

This paper reports a study of the air medium where welding processes take place, with special attention paid to the evolution of carbon monoxide (CO) in the working medium in the process of gas welding. Plots were constructed and polynomial dependences were obtained to show a change in the concentration of carbon monoxide in the air of the working area during gas welding.

It was confirmed experimentally that the concentration of carbon monoxide exceeds the permissible sanitary and hygienic indicators MPC (20 mg/m³) during gas welding. As a result of the experiment, the effectiveness of the use of an additional device was proven, namely an umbrella gas concentrator, in order to capture welding gases that are formed during gas welding. It was established that the MPC is exceeded under certain working conditions and welding wire. The carbon monoxide formation during gas welding was analyzed; these processes were compared with electric arc welding. The mathematical dependences derived make it possible to assess the risks of the welders' work and conclude that the electric arc welding is characterized by a much higher rate of CO evolution from the beginning of the welding process (8.5 mg/s), that speed then decreases over 20 s by 2 times (to 4.5 mg/s). In 90 s, the speed becomes constant, to 2 mg/s. In comparison, gas welding has almost the same rate of CO formation, namely 0.3–0.9 mg/s.

By changing the types of welding wires used in gas welding and taking into consideration the type of material that needs to be welded (including the period of its use), it is possible to influence the volume of CO emissions entering the working area and an employee's respiratory area

Keywords: gas welding, analyzer-signaling device, carbon monoxide, harmful concentrations, gas poisoning

DETERMINING THE DYNAMICS OF CARBON MONOXIDE FORMATION DURING GAS WELDING PROCESSES

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1. Introduction

The industry uses more than 60 different types of welding processes. Among them, the most common are arc and electric arc welding. Based on the studies conducted in the 1970s, applying the above types of welding did not lead to significant changes in the health of employees over one or two shifts. Minor deviations were observed in the cases where semiautomatic types of welding were used in the carbon dioxide medium. Until 2021, very few studies were carried out into the formation and impact of carbon monoxide on the health of workers who executed arc welding processes.

Welding technology has moved significantly forward: over time, new gas welding mixtures have appeared, a methylene-alenic fraction (MAF gas) began to be used for welding, which is produced from the non-hydrogenated hydrocarbon fraction of ethylene production [1]. With positive technical characteristics, there is a poisonous aspect of its use, namely dizziness, suffocation, headache [2]. It should be noted that the specified symptoms are similar to the diagnosis of carbon monoxide poisoning.

Welding is widely used in large industrial centers. For example, in the city of Lviv (Ukraine), there are more than

200 large and about 9 thousand small enterprises, which, despite the general reduction of production for various reasons, execute activities related to the repair and retrofitting of various equipment. The main danger of the use of welding processes is that under a prolonged exposure of the employee's body to aerosols, dangerous ingredients accumulate in the body and increase the risk of cardiovascular and oncological diseases [3].

The SIZOD directory lists the dangerous ingredients that accompany the welding process with various materials but this list lacks carbon monoxide [4]. This indicates the probable risk of exposure to carbon monoxide with different consequences.

The relevance of this study is predetermined by the fact that the risk of getting an occupational disease from constant inhaling of welding gases is quite high. A survey of professional welders suggests that in many cases they experienced a condition similar to carbon monoxide poisoning but disregarded these symptoms. Job managers were also unaware about the possibility of carbon monoxide poisoning and, therefore, they did not warn workers. Such a situation cannot be considered normal and should be corrected immediately, by providing more information on the formation of carbon monoxide during welding operations.

2. Literature review and problem statement

Paper [5] describes the hazards that accompany the welding processes. The peculiarity of these processes is intensive heat generation (ray and convective), dusting, which leads to the dustiness of production facilities with toxic fine dust, and changes in the gas composition of the air of working area, which act in a complex negatively on the body of workers. In the process of welding, a high temperature of the welding arc is used, which contributes to the strengthening of oxidation and evaporation of metal, flux, protective gas, alloying elements. The vapors that are formed with convective flows carry gases and dust upwards, leading to great dustiness and gas pollution of production facilities. The ingress of harmful gaseous substances into the worker's body occurs through the respiratory tract and digestive tract, sometimes causing severe damage to the whole body. However, the issue of carbon monoxide formation during welding operations remained unresolved. Study [6] provides information that the most harmful gases released during welding and cutting include nitric oxides (especially nitrogen dioxide), which cause diseases of the lungs and blood circulatory organs. Carbon monoxide (suffocating gas) is a colorless gas, which has a sour taste and smell; when it accumulates in the room it displaces oxygen at a concentration of CO exceeding 1 %, leads to irritation of the respiratory tract, causes loss of consciousness, duffle, convulsions, and damage to the nervous system. Ozone, the smell of which in high concentrations resembles the smell of chlorine, is formed during welding in inert gases, quickly causes eye irritation, dry mouth, and chest pain. Fluorinated hydrogen is a colorless gas with a strong odor, which acts on the respiratory tract and, even in small concentrations, causes irritation of the mucous membranes.

