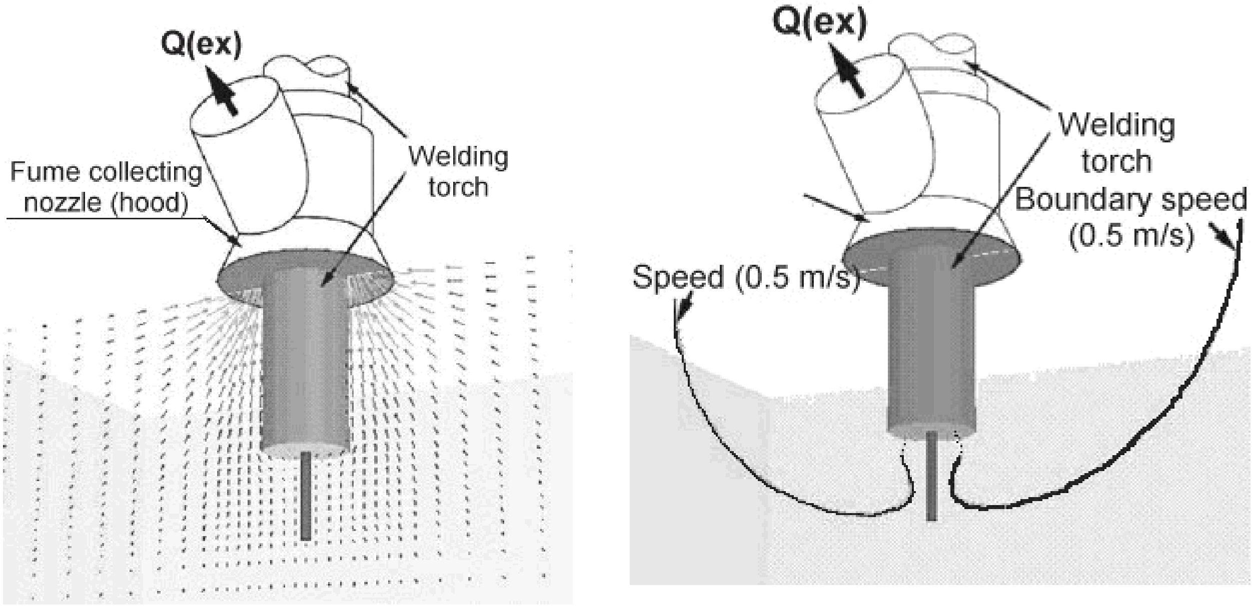


Figure 44 - Velocity vectors near the hood opening (left) – Velocity contour at 0.5 m/s (right)

The contour line in **Figure 44** (right) shows a velocity of 0.5 m/s near arc point obtained by the CFD analysis as well. This contour line of 0.5 m/s drawn near arc point was almost coincided with the measured value. In addition, by this air velocity, no blowhole was seen in the weld metal.

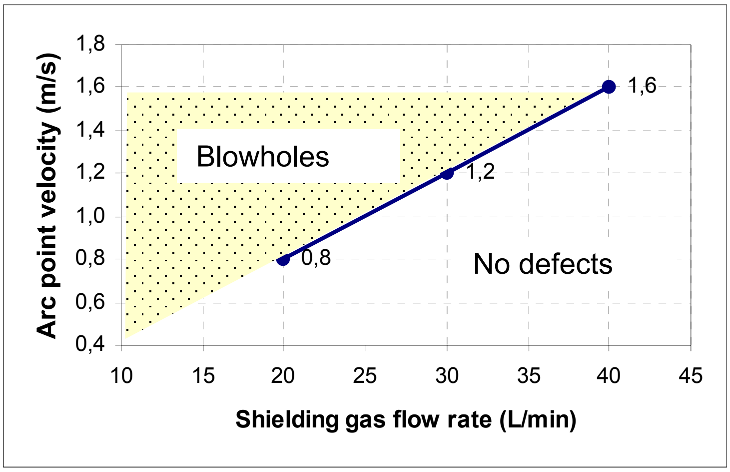


Figure 45 – Arc point velocity vs. shield gas flow rate - Boundary at which welding defects occur

When used in the robotized welding process at a car manufacturing factory, this fume collecting torch showed an adequate capture efficiency. When welding fume collector was not operated, the fume concentration was 2.33 mg/m^3 and when operated it went down to 0.25 mg/m^3 thus achieving a 90% reduction of fume concentration at welder's breathing zone.

Figure 45 shows the relationship between the uniform stream air velocity at the arc point and the welding quality (by radiographic examination) when the CO_2 gas flow rate was changed.

