Analysis and Interpretation of TIG Brush Fumes

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Background

The TIG Brush is a device which produces a low voltage, high current electrical output through a conductive brush which when used in conjunction with specific conductive liquids, removes iron based oxides from stainless steel TIG welds. The TIG Brush has safety and performance advantages over the traditional method of wiping the iron oxide stains with a pickling paste. Pickling paste is inherently hazardous to the operator and those surrounding due to its components hydrofluoric acid and nitric acid. This presents a severe toxic hazard in the vapour and contact form.

The most conductive liquid for the TIG Brush technique that provides the best oxide removal and leaves the metal surface with the most desirable appearance and profile is based on orthophosphoric acid. The developers and suppliers of the TIG Brush, Ensitech Pty Ltd., produce their own orthophosphoric acid solutions named TB-20 and TB-25.
When the TIG Brush is used in its recommended manner on stainless steel TIG welds with either TB-20 or TB-25, fumes are emitted from the contact area between the conductive brush containing the acid solution and the steel it contacts.

Study Aim

As TIG Brush operators are inside arms length distance from the point where these fumes are generated, it is sensible to know what the fumes are comprised of and what risk they present to the operator and the surrounding work area. Once this risk is determined, appropriate personal protective equipment and/or ventilation can be matched.

Study Hypothesis

There are three entities that can contribute to the fumes.

Entity 1: Stainless Steel
Entity 2: TB-20 or TB-25 Solution
Entity 3: TIG Brush fibres

Entity 1: Stainless Steel.

Stainless steel is commonly defined as a steel alloy with a minimum of 10% chromium content by mass. It is a solid comprised of a combination of elements including iron, chromium, nickel, carbon, manganese, silicon, phosphorus and sulphur. Stainless steel is produced in a variety of grades. The difference between grades is the ratio of elements in the steel. The variations in elemental ratios give the metal varying qualities such as corrosion resistance, temperature resistance, weldability, strength , etc.

The most common grades of stainless steel are 304 and 316. See below for their percentages of non-ferrous metals.

Stainless Steel Grade	% Cr	%Ni	%C	% Mn	%Si	% P	% S
304	18-20	8-10.5	0.08	2.0	0.75	0.045	0.03
316	16-18	10-14	0.08	2.0	0.75	0.045	0.03

Iron makes up the remainder of each composition.

The knowledge of the elemental composition of the steel is important in this study since chromium can form compounds that are known human health hazards.

Note: 316 stainless steel was used in this study.

Entity 2: TB-20 or TB-25 Solutions.

These solutions are primarily a 50:50 combination of orthophosphoric acid and water. They contain small quantities of non-phenol surfactants and oils.
The most likely contributors from these entities to the fumes will be water and the orthophosphoric acid.
TB-20 was used in this study although due to their similarity, the results for TB-25 are expected to be the same.

Entity 3: TIG Brush Fibres.

These are primarily carbon and slowly degrade due to the high temperature at the arcing points between the brush tip and the film of orthophosphoric solution over the stainless steel. These are not expected to contribute significantly to the fumes due to the very low degradation rate.

Study Method

A 316 stainless steel plate with a 10cm long TIG welded strip showed extensive iron based oxidation immediately on the weld as well as a 5mm strip on both sides of the weld strip. The iron based oxidation manifests as a brown, red to black mark.

The TIG Brush can be set to a range of power settings designed for various grades of stainless steel. There is also a high power setting for electopolishing.
The settings of 3C was used in this study since it is the setting recommended by Ensitech for this grade of stainless steel, and in testing worked effectively to remove the post- weld oxide marks.

The TIG Brush technique involves dipping the TIG Brush brush into the TB-20 and then immediately drawing the tip of the brush over the dark marks on and around the weld strip. The electrical current creates a high temperature area on the surface of the stainless steel that accelerates the deoxidising action of the TB-20 solution. The iron oxides are dissolved, releasing free ferric and ferrous ions and oxygen. It is through this process that fumes are created.