However, it should be noted that in addition to the toxic substances mentioned above, there are heavy metals that accompany the welding processes. In paper [7], the analyzed metals in evaporation decreased in the following order Fe>K>Pb>Co>Cd>Ca>Ni>Mn>Zn>Cr>Al>Cu>Mg. Observation of changes in the behavior of the animals studied, compared to control, testified to probable toxicity. It was found that exposure to welding vapors containing a significant amount of heavy metals caused noticeable symptoms of toxicity while increasing the level of metals in the blood. However, it is necessary to take into consideration the complexity of the influence of heavy metals and other ingredients formed during welding.

Paper [8] reports the results of a study at one of the metallurgical plants in 2017. Seven types of welding were studied, including SMAW-E7018, SMAW-E730, MIG, MAG, PAW, SAW, and GTAW. Samples from NO, NO₂, CO, CO₂ and O₃ were taken using direct reading devices. An approach proposed by the Singapore Department of Labor Protection was used to assess the risk of radiation for health. The study results showed that the average range of exposure of welders to gases NO, NO₂, CO, CO₂ and O₃ in various welding processes was 30–50; 2,456–5,000; 2–12; 3.5–6; and 0.16–0.5 parts per million (ppm). The maximum and minimum impact concentrations of each gas were observed during the MIG and PAW welding processes. The results of the risk assessment showed that ozone and nitrogen dioxide had a very high level of risk, while that of nitrogen oxide is «insignificant» in all types of welding. Among the different types of welding, the biggest and least risks of welding were related to MIG and PAW, respectively.

CO connects to hemoglobin 250 times easier than oxygen. In this case, carboxyhemoglobin (HbCO) is formed, which cannot transport oxygen, which results in hypoxia – together with cytochrome oxidase. This impairs the transport of electrons in the respiratory chain and leads, among other things, to the formation of free radicals and damage to the membrane structures of cells. The lethal dose depends on the concentration of CO in the air that is inhaled, exposure time, respiratory activity (accumulation of poison); the concentration of 1,000 particles per million (0.1 %) is dangerous for health while the concentration of 1,500 particles per million (0.15 %) quickly leads to death [9].

Paper [10] reports the results of a study that determined that the CO evolution rate is 386–883 ml/min using a solid wire and 331–1,293 ml/min using a wire powder wire, respectively. It was found that the concentration of CO in the premises would theoretically be maintained below OSEL PEL (50 ppm) provided that the ventilation speed in the premises is 6.6–25.9 m³/min. At that time, the actual need for ventilation was estimated at 6.6–259 m³/min, taking into consideration incomplete mixing. However, an issue remained unresolved related to providing ventilation to jobs in mines, ditches, or other places not adapted for welding. Repair and emergency work of welders should be carried out at their own risk in such places. An option to overcome the corresponding difficulties may be to study the nature of the formation of welding gases and ensure appropriate conditions for the protection of workers.

Paper [11] states that gases such as helium, argon, and carbon dioxide displace oxygen in the air and can lead to suffocation, especially when welded indoors. Carbon monoxide can form, which poses a serious danger of strangulation, so welders must understand the dangers of the materials they work with. Welding surfaces should be cleaned of any coatings that could potentially cause toxic effects, such as solvent residues and paint. It is indicated that workers should remain in the wind when welding in open. This is very important, especially when performing repairs with outdated metal appliances, pipes, etc. However, the issue of the impact of obsolescence of materials on the formation of aerosol welding gases and carbon monoxide remained unresolved. The reason for this may be a lack of information on the formation of carbon monoxide during gas welding operations, which makes relevant studies.

Paper [12] proposes assessing the health risks associated with the flue gases from welding by using five methods of assessing the health risks of employees and to compare the advantages, disadvantages, and applicability of these methods in assessing the health risk of welding smoke. All five models are suitable for assessing health risks from welding vapors but they all have certain disadvantages. They should be combined with qualitative and semi-qualitative evaluation results for a comprehensive analysis taking into consideration carbon monoxide. Paper [13] reports a study into the effect of protective gas composition with different CO₂ content on the appearance and efficiency of the welding seam in the process of hybrid welding with laser-tungsten inert gas (TIG). The paper does not specify the means of protection of employees. In article [14], the purpose of the study was to analyze and assess the impact of production aspects of welding processes (the stability of short-circuit metal transfer and protective gas composition) on the level of gas emissions during MIG/MAG welding (the aspects of labor and the environment protection). It was found that the richer the composition of protective gas in CO₂, the more CO and CO₂

is formed by the arc. However, unlike smoke emissions, the stability of voltage and transmission did not affect the formation of these gases. It was also found that despite a large amount of CO and CO₂ released by the arc, especially when using pure CO₂ protective gas, there was no high residual concentration of CO and CO₂ in or near worker's respiratory area, even in confined working chambers.