When the shielding gas flow rate is 20, 30 and 40 L/min, blowholes occur at a uniform stream air velocity of 0.8, 1.2 and 1.6 m/s respectively. From the results mentioned above, it can be concluded that the extraction rate must assure air velocity at arc point in the range of about 0.5-0.7 m/s.

The recommended value of air stream velocity is within 0.3-0.7 m/s, which reduces fume concentration at the welder's breathing zone below the occupational exposure limits without any production of blowholes or defects.

3.3.3 University of Wollongong – Australia – Norrish et al.

Following earlier works *[Ref. 7, 42]*, which indicate excessive breathing zone fume exposure in still air conditions, many experimental investigations were therefore undertaken in Australia, at School of Mechanical Materials and Mechatronic Engineering, University of Wollongong to determine the natural fume distribution and the resultant breathing zone exposure for gas metal arc welding.

The trials were carried out in a controlled space with various ventilation and exhaust strategies and the effect of these engineering controls was assessed. In addition an attempt was made to model and simulate the fume distribution. It was established, as expected, that unacceptable exposure was seemingly in a confined space without adequate ventilation and the most effective control measure was local ventilation (LEV) adjacent to the welding torch. Uniform cross draughts of 0.7m/s were required to reduce the particulate fume levels to within acceptable limits.

In addition, saline solution scale model experiments have been carried out to determine the qualitative effect of the shielding gas on the initial dispersion of the fume plume above the workpiece. The main result of including the effect of the shielding gas is that the effective radius of the source of fume is significantly increased *[Ref. 43, 44, 45]*, which has important implications for the probable dispersion of the fume into the welders breathing zone.

Indeed, in GMA process the intense heat of plasma column in the arc causes some of the molten filler to evaporate, and oxygen in the ambient atmosphere may further react with the metal vapours to produce metal oxide. The fume plume is formed in close vicinity to the arc weld pool area, and tends to be dispersed into the surroundings by the shielding gas. The extent of the radial spread of the impinging fountain model is crucial, as this determines the initial size of the buoyancy driven plume.

Whilst the metal vapour fume is generated in the vicinity of the arc and weld pool, it tends to be conveyed first by the wall jet (**Figure 46**), radially outwards (Coanda effect).

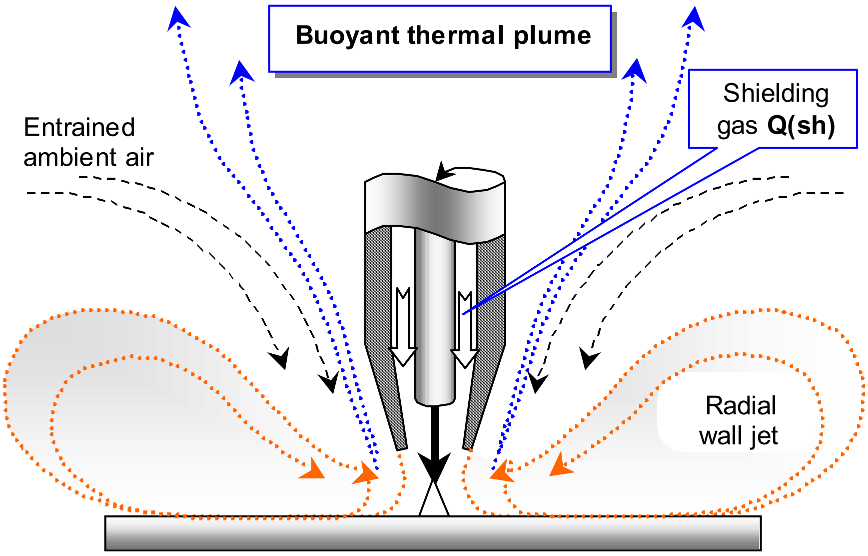


Figure 46 – Radial wall jet effect of shield gas flow field impinging on a flat surface (Coanda effect)

The shielding gas flow in the wall jet is retarded as it moves away from the arc region, mainly because the wall jet mixes with the surrounding air through the chaotic phenomenon of turbulent entrainment (plume dilution). At the same time the shielding gas is heated by contact with the hot arc and the weld pool. The density therefore is reduced and the horizontal flow is subjected to a vertical buoyancy force. Hence, as the flow proceeds outward along the surface, the vertical buoyancy forces become progressively more dominant over the horizontal inertial forces. This makes the flow change direction at a particular radial distance, resulting in a rising thermal plume which is buoyancy driven. This buoyancy driven thermal fume plume may be transmitted directly into the breathing zone of the welding operator.

CFD simulations were carried out for different extraction system configurations to facilitate comparison of their effectiveness in capturing the welding fume.

