Fumes from Welding and Cutting

By R GHOSH*

Introduction

It is impossible to over-estimate the influence of environment on productivity. Workmen can, naturally, produce more and better work in well-ventilated, well-lighted and temperature controlled factory premises than in a dingy, ill-lit and cold work-shop. This, in no small measure, is due to an improved mental outlook that develops from healthy surroundings. There has been also a very substantial change from the original idea of a factory which was merely a place to house machinery ; the fact that human beings had to spend a large part of their lives in these buildings was given little or no consideration. The recognition of the value of conserving the health of the employee carries with it a new concept concerning the surrounding and equipment. Now-a-days in all the progressive and industrially advanced nations, there are protective legislations in respect of environment in which a factory worker should work. More often voluntary reform work has been the fore-runner of these protective legislations and the voluntary reform work of one period became the basis of the legal regulation of a later day.

Ventilation

The Factory Act, 1948 stipulates the conditions relating to lighting, ventilation etc. of factory buildings; but on examination of most of the relevant clauses in this Act, one cannot help but feel that the stipulations in this Act in respect of lighting, ventilation etc. could have been, perhaps, more specific or quantified. In contrast, however, the stipulations in the National Building Code, 1970 in these respects are specific. Part VIII Building Services, Section I—Lighting and Ventilation of the National Building Code stipulates the requirements for lighting and ventilation in various types of buildings including factories. In the context of the subject under review, it will be worthwhile quoting from the Clause "5.2.2.1—Recommended Values for Air Changes" for factories reading as under :

> "5.2.2.1—Recommended Values for Air Changes—The following minimum standards of ventilation are based on control of body odour or the removal of products of combustion when no other contaminants are present in the air.
>
> (e) FACTORIES—No standards have been laid down under the Factories Act (1948), as regards the amount of fresh air required per worker or the number of air changes per hour. Section 16 relating to safe-guarding requires that atleast 14 m^3 to 16 m^3 of space shall be provided for every worker and for the purpose of that section no account shall be taken of spaces in a workroom which is more than 4.25 m above the floor level. The minimum fresh air required in a work room where there are no contaminants to be removed from air, shall be such as to effect three air changes per hour."

* Mr. R. Ghosh is the Chief Technical Advisor of Indian Oxygen Ltd., Calcutta This paper was presented by him at the Institute's Seminar held in Calcutta in July 1973.

Neither the Indian Factory Act, 1948, nor the National Building Code, 1970, makes any special reference to welding and cutting operations. The American Welding Society suggests that for metal are welding of mild steel, natural ventilation is adequate provided the room volume is 283.4 m^3 (i.e. approximately 10,000 cubic feet) per welder and the ceiling height is atleast 4.87 m (i.e. 16 feet), unless electrodes having fluorides in the covering are used and cross ventilation is blocked by partition, equipment etc. If these requirements cannot be met, recourse to forced or mechanical ventilation at the rate of approximately 56.6 m^3 (i.e. 2,000 cubic feet) per minute is recommended. Studies carried out in Netherlands by R Frant indicated that "using a general ventilation system, a medium size room of 10,000 m^3 would need a ventilation capacity of 100,000 m^3" requirng 10 air changes per hour, to provide 20 welders with adequate protection.

Fumes in Welding & Cutting

Unlike many industrial processes, welding and cutting are carried out in factories and in open air. Broadly, the welding and cutting sites can be divided into four categories :

(1) open workshop,
(2) open air,
(3) semi-confined spaces, and
(4) confined spaces.

Welding and cutting operations evolve quantities of gases, dusts and metal fumes, and these irrespective of the location of operation will influence the immediate environs. The amount of gases or fumes a welder is likely to inhale, is dependent on many factors such as the dimensions of the welding area, the number of welding or cutting operators, the duty or operational factor (viz. arc time etc.), the method of welding or cutting employed, the material involved, the size and type of filler wire(s) and flux(es) used, the ventilation system employed etc. The single important factor is the one which is governed by the welder himself viz. the position of his head in relation to the plume of the fumes—two welders may have largely varying degrees of exposures to the welding fume, doing exactly the same job and in the identical environment, all depending on the position of their heads.