The results of a study of carbon monoxide and carbon dioxide formation are given in paper [15], which indicates that carbon monoxide (CO) and CO₂ can be formed in melted welding processes by the effect of heat on flux materials such as carbonates and cellulose. Flame processes also generate CO and CO₂. Relative amounts depend on whether the flame is oxidized or reduced; in this case, CO is present in higher concentrations when the flame is restored. It is emphasized that CO is the most dangerous of the two gases. This can lead to a decrease in the carrying capacity of the blood to oxygen, which can be fatal. In lower concentrations, it causes headaches and dizziness, nausea, and weakness. CO has a short exposure limit (15-minute control period) of 200 ppm and a long-term (8-hour control period) of 30 ppm. The amounts of CO and CO₂ resulting from flaming processes are also small, so the risk of excessive exposure is usually low. In special cases, such as high-speed cutting of oxygen-fuel gas, when a large amount of gas is consumed over a short period of time, there may be a problem of excessive exposure to CO.

Paper [16] proposes a higher-level ART mechanistic model for assessing the inhalation effects of chemicals using a Bayesian approach. The ART model does not include the influence of welding vapors within its scope; it was adjusted only for fumes, fog, and dust. To expand the application scope of metal fumes, it is proposed to revise the structure of the model to make sure that it is appropriate and to adjust the updated model using existing measurements of welding smoke exposure.

Study [17] states that the International Agency for Research on Cancer (IARC) has reassigned welding aerosols into Class 1 carcinogens and stressed the real health risks of welders. Previously, they were categorized as «possibly carcinogenic to humans», and, therefore welders should take all possible precautions to protect their health, even if the risk is not visible. The exact composition of the welding smoke varies depending on the application and the welding technique used. There are two main components: metal dust particles, caused by welding, are so small (approximately 0.0001 mm) and highly concentrated that seem to be smoke, posing a high risk of inhalation. This dust can consist of several toxic metals, including aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, iron, lead, manganese, molybdenum, nickel, silver, tin, titanium, vanadium, and zinc. Melting metals forms several potentially toxic gases. These include argon, carbon dioxide, carbon monoxide, helium, fluoride hydrogen, iron oxide, nitric acid, nitrogen dioxide, ozone, and phosgene.

Our review of the literary data has proven that scientists are conducting research on welding processes regarding the dusting of production facilities with toxic fine dust and changes in the gas composition of the air of working area, which act in a complex negatively on the body of workers. The studies' results indicate that they were carried out comprehensively in order to determine the maximum amount of emission entering a working area.

The problem is that those studies did not pay attention to the following:

- gas welding, especially when working with outdated metal products that are welded during repair work in closed areas;

- carbon dioxide, which is the source of many poisonings of people in fires and other operations with open flames;
- there is practically no information on the dynamics of carbon monoxide formation during gas welding and the factors that affect these processes.

3. The aim and objectives of the study

The purpose of this work is to determine the dynamics of carbon monoxide formation and its distribution in the working medium during gas welding operations. The would-be results could provide an opportunity to calculate the risks of carbon monoxide poisoning of welders, to provide recommendations on the use of ventilation systems and analyzer-signaling devices in a working area of welders. That would make it possible to minimize the risk of carbon monoxide poisoning when performing gas welding.

To accomplish the aim, the following task has been set:

- to investigate the factors of influence on increasing the concentration of CO during gas welding.

4. The study materials and methods

Our experiment to investigate carbon monoxide in gas welding was conducted at the National Technical University «Kharkiv Polytechnic Institute» in 2021. The ambient conditions were as follows: atmospheric air pressure – 735 mm Hg, air temperature – 28.5 °C. The experiments were carried out in a closed utility yard and in the premises equipped for gas welding work.

Devices, equipment, and materials. The material that was welded was chosen among those that are more often welded during repair work on home pipeline networks. The elements that were welded were metal samples (pipe), made of steel St5, and metal samples (pipe) made of steel ASt20. The thickness of the pipe wall was 4 mm.