A typical set of operating dimensions was chosen by Norrish and his team, as summarized in **Figure 47**. The results presented in **Figure 48** do not account for the influence of complex phenomena that would influence the flow in the immediate vicinity of the arc, including metal vaporisation, movement of the torch relative to the workpiece, spatter, distortion of the weld pool surface from a horizontal plane, etc.

The CFD simulations have confirmed that the flow from a GMAW torch nozzle is fundamentally similar to the impinging fountain flow and have shown excellent agreement with previous fundamental studies by Cooper and Hunt *[Ref. 43]* on impinging fountains.

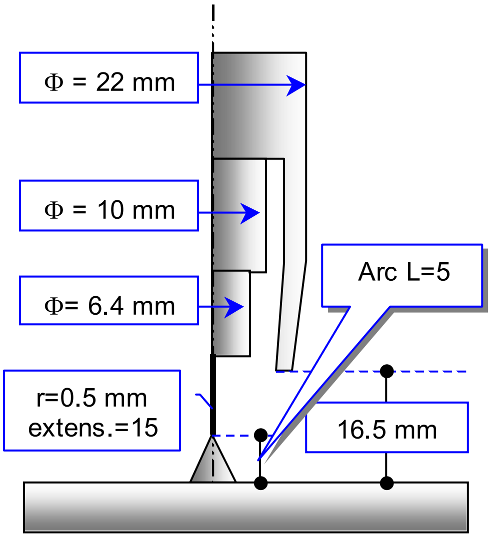


Figure 47 - Typical nozzle dimensions

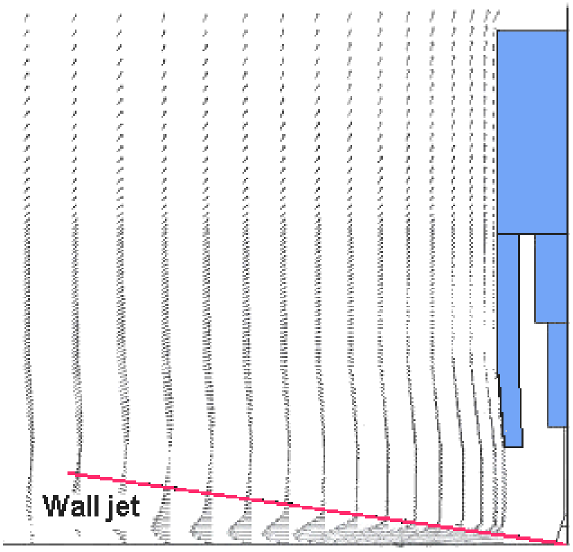


Figure 48 - Velocity vector field of shielding gas flow rated at Q(sh)=15 L/min

Attempts to capture the fume in the radial wall jet by means of an annular extraction sleeve placed around the GMAW nozzle of a conventional torch have been investigated by Norrish and his team using CFD simulations carried out for different extraction designs (**Figure 49**), to facilitate comparison of their effectiveness in capturing the fume plume *[Ref. 44, 45]*.

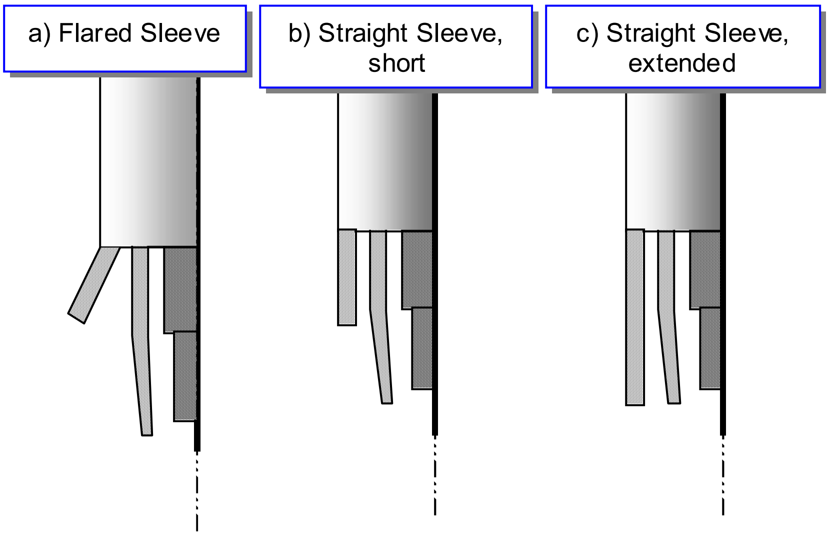


Figure 49 – Typical extraction nozzle designs

The flow fields in **Figures 50 and 51** demonstrate that the on-torch extraction through a concentric sleeve does not cause significant reduction in the concentration of the fume released into the ambient atmosphere, even with extremely high extraction flow rates, which would not be achievable in practice.