The toxic hazards to which an operator may be exposed during welding and/or cutting, will depend on the welding or cutting process, the base metals and the filler metal(s), the flux(es), the presence of contaminants, the presence of volatile solvents in air etc. The toxic hazards can be divided in two categories viz. (i) gases and (ii) fumes. The gases involved are (1) carbon dioxide, (2) carbon monoxide, (3) hydrogen fluoride, (4) ozone, (5) phosgene (6) nitrogen dioxide and (7) sulphur dioxide. A fume can be defined as "particulate matter of submicron particle size which arises from the volatilisation of metals or salts when heated to sufficiently high temperatures". The metals and their salts involved in common welding and cutting processes are listed in Table 1. The degree of toxicity of these gases and fumes vary greatly and is expressed in terms of "Threshold Limit Values" (TLV)—this is the maximum atmospheric concentration in milligrams per cubic metre of air which is felt safe for a normal individual to breathe for eight hours a day, five days a week—since in India six days a week are worked, appropriate adjustment will have to be made. It should be, however, noted that actual body damage or hazard will not occur unless an individual inhales these gases and fumes in subtantially greater amounts for long periods of time. The "Threshold Limit Values" for materials commonly encountered in welding and cutting are given in Table 1.

Conditions produced by inhalation of the freshly formed toxic gases and fumes may not be directly related to their turn toxicities, Fluorine compounds are normally absorbed by the human organism from food and particularly water, the quantity varying according to geographical area, the range may vary from 0.4 to 1.0 mg of fluoride per day ; in certain parts of the world it may be greater. But in most cases a balance between fluoride intake and output is reached, there being some retention in bones, teeth and hair, excretion of excess fluorides taking place through urine, sweat etc—the concentration of fluorides in urine can range from 0.3 to 4.6 mgm per litre. The metabolism of fluorine compound absorbed by inhalation tends to follow the same pattern as that produced by ingestion i.e. urinary and sweat excretions show prompt response. Inhalation of fluoride equivalent of TLV level of 2.5 mg/m^3 will result in its excretion in the urine in concentration of 4.0 mg/litre. Notwithstanding such observed results, it has been the experience that the effects on health from exposure to fluorine and its compounds are either of an acute or chronic nature, irritating action on the skin and on the mucous surfaces of the eyes, respiratory and alimentary passages, prolonged exposure leading to chronic fluorosis with symptoms of anaemia, digestive disorder and calcification of bones and ligaments. These symptoms have also been noted when fluoride contents in drinking water reaches the toxic level of 2 ppm.

TABLE 1

Threshold Limit Values for Common Materials and Gases encountered in welding and cutting

Materials/Gases	*T L V* mg/M^3
Antimony	0.5
Arsenic	0.5
Beryllium	0.002
Carbon dioxide	5000 ppm
Carbon monoxide	50 ppm
Cadmium oxide fumes	0.1
Chromates (as Cr_2O_3)	0.1
Chromium (metallic)	1.0
Cobalt	0.1
Copper fumes	0.1
Metallic fluorides	2.5
Hydrogen fluoride	3 ppm
Iron oxide fumes	10.0
Lead	0.2
Magnesium oxide fumes	15.0
Manganese	5.0
Mercury	0.1
Molybdenum	15.0
Nickel carbonyl	0.007
Nickel (metallic)	1.0
Nitrogen dioxide	5 ppm—Ceiling Value (TLV 9mg/m³)
Ozone	0.1 ppm
Phosgene	0.4
Selenium	0.2
Silver	0.01
Tellurium	0.1
Titanium dioxide	15.0
Sulphur dioxide	5 ppm
Vanadium fumes	0.1
Zinc oxide fumes	5.0
Zirconium	5.0

Note : **(i) In most cases of toxic gases, Threshold Limit Values in the table above have been shown as "parts per million" ; their TLVs in mg/m³ are shown below—**

Carbon dioxide	**—9000.00 mg/m³**
Carbon monoxide	**— 55.00 ,,**
Hydrogen fluoride	**— 2.00 ,,**
Nitrogen dioxide	**— 9.00 ,,**

(ii) Celling value shown in case of nitrogen dioxide indicates that the concentration of this gas in air should not exceed this limit at any time.

Inhalation of zinc and magnesium fumes exceeding the TLV limits will cause chills, fevers and nausea invariably within 24 hours of exposure, if not earlier. Excessive cadmium fumes may cause fume pneumonitis while nickel, cobalt and mercury can possibly cause chemical penumonitis. Iron and aluminium do not cause any metal fume fevers ; inhalation of very large amount of iron fumes over extended period of years will lead to deposition of iron in the lung, known as siderosis, a seemingly harmless condition.

Respiration Hazards in Welding Processes

It is well known and it is accepted that the various welding and cutting processes can produce toxic gases and fumes. Whether these reach the Threshold Limit Values to have any effect on the operators depends on the types of welding sites mentioned earlier in this paper and also the exact location where their presence can have a telling effect on the health of operators, the four locations being.

