CONCENTRATIONS OF CARBON OXIDE AND NITROGEN DIOXIDE IN AIR OF A WORKING ZONE IN COVERED-ELECTRODE WELDING

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The paper presents the results of investigations of dependencies of concentrations of noxious gases (carbon oxide and nitrogen dioxide) released into working zone air in covered-electrode manual arc welding on distance to welding arc under different ventilation conditions (with general ventilation, local ventilation and without ventilation). Respective analytical equations are derived that allow forecasting noxious gas concentrations in different points of the working zone depending on welding arc power.

Keywords: *arc welding, covered electrodes, noxious gases, carbon oxide, nitrogen dioxide, ventilation, concentration of gases in air, prediction*

One of the negative effects of electric-arc process is formation and accumulation of the welding fumes and gases in air of a working zone. Protection of the workers and production environment from their effect is carried out with the help of different types of the ventilation systems which should provide a content of harmful substances in air of the working zone not higher than the maximum allowable concentration (MAC). The experimental data about concentration of the harmful substances in air of the working zone at different types of ventilation are necessary for selection of required ventilation and increase of its efficiency on the work places of welders. Data on investigation of pollution of air in the working zone with harmful substances in a form of fumes, formed in covered-electrode welding (for example, in [1]) exist in literature in sufficiently large amount, but data on noxious gases are absent. This is explained by the fact that obtaining of such data using generally accepted techniques [2, 3] is sufficiently long and labor-consuming task. Thus, sampling of only one gas specimen in one point of airspace of the welder's work zone applying specific grade of welding consumable takes virtually a working shift. At that, a relative error of obtained data should make ±25 % in accordance with requirements [4] that allows providing a selective definition of content of a substance at the level not higher than 0.5 MAC. Today there are no safe gas analyzers which would allow providing a high reliability for definition of their concentration in air of the working zone. Therefore, a necessity has appeared in obtaining of such data through a calculation based on experimental data.

Noxious gases, forming in an arc atmosphere during covered-electrode welding, include carbon oxide, nitrogen dioxide, hydrogen fluoride and ozone. A composition of electrode coating [5] determines to a significant level a composition of forming gases. High-temperature and photochemical oxidation of air nitrogen [6] is mainly the reason for formation of poison nitrogen dioxide. The level of formation of these gases depends on welding arc power.

The aim of the present paper is to investigate the carbon oxide and nitrogen dioxide concentration dependencies in different points of air of the working zone on the welding arc power, distance to welding point (welding arc) and type of ventilation system in low-alloy covered-electrode welding.

The experiments were performed on a typical work place for manual arc welding using general and local ventilation as well as without ventilation in the E.O. Paton Electric Welding Institute. Gas samples were taken around the arc in three points at different distance from the arc: 55 cm (welder's breathing zone), 100 and 150 cm (working zone). A capacity of general as well as local ventilation was selected equal 1500 m^3/h for efficiency comparison. A typical axial-blow blower was used in the general ventilation system and typical welder's table with built-in exhaust device of inclined panel type [1] was applied in the local one.

Gas samples were taken in the process of surfacing with general-purpose covered-electrodes of ANO-36 grade of 4 mm diameter on plates from St3sp (killed) steel. Direct current of reversed polarity was used. The welding current was changed in the ranges from 130 to 230 A, arc voltage made 24–40 V for determining the dependence of concentrations of gases in air of the working zone. Gas analyzer «Akvilon-1-1» was used for definition of carbon oxide CO concentrations in air of the working zone and «Akvilon-1-2» was applied for nitrogen dioxide NO_2. A validity of obtained experimental data was checked in accordance with the accepted procedural instructions [4]. Ana-

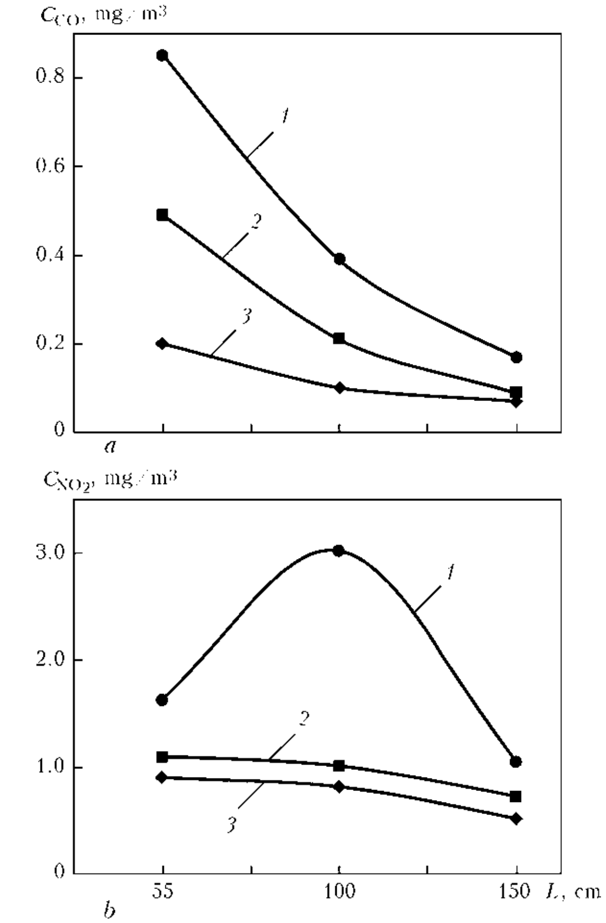

Figure 1. Dependence of carbon oxide C_{CO} (*a*) and nitrogen dioxide C_{NO_2} (*b*) concentration in air of the working zone on distance *L* to the welding arc in welding without ventilation (*1*), with general (*2*) and local (*3*) ventilation