Figure 50 shows the corresponding shielding gas concentration field of an extended sleeve. Although some of the shielding gas is captured into the extraction sleeve, the shielding gas concentration in the arc/weld pool region appears to be high and relatively unaffected by the extraction flow. Increasing the extraction flow rate further, with a view to extracting more fumes, has the effect of short-circuiting the shielding gas flow from the nozzle, so that the concentration of shielding gas in the arc/weld pool region is depleted. This will have a detrimental effect on the weld quality.

It is seen that even with relatively large extraction volume flow rates (extraction velocity of order 10 m/sec), the flow in the wall jet remains predominantly radially outward. This radial flow carries the bulk of the fume with it, with the result that the extraction port will have little effect on the fume concentration in the breathing zone of the operator. This is clearly seen in the corresponding streamline plot shown in **Figure 51**. The suction port of the short sleeve is located too far away from the fume rich region of the flow field, and can only extract the ambient air, in preference to the fume.

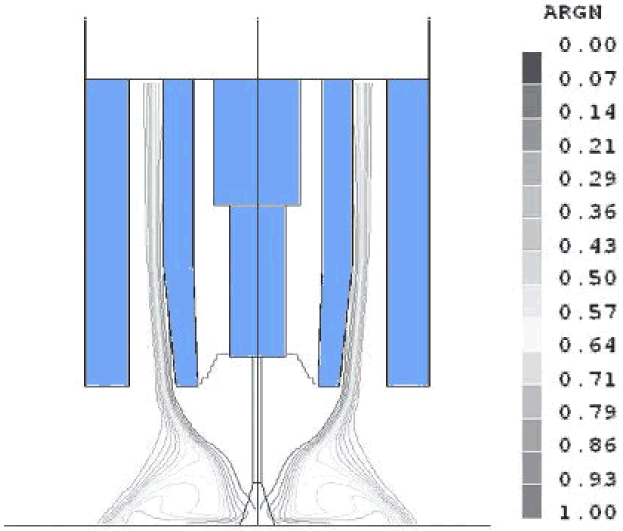


Figure 50 - Shielding gas concentration field at Q(ex) / Q(sh) = 6 (extended sleeve)

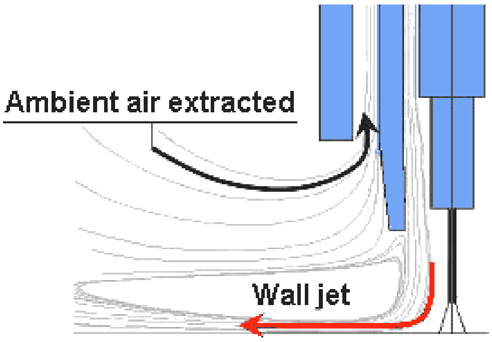


Figure 51 - Velocity vector field - Shielding gas flow rated at Q(sh)=15 L/min - Q(ex) / Q(sh) = 12.5 (short sleeve)

A summary of these CFD results on the fume capture efficiency as a function of the extraction flow rate is presented in **Figure 52** for two short sleeve designs which were investigated and modelled *[Ref. 46]*. These results show that the fume capture efficiency rises approximately linearly with extraction flow rate Q(ex), however, extremely high flow rates are required to achieve a useful fume capture efficiency.

The flared sleeve is somewhat more effective than the cylindrical straight sleeve. It is likely however that the higher extraction flow rates (of the order of 90 L/min) will draw away the essential shielding gas envelope from around the weld, thus adversely affecting weld quality, entraining air and potentially increasing fume generation.