(1) in the plume of fume rising from the welding or cutting operation,

(2) the general atmosphere in the working area,

(3) breathing level in the vicinity of the welding mask, and

(4) the atmosphere actually breathed by the welder behind the welding shield.

Various methods are used for collection of samples of gases and fumes for analysis ; standard methods of analysis such as detector tubes, gas chromotography, simpe chemical analysis etc. are used. Special mention should, however, be made of the instruments used for personal sampling of fumes ; this instrument is known as a respirometer and is worn by the welder ; the use of such instruments often hinders the use of normal type welder shields. For determination of toxic gases in the atmosphere breathed by the welder, sampling probe with inlet at the side of the welding shield is used. R Frant in his studies on welding fumes in metal arc welding claimed greater accuracy for measurement of fumes by the straight gravimetric method than by the optical method. The method adopted involved sucking through a filter holder a known amount of air the filter being weighed before and after the test under well defined condition of temperature and humidity for some hours, the difference in weight indicating the amount of solid material in the fumes collected during welding.

Some of the respiratory hazards due to toxic gases and fumes in a few commonly used welding and cutting processes are analysed hereunder—

(a) Gas Cutting

Cutting of steel does not produce harmful fumes under normal or well ventilated conditions except in very confined and semi-confined spaces. There is, of course, the danger of formation of oxides of nitrogen in harmful quantities in enclosed areas where a large amount of cutting is carried out.

The studies which were undertaken in shipyards in the United Kingdom, showed that out of four samples taken for determination of carbon monoxide, the highest was 40 ppm in the plume of the fume and the lowest 9 ppm at breathing level, the average of the three samples at breathing level being 18 ppm—in every case lower than TLV of 50 ppm. Similarly, carbon dioxide in confined and semi-confined conditions from four samples ranged between 700 ppm to 3,000 ppm, averaging 1,900 ppm (TLV level 5,000 ppm). In case of nitrogen dioxide, in one confined space the concentrations of 12 ppm in two samples were recorded in the plume of the fume. This dropped to about 10 ppm average from three samples taken at 1.2 m above the cutting zone, reducing further to 9 ppm at the breathing level—TLV level 5 ppm.

The other most toxic fume which may be experienced in gas cutting is iron oxide. Samples taken with personal respirometer in confined and semi-confined spaces were found to exceed the TLV level.

(b) Plasma Arc Cutting

This process of cutting, specially for cutting of stainless steels and aluminium is gaining in popularity. Indian industry is also adopting this process. Apart from increased ultraviolet and infra-red light, the possibility of increased ozone formation and high concentrations of nitrogen dioxide when nitrogen is used, cannot be totally ruled out. In addition, large quantities of metal fumes and dust may be produced with very high noise level. The use of water table, recently introduced in the fleld of plasma arc cutting, tends to reduce substantially these shortcomings of this process. Dr. R. A. Cresswell, however, reports that with normal ventilation the levels of toxic gases and toxic fumese never go beyond the maximum allowable concentration, and in some cases these are lower or comparable to those produced by high power TIG or MIG processes.

(c) Gas welding and Brazing

Toxic gases and fumes produced in gas welding of common metals hardly exceed the Thereshold Limit Values. In welding of brass and bronze exceesive fuming of zinc can be easily controlled by the use of satisfactory fluxes and of a distinctly oxidising flame. Nevertheless, fluxes containing fluorides are frequently used for brazing and welding of light metals. Incorrect use of fluxes including overheating of the fluxes, may lead to release of hydrogen, fluoride beyond the Threshold Limit Values of 2.5 milligrams per cubic metre (i.e. 3 ppm). Similarly, overheating of (silver) brazing alloys containing cadmium, may lead to its volatilisation—easily distinguishable by the yellow-brown fumes, inhalation of which in large quantities may cause severe lung damage on short exposure.

(d) Manual Metal Arc Welding

It is the most commonly used welding process. Electrodes having rutile type of coatings, are most commonly used. The fumes and gases from these types of electrodes are mainly iron oxide and gases of varying amounts from the flux coating materials. When welding in confined areas, the concentration of iron oxide fumes may exceed the Threshold Limit Value for iron oxide —10 milligrams per cubic metre of air—high enough to reducee visibility markedly.

Sampling studies carried out in shipyards in the United Kingdom indicated that excepting when welding is carried out in confined and semi-confined spaces, the concentrations of individual toxic gases viz carbon monoxide, carbon dioxide, nitrogen dioxide and toxic fumes in excess of the Threshold Limit Values were not detected. Ozone was not found on any occasion although the sampling sites varied from open air to confined spaces, except when welding manganese steel using hydrogen controlled basic coated electrodes. Findings in the later case, tend to indicate the need for use of local exhaust ventilating system in order to bring the concentration of ozone well below TLV level.