lytic and statistic processing of determined dependencies was carried out using special program, developed in the National RI of Industrial and Occupational Safety, with the help a method of regression analysis [7, 8] underlying in it.

Investigations of carbon oxide concentration dependencies on distance to the welding arc (Figure 1, *a*) indicate that they are maximum in welding without ventilation, minimum at the local ventilation and reduce with an increase of arc distance, but for all cases do not exceed MAC (20 mg/m^3). The reason for formation of carbon oxide during covered-electrode welding is, mainly, the air oxidation of carbon, which is contained in metal and electrode coating, at the first stage:

$$C + O_2 = CO_2,$$

and dissociation of carbon dioxide as a result of high temperature of the welding arc at the second stage:

$$CO_2 \leftrightarrow CO + \frac{1}{2} O_2,$$

as well as metal reduction of carbon from its dioxide,

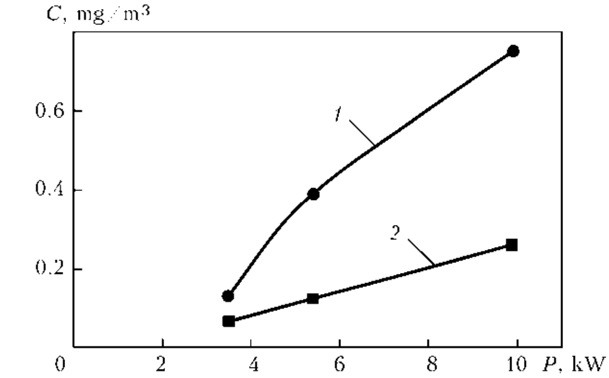

Figure 2. Dependence of carbon oxide (*1*) and nitrogen dioxide (*b*) concentration in air of the working zone on the arc power at 100 cm distance to the welding arc

$$CO_2 + Me = CO + MeO.$$

Besides, a presence of carbon dioxide in ambient air in the amount of 0.03–0.04 % [9] can be a source for formation of carbon oxide in a low quantity. As a result of chemical reaction (2) the carbon dioxide decomposes to the carbon oxide at high temperature of the arc. Therefore, total low concentration of carbon oxide in air of the working zone is explained by insignificant content of carbon in the composition of metal to be welded and ambient air. Carbon oxide is also formed in welding by electrodes with cellulose and carbonate-containing coating as a result of thermal dissociation of these gas-slag-forming components of the coating. In these cases an increased amount of carbon oxide is released in air of the working zone.

Dependencies of nitrogen dioxide concentration in air of the working zone on distance to the welding arc have more complex form, in particular, in welding without ventilation (Figure 1, *b*). This is explained by successive oxidation of air nitrogen in two stages. Firstly, nitrogen oxide appears in the near zone as a result of high-temperature oxidation of air nitrogen, surrounding the arc:

$$N_2 + O_2 \leftrightarrow 2NO,$$

then, nitrogen oxide oxidizes with time and removing from the arc up to poison nitrogen dioxide [6, 10] under the effect of ultraviolet radiation of the arc:

$$2NO + O_2 \leftrightarrow 2NO_2.$$

Therefore, at certain distance from the arc (around 1 m) the concentration of nitrogen dioxide increases due to its accumulation in air in welding without ventilation and decreases at further removal from the arc (up to 1.5 m) due to dispersion.

It should be noted that the concentrations of nitrogen dioxide in the working zone do not exceed MAC (2 mg/m^2) at application of the local as well as general ventilation. In welding without ventilation the concentration of nitrogen dioxide exceeds MAC (see Figure 1, *b*) at a distance from 80 up to 130 cm to the welding arc.

Table 1. Values of the relative errors and total correlation factors of dependencies (1)–(6)

Dependence	Relative error, %	Total correlation factor
(1)	18.0	0.940
(2)	18.2	0.986
(3)	19.2	0.939
(4)	5.0	1.0
(5)	10.0	0.074
(6)	11.5	0.960

An increased content of nitrogen dioxide in the zone near to the welding arc in application of the local as well as general ventilation is explained by more active nitrogen oxidation then in the zone distant from it. This result in formation of larger amount of nitrogen oxides in the breathing zone, and the intensity of oxidation of air nitrogen, naturally, decreases with increase of a distance from the welding arc.

It can be seen from the dependencies of concentrations of carbon oxide and nitrogen dioxide in air of working zone on the welding arc power that the concentrations of these gases in air raise with increase of arc power (Figure 2).