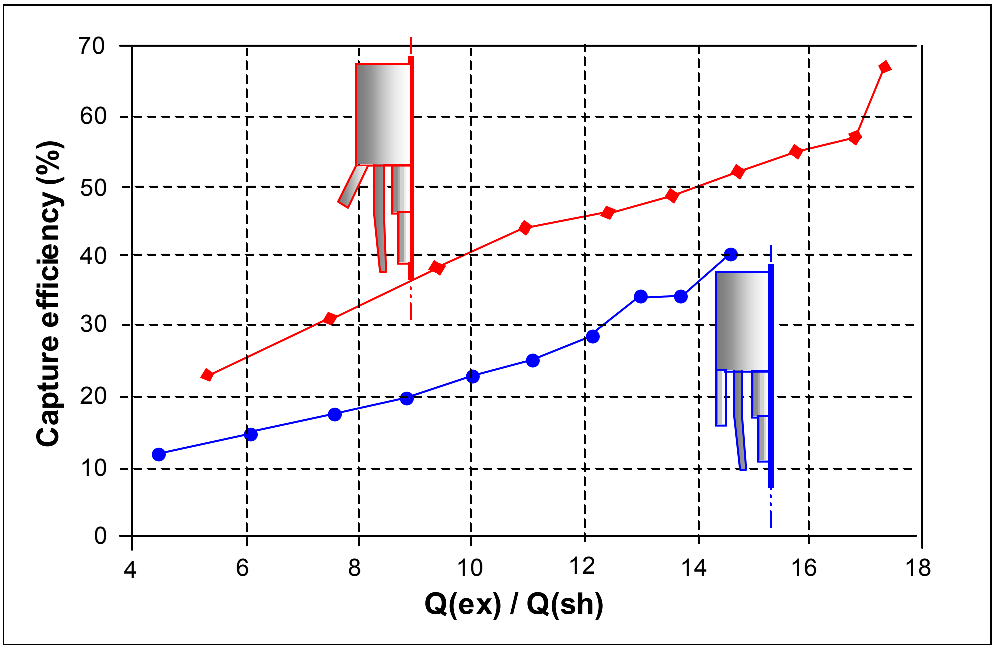


Figure 52 - Fume capture efficiency vs. normalized extraction flow rate Q(ex) / Q(sh) with Q(sh)=15 L/min *[Ref. 46]*

3.3.4 University of Wollongong – Australia – Patent Norrish et al.

The fundamental reason for the inadequacy of an external fume extraction sleeve surrounding the shield gas envelope is that a flow field which is created by virtue of the positioning of the work normal to the axis of the welding torch causes the formation of a radially outward gas flow along the surface of the work (wall jet) and this wall jet is not significantly affected by the external suction. Even with this strong suction it has been found that the flow in the wall jet remains directed radially outward.

This flow carries the bulk of the fume with it, with the result that the breathing zone of the operator is still likely to contain unacceptably high concentration of fumes.

According to applicants *[Ref. 19]*, their invention provides an arc welding torch having a welding electrode and one shield gas port adapted to direct a shield gas curtain around the electrode and welding pool, and another shroud gas port spaced radially outward from the shield gas port and adapted to impart to an exiting shroud gas a radially outward component of velocity (**Figure 53**).

The shroud gas port is preferably adapted to direct the exiting shroud gas in a radially outward direction (between 30° to about 90° with respect to the axis of the torch body). The torch includes an inner and an outer sleeve, circumscribing the torch, for defining there between a passage for the shroud gas, and the shroud gas port is positioned at or near the distal end of the passage.

The torch typically includes a fume gas extraction port adapted to receive fume plume from an area surrounding the welding pool. The fume extraction port is ideally positioned radially intermediate (a) the shield gas port and (b) the shroud gas port. The inner sleeve and the body of the torch define there between an extraction passage for fume plume extraction.

In one embodiment the shroud gas port and the shield gas port are concentrically coaxially located at spaced relationship around the welding electrode.

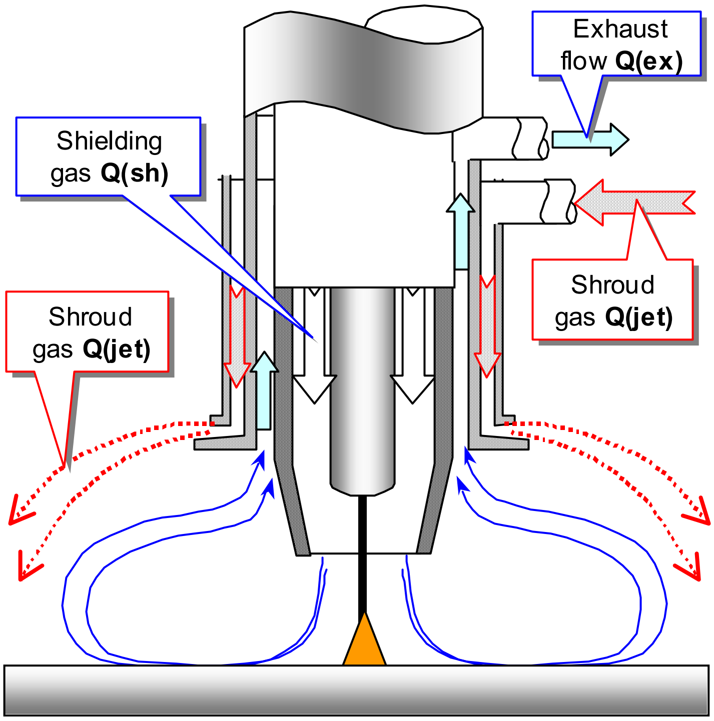


Figure 53 - Schematic extraction nozzle with radially directed shroud gas jet *[Ref. 19]*

Whereas, in the absence of the shroud gas port and the shrouding gas the wall jet continues in a radially outward direction, the applicants have found that by introducing a radially outward component of velocity to the shroud gas, when fume is extracted from the torch, the resulting wall jet flow is substantially contained and within the space around the weld pool shrouded by the shroud gas the direction of gas flow along the face of the work being welded is radially inwards. In other words, the shroud gas curtain tends to form an <u>aerodynamic flange</u> around the torch and the welding pool, thus isolating the fume rich region from the surroundings and allowing the fume gas to be extracted from within the envelope. As a consequence, improved fume extraction efficiency is achieved via the fume gas extraction port.