To simulate the typical use of the TIG Brush, a weld was cleaned for two minutes with dips into fresh TB-20 every 20 seconds.
Placing an RO water moistened 11cm diameter No. 41 Whatman Ashless filter paper directly in the path of the fumes being emitted captured the fumes. The filter paper was placed 30cm from the metal surface to simulate an approximate minimum distance to an operator's face. At the end of two minutes, the filter paper was sealed in a new polyethylene bag.

This process was repeated with a fresh filter paper.

Two separate filter papers the same as those used to capture fumes were individually sealed in plastic bags. These provided the analysis a set of blanks from which any contaminants could be subtracted from the test results.

All filter papers were analysed for inorganic components at the UNSW Analytical Laboratory by the department's head chemist Terry Flynn.

Note: the volume of air through which the two minutes of fumes were created was estimated as 200L .

See Appendix A for a copy of the complete UNSW report.

Below are the results of the analysis expressed as an average between the results of the two test filter papers:

Table 1: TIG Brush Fume Inorganic Analysis

TIG Brush fume over two minutes		Derived From
Aluminium	0.39 µg	TB-20
Boron	<0.01 µg	Not significant
Barium	<0.01µg	Not significant
Calcium	9.7 µg	TB-20
Cadmium	<0.01 µg	Not significant
Chromium	0.54 µg	Stainless steel
Copper	0.60 µg	TB-20
Iron	3.60 µg	Stainless steel
Magnesium	<0.01 µg	Not significant
Manganese	0.03 µg	Not significant
Sodium	<0.01µg	Not significant
Potassium	<0.01 µg	Not significant
Nickel	0.05 µg	Stainless steel
Lead	<0.01 µg	Not significant
Zinc	<0.01 µg	Not significant
Chloride	100 µg	TB-20
Fluoride	<0.01 µg	Not significant
Nitrate	<0.01 µg	Not significant
Sulphate	<0.01 µg	Not significant
Phosphate	433 µg	TB-20

Interpretation of Results

The interpretation of the fumes in this report is threefold

1. Determine what entities are present in the fumes
2. Determine what amounts are present in the two minute fume generation period. This analysis gives a confident indication of what a user would to be exposed to if they had total contact with the fumes for two minutes.
3. By consultation with the Australian Federal Government Hazardous Substances Information System, assess the risk to worker safety. This is the foremost authority on workplace chemical hazard limits.

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(Note that whilst not analysed for in this study, the fumes are mostly comprised of water vapour from the heat placed on the TB-20). Of the approximately 2 mL of TB-20 for each brush load, almost all of the water, (approximately 1mL) will be converted to steam and be the major component in the fumes.

In the analysis table, noted in this report as Table 1, the ratio of elements is regarded as typical of a high heat event on stainless steel with phosphoric acid present. The results are dominated by phosphates derived from the boiling of the phosphoric acid in theTB-20.

The next highest inorganic entity was chloride. As the steel is low in chlorides as well as is the phosphoric acid, the water in TB-20, which is sourced from the Sydney municipal system, is thought to have contributed here. The monochloramines used for bacterial control in Sydney water will be released as chlorine complexes that will appear in this analysis as chloride. Calcium is also from the water component in the TB-25.

The next most prominent entities are those derived from the stainless steel.
The presence of chromium, nickel, iron and manganese in the fumes indicate that the TIG Brush (together with the TB-20) activity is dislodging these elements from the metal surface. Interestingly the ratio of presence in the fumes is not aligned with the ratios in the steel. Nickel levels in the fumes are lower than this element's proportional concentration in the stainless steel.

The high iron content in the fumes is in fact a confirmation of the theory that the TIG Brush removes the iron oxide that makes up the dark staining after TIG welding.
We can also see relatively high chromium levels in the fumes in comparison to the nickel levels. This is due to the surface of the steel being dominated by chromium oxides that give stainless steel its inherent corrosion resistance. These oxides are removed by the TB-25 and when exposed to the high heat of the TIG Brush, will become part of the fumes.

All other entities are in extremely low concentrations and will not present a hazard to an operator whilst at these low levels. Further recommendations with respect to these elements will not be provided in this report.