As to toxic fumes, iron oxide is the most important, particularly in respect of visibility. Lack of ventilation in work space may raise the concentration of iron-oxide fumes beyond the TLV level—Tables 2 and 3.

Manganese, nickel, copper and cobalt fumes may be observed in the fumes from metal arc welding depending on the composition of the base metal and electrodes used, but these metal fumes hardly exceed the Threshold Limit Values.

Special mention must be, however, made of hydrogen controlled basic coated electrodes. The flux coverings of these electrodes usually contain fluoride compounds in the order of possibly 5 to 10 percent. Since the use of this type of electrodes was introduced by French technologists in 1934, their popularity has increased because these electrodes deposit a metal which has a low sensitivity to hot and cold cracking, which is little influenced by the impurities in the base metal, which offers excellent mechanical properties and which is likely to contain a small quantity of dissolved hydrogen, a gas which adversely affects the mechanical properties of the joint. The fumes produced from these basic coated hydrogen controlled electrodes may produce hydrogen fluoride in varying quantities though not very large. The amount off fluoride that may be inhaled by the welder will depend on the fluoride fumes generated by an electrode, the size, shape and position of the weld, and lastly the individual work habit of the welder i.e. where he positions his head in relation to the plume of the fume. The possibility of fluoride fumes exceeding the Threshold Limit Value in confined and semi-confined spaces certainly exists unless mechanical or forced ventilation measures are adopted. Taking due account of the effect of the total toxic gases and fumes that may be experienced when using these classes of electrodes, the International Institute of Welding, Commission VIII—Hygiene and Safety, made the following recommendations :

"Nevertheless Commission VIII is of the firm opinion that if the ventilation provided maintains a ceiling level of 10 mg/m^3 total fume or below, there will probably be few complaints concerning the irritant effects."

(e) Submerged Arc Welding

Many of the fluxes used for submerged arc welding contain fluorides which will break up mainly as hydrogen fluoride and may be detected in level higher than TLV immediately above the weld zone. The hazard associated with the process is more when used as a semiautomatic process than when used with machine welding. Carbon monoxide concentration above the weld zone may vary between 300-1,000 ppm but tests conducted indicated concentration of 0-30 ppm at the breathing level. Carbon dioxide concentration is well with in the TLV level, so is nitrogen dioxide.

(f) Gas Shielded Arc Welding Processes TIG & MIG

Carbon monoxide and carbon dioxide produced during welding with these processes using argon as a shielding gas are minimal. Nitrogen dioxide in the breathing level in well ventilated workshops is well within the limits, the head shield also providing some measure of protection. Ozone which is produced by the action of ultraviolet. light on oxygen of air, has been detected in the weld zone in volumes higher than Threshold Limit Value, but in ventilated shops, the ozone content in the breathing level behind the welders head shield is well below the TLV level.

Carbon dioxide is extensively used as a shielding gas in MIG welding and is decomposed by the arc to produce carbon monoxide. Although the quantity produced is very small, relatively high concentrations, 200-500 ppm may be observed in the fume over the arc zone. This falls off sharply a few millimeters away from the weld zone and at the breathing level the concentration is well within the safe limit. Carbon dioxide concentration close to weld is likely to be high but again in well ventilated work place the concentration at the breathing level is well within the limit. These observations point to the necessity for forced ventilation when welding in confined and semi-confined spaces. Fumes produced when MIG welding with cored tubular filler wires or gasless tubular filler wires, are more than when using solid wires ; these fumes often reduce visibility substantially. Many of the latest MIG torches/guns have inbuilt fume extraction devices.

TIG or MIG welding must not be carried out in the vicinity of Tri and Perchloroethylene, a distance of 50 metres may be too close. Trichlorethylene decomposes in

TABLE 2

Showing Concentration of Iron Oxide—Metal Arc Welding in confined and semi^{3}confined spaces vis^{3}a^{3}vis open workshops and open site condition.

Sampling site	*Sampling positions*	*Number of samples*	*Number of times TLV exceeded*	*Recorded minimum and maximum concentrations of iron oxide fume in milli-grams/cu. metre*	*Recorded average concentration of iron oxide fume in milli-grams/cu. metre*
Confined and semi-confined spaces	General atomosphere	28	5	0.1-56.0	8.5
	Personal respirometer samples	32	9	0.1-60.0	13.2
Open Workshop and open air sites	General atmosphere	20	—	0.1-3.3	0.9
	Personal respirometer samples	7	—	0.1-5.0	2.6

TABLE 3

Same as Table 2 showing differential between natural ventilation and forced general ventilation.