The shroud gas port can be axially adjustable relative to the shield gas port for allowing welder to fine tune the fume extraction efficiency. The torch also includes control means to adjust the flow rates of the shield gas, the shroud gas and the rate of fume gas extraction. The following features of the aerodynamic flange, created by the reinforced curtain of the shroud gas jet, are claimed to be innovative in the patent *[Ref. 19]*:

- The shroud gas jet is chosen from the group consisting of Nitrogen, Helium, Argon, Carbon Dioxide or their mixture. Since the shield gas provides sufficient protection of the weld pool from atmospheric contamination, compressed air may be used for the shroud gas in some circumstances.
- The shield gas flow rate may be about 5 to 50 L/min and the shroud gas flow rate about 1 to 50 L/min. The fume is preferably extracted from a location intermediate the heat source or shield gas curtain and the shroud gas curtain at a flow rate of between about 5 to 50 L/min. Typically the fume gas extraction flow rate is similar to the shielding gas flow rate, which the applicants has found is an order of magnitude less than the conventional fume extract systems to provide the same degree of fume extraction.
- Typically, the ratio of shroud gas flow rate to shield gas flow rate is chosen to be <u>2:1 to about 3:1</u>, while the ratio of fume extraction rate to shield gas flow rate is about <u>1:1</u>.
- The shroud gas and shield gas are generally supplied at room temperature, although this temperature is not critical. However, the shroud gas and/or the shield gas can be cooled sufficiently to promote fume <u>plume condensation</u>. Cooling assists condensation of the metal vapour to a fine particulate material thereby allowing improved extraction efficiency. Furthermore, cooling the shroud/shield gas reduces the temperature of the exhausted gas.
- An interesting opportunity can be achieved by mixing the shroud gas and/or shield gas with a <u>component reactive</u> with the welding fumes and/or a UV light absorbing component.

The applicants have used a commercial GMAW torch adapted according to the patent and configured with a wire Φ=1.2 mm, using Argoshield universal gas.

Welding parameters have been chosen to have high fume generation with typical welding current set at 250 A and welding voltage at 32 V.

The following distances have been used:

- Workpiece to torch nozzle distance = 22 mm;
- Workpiece to shroud gas curtain (radial jet) = 22 mm (for maximum efficiency) and 32 mm (for weld pool visibility);
- Radial distance between welding wire to shroud gas curtain (radial jet) outlet = 40 mm;
- Better than 85% fume removal was achieved with 22 mm radial jet stand off.

The optimum shroud gas flow rate appears to be a function of the shield gas flow rate, which is preferably 2:1 to about 3:1. Further, the fume gas is preferably extracted at a rate equivalent to the rate flow of shield gas. (**Figure 54**) In other words, a significant portion of the shield gas (bearing the fumes is extracted by fume gas extraction port and the shroud gas is mostly lost to atmosphere.

Typical set-up for test performed by Norrish and his team are:

- Shroud gas flow rate = 30 L/min
- Shield gas flow rate = 15 L/min
- Fume gas extraction rate = 15 L/min