The workplace hazards from the TIG Brush fumes will therefore be due to the following:

1. phosphate
2. chromium
3. aluminium
4. copper
5. chloride

<u>Phosphate</u>

The phosphate determined in the analyses is an expression of detected phosphorus. This will be derived from the breakdown of the phosphoric acid. Phosphorus will be present as mostly as the compound phosphorus pentoxide. All other forms will be extremely low and not approach the level of hazard of the pentoxide form.
The Australian HSIS does not have an exposure limit for this compound but the European Union has a "maximum workplace concentration" limit for it.

The EU specify that the maximum workplace concentration for phosphorus pentoxide as an inhalable fraction is 2 mg/m^3 of workplace atmosphere. The 433ug (0.433mg) measured in this study was in a column of air estimated to be approximately 200L in the two minute period. That represents a 2.2 mg/m^3 concentration of phosphorus pentoxide which slightly exceeds the EU limit.

Chromium

The chromium detected in the fumes will be in three forms. The first and lowest amount will be metallic spatter that occurs when the chromium metal is placed under the heat of the TIG Brush. The heat will tend to ionise most of the chromium atoms thereby creating chromium oxides in the air. The metallic form represents a relatively minimal hazard.

The next form is the trivalent chromium oxide Cr_2O_3. This is a state that ionised chromium forms easily and readily in the heat of the TIG Brush environment.
The exposure limit as per HSIS is 0.5 mg/m^3. If the entire chromium level detected was trivalent, we would have 0.54ug /approx 200L in this study which equates to 0.0027mg/m^3. This is far below the HSIS recommendations.

The trivalent form of chromium can further ionise to the hexavalent form $HCrO_4$. The HSIS exposure limit of 0.05mg/m^3 illustrates the higher toxicity of the hexavalent form compared to the trivalent form. The 0.0027mg total chromium/m3 air, is again far below the HSIS exposure limit.

Aluminium

Aluminium can be toxic at relatively high levels with HSIS exposure limit being 2mg/m^3 for the most toxic forms. The 0.00195mg/m^3 aluminium detected in this study is far below the limit.

Copper

Copper in a fumed form can be toxic at relatively high levels with HSIS exposure limit being 0.2mg/m^3. The 0.003mg/m^3 copper detected in this study is far below the limit.

Chloride

The most toxic form of chloride is phosgene that is created when chlorides are reacted with carbon monoxide. This does not happen in the TIG Brush process. The most likely form of chloride is iron chloride that poses no hazard to the operator. Chlorides are of no significant hazard.

Conclusion

This study shows that a range of toxic entities is created which poses a hazard to the operator.
In all cases, the levels of these toxic entities were below the HSIS exposure limits, however the levels of phosphorus pentoxide slightly exceeds the EU exposure limit as well as the current knowledge that phosphorus pentoxide is an inhalation and skin contact hazard. Operators of TIG Brushes should therefore be protected from the TIG Brush fumes for inhalation and skin contact, even though there are no Australian HSIS exposure limits.

This study measured the components in the entire stream of the fumes as it was emitted from its source. This is the most concentrated fume area and therefore all areas around the fume stream will contain less toxic levels as found in this study.

Note that the HSIS limits and guidelines do not take into consideration people who have specific sensitivities to chemicals. If those specific sensitivities exist, appropriate PPE needs to be used.

Whilst the immediate hazard to the operator is relatively low as determined by the Australian Federal Government HSIS, the effects of chronic exposure is not covered in this study.
If an operator is a long-term TIG Brush user, good practice to ensure safety includes excellent exit flow ventilation, appropriate respiratory protection for acid and inorganic gases and fumes and avoiding breathing the fumes when possible.

Examples of appropriate respirators for use with the TIG Brush are:

3M fullface 6000 series
3M half face 6000 and 7500 series
Both of these should be used with the 3M 6057B filter cartridges with a P2 particle filter eg. 3M 5925.

Workers using the TIG Brush in confined spaces must wear appropriate PPE including respirators such as listed immediately above.

END