Analytic and statistical processing of determined dependencies (see Figure 1), made with the help of the method of regression analysis [7, 8], taking into account influence of the distance to welding arc and its power (see Figure 2) allowed obtaining the following dependencies:

• dependence of CO concentration (C_{CO}) on power (I_wU_a) of the welding arc and distance to arc L (m) in welding

without ventilation:

$$C_{CO} = -0.197 + 2.178\cdot10^{-4}I_wU_a + 0.071L - 1.192\cdot10^{-4}I_wU_aL, \quad (1)$$

with general ventilation:

$$C_{CO} = -48.099\cdot10^{-2} + 2.929\cdot10^{-4}I_wU_a + 34.679\cdot10^{-2}L - 3.268\cdot10^{-4}I_wU_aL + 0.902\cdot10^{-4}I_wU_aL^2, \quad (2)$$

with local ventilation:

$$C_{CO} = -2.657\cdot10^{-2} + 0.439\cdot10^{-4}I_wU_a - 0.857\cdot10^{-2}L - 0.177\cdot10^{-4}I_wU_aL; \quad (3)$$

• dependence of NO_2 concentration on power of the welding arc and distance to arc in welding

without ventilation:

$$C_{NO_2} = -4.991\cdot10^{-2} + 0.414\cdot10^{-4}I_wU_a + 0.942\cdot10^{-2}L - 0.11\cdot10^{-4}I_wU_aL, \quad (4)$$

with general ventilation:

$$C_{NO_2} = 1.344\cdot10^{-2} + 0.209\cdot10^{-4}I_wU_a - 4.014\cdot10^{-2}L, \quad (5)$$

with local ventilation:

$$C_{NO_2} = 2.195\cdot10^{-2} + 0.162\cdot10^{-4}I_wU_a - 4.182\cdot10^{-2}L. \quad (6)$$

The values of relative errors and total correlation factors of determined dependencies are shown in Table 1. As can be seen from the Table, the values of relative errors do not exceed (25 %) value [4] indicated by procedural directives. The total correlation factors of data of dependencies have values from 0.94 to 1.0 (see Table 1) that indicates that obtained mathematical dependencies can be used for calculation of concentration of carbon oxide and nitrogen dioxide in the welder's breathing zone and in the working zone for the purpose of hygiene and sanitary evaluation of the work environment.

Comparison investigations of concentration of these gases in different points of space in welding without ventilation with other known grades of the electrodes were carried out with the aim to check the validity of mathematical dependencies (1)–(6) for other grades of electrodes differing by coating composition. These results showed that the mean concen-

Table 2. Concentration of carbon oxide in air of the working zone

Electrode grade	Distance to welding place L, m		
	0.55	1.00	1.50
	Minimum and maximum allowable concentration CO, mg/m^3		
	0.64–1.06	0.29–0.49	0.13–0.21
ANO-36	0.85	0.39	0.17
ANO-4	0.65	0.43	0.13
ANO-24	0.40	0.22	0.10
UONI-13/55	1.23	0.29	0.50
ANO-6	1.19	0.02	0.73

Table 3. Concentration of nitrogen dioxide in air of the working zone

Electrode grade	Distance to welding place L, m		
	0.55	1.00	1.50
	Minimum and maximum allowable NO_2 concentration, mg/m^3		
	1.22–2.04	2.26–3.78	0.79–1.31
ANO-36	1.63	3.02	1.05
ANO-4	1.56	2.60	1.23
ANO-24	0.85	1.42	1.37
UONI-13/55	2.34	1.58	1.33
ANO-6	2.40	1.78	1.98

trations of determining gases do not exceed the limits of allowable error (25 %) among the electrode grades, indicated in Tables 2 and 3, only in welding with ANO-4 electrodes. Thus, a conclusion can be made that the mathematical dependencies (1)–(6) can be used for prediction of air pollution of the working zone, at least, in welding with rutile and rutile-cellulose covered electrodes.

The results of investigations of carbon oxide and nitrogen dioxide concentration dependencies in manual covered-electrode welding should be taken into account in carrying out the hygiene and sanitary evaluation of the work environment. At that the requirements of GOST 12.1.005–88 [11] should be followed. According to it, a total effect on human organism of unidirectional substances should be taken into account to prevent the possibility of excess of MAC in air of the working zone. Therefore, considering that carbon oxide and nitrogen dioxide have unidirectional general-toxic effect [11] the hygiene evaluation of air in the working zone and selection of ventilation system in this case are to be carried out keeping the following conditions:

$$\frac{C_{CO}}{MAC_{CO}} + \frac{C_{NO_2}}{MAC_{NO_2}} \le 1. \qquad (7)$$

Calculations, obtained on formula (7) based on data of Figure 1, showed that the results of total effect of oxide and nitrogen dioxide can take different values depending on the welding conditions (presence or absence of ventilation), distance to the welding arc and welding mode, i.e. can be more or less than 1, that makes the basis for selection of type and capacity of ventilation.

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