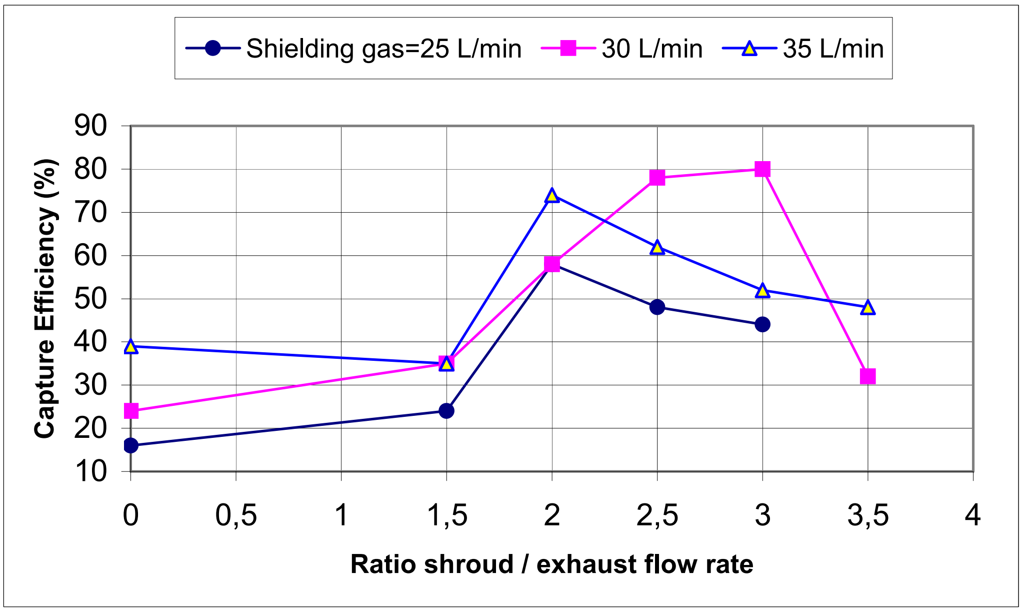


Figure 54 - Fume capture efficiency vs. ratio shroud to exhaust flow rate *[Ref. 19]*

3.*3.5* *Robotic torches*

The new welding torches for fume capture at source *[Ref. 9, 47]* are compact in design and can be used on both manual or robotic welding. Their collection nozzles (**Figure 55**) are strategically located above the welding nozzle for optimum capture of the welding contaminants. Dual or triple orifice openings remove the fume plume and related fragments close to the source before they have an opportunity to dissipate into the atmosphere. Out of position welding may result in insufficient fume capture: for best results, weld in the optimal positions with nozzle orifices directly placed over the welding process.

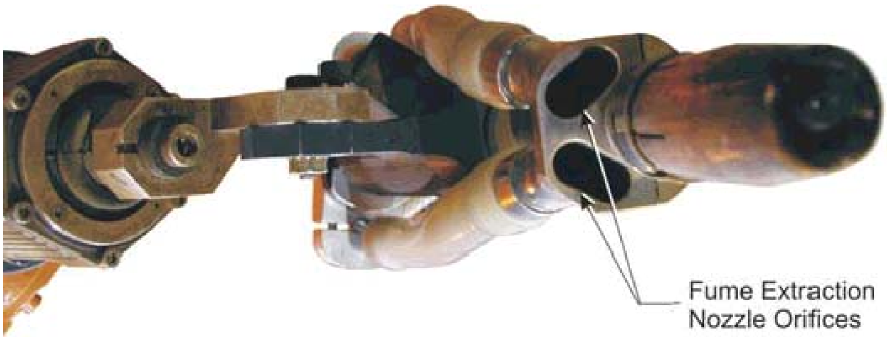
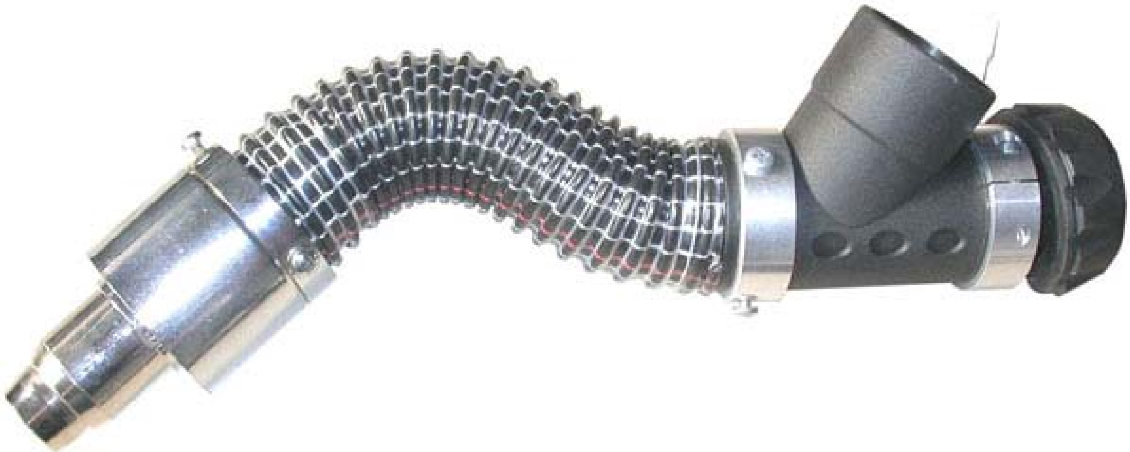


Figure 55 – Fume exhaust torches for robotic applications. Photo courtesy of Rimrock-Wolf Robotics Inc. – USA (upper) and Aspirmig Srl – Italy (lower)



The compact size of the components eliminates the need for a large fume extraction hood to cover the entire welding area that would require additional lighting and block access to the production area from overhead cranes for loading/unloading of components. The capture unit is small enough to be positioned nearby without interference and is easily maintained.