Sampling positions	*Type of ventilation*	*Number of samples*	*Number of times TLV exceeded*	*Recorded minimum and maximum concentration of iron oxide fume in milli-grams/cu. metre*	*Recorded average concentration of iron oxide fume in milli-grams/cu. metre*
General atmosphere	Natural ventilation	14	6	0.5-56.0	15.1
	Forced general ventilation	13	—	0.1-7.5	1.7
Personal respirometer samples	Natural ventilation	13	4	3.0-60.0	21.8
	Forced general ventilation	12	4	0.1-29.0	9.6

the arc producing highly toxic phosgene and other gases in dangerous quantities ; even welding of parts degreased with these compounds must be approached with caution.

(g) **Welding/Cutting on Coated Materials**

Welding or cutting on coated material sometimes becomes a necessity, but the possibility of health hazard exists. Also in shipyards, the plates are now-a-days pre-painted with protective coats of paint before cutting or welding—the paints chosen for such applications normally produce less toxic gases and fumes than many other coating materials. But in repair work, a varied range of coating materials may be met with ; in such cases the coating material must be removed from the weld zone or even possible heat affected zone prior to commencing welding or cutting operations.

It will be seen from this paper that there is little health hazard from gases or fumes produced from welding or cutting in well ventilated workshops and work sites ; but welding and cutting in confined and semi-confined areas and also on coated materials may give rise to health hazards to operators. In such cases it becomes an absolute necessity to dilute or reduce the concentrations of toxic gases and fumes from the work place. To achieve this, it may be necessary to use (1) forced ventilation, or (2) exhaust ventilation, or (3) individual operator respiratory protective equipment (the type depending on the toxicity of fumes or gases)—singly or in combination as dictated by circumstances.

The main objective of presenting this paper is to focus attention on possible health hazards in welding and cutting operations, particularly under some specific condition, so that appropriate measures can be adopted for the well being of operators and in the interest of higher productivity. It must be however, emphasised that in well-ventilated workshops the health hazards from toxic gases and fumes resulting from the various welding and cutting processes, are virtually non-existant.

While considerable studies on this subject are being carried out in many industrially advanced countries, no studies in this area, to the best of author's knowledge, have yet been undertaken in India. This subject is also engaging the attention of International Organisation for Standardisation (ISO). Technical Committee—Welding, ISO/TC/44, and the International Institute of Welding. The author in the last meeting of Welding General Sectional Committee (SMDC-14) of Indian Standards Institution drew the attention of the Committee Members to this subject and it was agreed that a Sub-Committee or at least a Panel would be appointed shortly to draw up standards of recommendations of practices in this field.

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Bibliography

1. Indian Factory Act, 1948
2. National Building Code of India, 1970—Indian Standards Institution.
3. Welding Engineering—B. E. Rossi
4. Principles of Industrial Organisation—D. S. Kimball and D. S. Kimball (Jr)
5. Procedure Handbook of Arc Welding Design and Practice—The Lincoln Electric Company, Cleveland, U. S. A.
6. Report on Shipbuilding and Shiprepairing Industry.
   —Fumes from Welding and Flame Cutting—Her Majesty's Stationery Office, London.
7. Welding Handbook—American Welding Society.
8. Health and Safety Aspects of Plasma Cutting—R. A. Cresswell (U. K.) ; IIW, DocumentVIII—433-71.
9. Gas Chromatographic Determination of Chlorinated Acetyl Chlorides and Phosgene Present in Air in Very Low Concentrations—J. A. Dahlberg and I. G. Kihlman (Sewden) ; Document VIII—432-71.
10. Report on a Danish Investigation into Health and Working Environment of Arc Welders—A Fogh, J Frost and J Georg (Denmark) ; IIW, Document VIII—440-71.
11. Hygienic Aspects of Welding with Basic Electrodes —Working Group C ; IIW, VIII—441-71.
12. The Industrial Hazard from Nitrous Fumes with Special Reference to Welding, Cutting and Heating of Steels—R. Morley and S. S. Silk (U. K.) ; IIW, Document VIII—444-71.
13. Studies on Toxic Effects of Manual Electric Arc Welding—S. Byczkowski, M. Cempel, J. Gadomska, J. Krechniak, W. Senczuk, K. Wrzesniowska, A. Bohdanowicz (Poland) ; IIW, Document VIII —408-70 and VIII—449-71.
14. Welding Fumes—R. Frant (Netherland) ; IIW, Document VIII—457-71.