The welding torch capture device mounts to most welding torch model configurations and includes all the hoses and attachments required for operation. The components are small enough not to interfere with the cleaning process of automated torch cleaners on robotic welding systems and the replacement or servicing of consumables (i.e. welding torch nozzles and electrode tips).

Torch capture device components of both models include:

- Collector Nozzle - Attaches to welding torch neck and incorporates the fume nozzle collection holes.
- Extended hose collector tubes - Connects the mounting brackets to the torch fume collector nozzle.
- Mounting brackets - Attaches collector hose to welding torch with hose clamp.
- Suction hose - Flexible dual hose in assorted lengths depending on required reach of robot or manual welder.
- Hose reducer - Converts dual suction hoses into one hose adaptor for attaching to collection unit vacuum hose.

4 CONCLUSIONS

There are often problems associated with using conventional local exhaust ventilation hoods to control welding fume in the breathing zone of welder. The extraction hood requires continual re-positioning to keep it close to the arc. This re-adjustment is often thought by the welder to affect productivity, as it is an extra operation, and is therefore often not fully performed.

Integral fume extraction torches appear to be an attractive alternative to the use of an exhaust hood mounted on a conventional LEV device. However, there are problems with their application and use, as outlined in this report. Capture efficiency of fume extraction torches mainly depends upon:

- correct specification, selection and adjustment of extraction nozzle on the torch;
- efficient maintenance of the torch, including the fume extracting nozzle;
- welding position;
- weld joint configuration;
- performance of fume collecting unit;
- environmental conditions, e.g. draughts, confined workplace, etc.

There is a need to maintain a fine balance between extract air and shielding gas flow rates, especially for torches using a direct capture path. The goal is to achieve a good control of welding fume without stripping away the shielding gas, thus putting at risk weld quality. This is a delicate balance, sometimes hard to manage because shielding gases can often be stripped away due to draughts in and around the workplace, thus influencing fume capture capability. The effectiveness of on-torch extraction is influenced significantly by workplace and workpiece factors.

As welding fume is hot and therefore buoyant in ambient air, the angle at which the welding gun is held is of critical importance. This is also largely dictated by the nature and configuration of the workpiece.

The nozzle to workpiece distance is also important to the system balance in that it determines the distance between the arc and the extraction openings; if this distance is too great, fume may escape and limit the effectiveness., and if the distance is too small then the gas shield may be affected.

An excessive stick-out distance will also influence the performance of the extraction system. Where space or access is limited, a bulky torch sometimes cannot be positioned close enough to the workpiece. The operator may try to overcome this by using excessive stick-out distances with consequent effects on extraction efficiency.

The present status of capture efficiency of integral fume extraction torches emerging from this survey, is strongly affected by the three principal ways in which operator holds the welding tool:

1. **Horizontal weld** - The torch is held overhand and almost vertically above the weld, in the path of fume movement. In this position the fume extraction nozzle will be best sited to extract fume. Capture efficiencies on level horizontal plates can be in excess of 90%, although in practice this figure is not achieved. Capture efficiency for a horizontal weld on the inside of an angle formed between a horizontal and vertical plate, is in the order of 10% to 15% lower. Welding on external corners gives least effective capture reducing as radii decrease.
2. **Vertical weld** - Where components are in the vertical plane the angle of the welding torch to the components would typically vary between 50 degrees to 80 degrees (the torch nozzle would be nominally horizontal to the weld). The capture efficiency falls from about 90% to 10% because the torch is held at an angle where the fume extraction nozzle is not in the path of the welding fume.
3. **Overhead weld** - The torch is held vertical below the weld . When welding overhead, fume is often observed rising at such a rate that it is not captured by the on-torch extraction system.

Required ventilation flow rates typically quoted in the literature for torch with indirect capture path are in the range from 60 m³/h to 100 m³/h. These flow rates normally cannot be set higher as removal of the shielding gas may result. Flux cored electrode systems may be an exception to this rule as inert gas is not always used. Measured flow rates significantly below these levels have been found in torches provided with direct extraction path.

Static pressures required are in the range 13 KPa to 20 KPa. Conventional extract fans do not provide sufficiently high suction for on-torch systems, and multi-stage exhausters or positive displacement pumps are needed.

Extraction units are generally sized according to the maximum number of work stations expected to be operating at any one time. A properly designed system will take account of the range of operating conditions, i.e. maximum and minimum inlets required.

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