During the research, the welding wire of the brand SV08G2S was used made in Ukraine by LTD «ELIZ» Zaporizhzhia Transformer Plant (thickness, 1.4 mm). This alloyed wire for welding semi-automates SV08G2C with a diameter of 1.4 mm is made of rolled steel, grade SV08G2C, and has the following chemical composition:

The chemical composition of the welding wire SV08G2S with a diameter of 1.4 mm, in % [19]: C – not more than 0.08; Mn – 1.8–2.1; Si – no more than 0.7–0.95; P – 0.03; S – 0.025; Cr – no more than 0.2; Ni – not more than 0.25; Cu – no more than 0.25.

The gas used in gas welding: acetylene (pressure 15 atm.), in a cylinder of white color. Oxygen: (pressure up to 150 atm.), in a cylinder of blue color.

The study on determining the level of CO concentrations was carried out by the multicomponent individual signaling device-analyzer of gases «DOZOR-S-M», Kharkiv, Ukraine.

The measurement device specifications. We used the following: signaling device-analyzer DOZOR-S-M, manufactured by the research and production enterprise «ORION». The signaling device is designed to measure the concentration of components in the gas mixture of flue gases (released gases). The signaling device-analyzer can be used to control air pollution at production facilities.

The analyzed gas mixture was taken through a gas intake probe. A gas intake probe is designed to provide for

the accuracy of measurements of the concentration of flue gas components, sampling of flue gases from the chimney, as well as to protect equipment from abrasive wear by solid fuel combustion products. The sensing element to carbon monoxide (CO) and sulfur dioxide (SO₂) is a three-electrochemical cell, which, once a component to be detected is in the gas mixture, generates an electrical signal directly proportional to its concentration. Our research was carried out according to the manual to the signaling device-analyzer DOZOR-S-M.

The acquired measurement results were stored as an archive of research findings, registering the time and date of measurements by the device, as well as for viewing on a personal computer through a USB and an IR adapter port.

During the research, it was taken into consideration that the carbon monoxide released during the welding processes is difficult to determine in the working area, so we used an additional dome-shaped canopy directly in the welding zone in order to determine its concentration.

Fig. 1 shows the process of measuring the aerosols, which are formed during gas welding.



Fig. 1. The process of studying the concentration of aerosols, which are formed during gas welding using the signaling device-analyzer DOZOR-S-M

The results of CO concentration measurements of 5.1 were obtained only using an umbrella gas concentrator.

The peculiarity of the experiments is that the influence of carbon monoxide on the welder is investigated, due to the possible ingress of welding gases into the respiratory system. The distance of the welding working area to the respiratory organs of the worker is 0.5–0.8 m. The peculiarity of the negative impact of CO is the possibility of gas concentration in closed areas of welding masks and helmets of welders. Of course, in the open air, any gas would dissipate quickly and dissolve due to its diffusion in the air. However, under windless conditions and in enclosed areas (mines, basements, wells, etc.), this does not happen, and this can cause suffocation of the employee or poisoning. It is the umbrella gas concentrator that is the physical model of such a process of accumulation of welding gas. Carbon monoxide would accumulate in the area located near the respiratory system of the worker, which is dangerous and can cause occupational diseases and contribute to the occurrence of other concomitant diseases, the study of which is highlighted in [14–17].

Thus, our experiment proved the effectiveness of the use of an additional device, namely an umbrella gas concentrator, in order to capture welding gases that are formed during gas welding. With conventional measurements of gas emissions, even when using the suction device of the signaler-analyzer DOZOR-S-M, the concentration of CO was impossible to measure.

5. Results of studying carbon monoxide formation during gas welding processes

Table 1 gives the concentrations of CO in gas welding of steel pipes, grades St5 and St20, which have previously been used for more than 30 years.

Fig. 2 shows the built dependence of CO concentration on time in the welding zone during gas welding (steel pipe, St5 and St20).

Table 1

Results of research on the formation of CO during gas welding, mg/m³

Study title and its characteristics	CO concentration, mg/m ³						
	Experiment duration, s						
	30	40	50	60	70	80	90
Pipe (St5)							
Study 1	10.5	17.0	25.0	41.5	46.0	50.0	54.0
Study 2	10.7	17.5	26.5	41.5	47.0	51.5	56.0
Study 3	11.1	16.5	23.5	40.0	46.0	52.5	55.0
Determining an average value	10.8	17.0	25.0	41.0	46.0	51.0	55.0
Measurement error 1, mg/m ³ (%)	0.3 (2.7)	0 (0)	0 (0)	0.5 (1.2)	0 (0)	1.0 (2.0)	1.0 (1.9)
Measurement error 2, mg/m ³ (%)	0.1 (0.92)	0.5 (2.9)	1.5 (2.0)	0.5 (1.2)	1.0 (2.2)	0.5 (1.0)	1.0 (1.9)
Measurement error 3, mg/m ³ (%)	0.3 (2.7)	0.5 (2.9)	1.5 (2.0)	1.0 (2.4)	0 (0)	1.5 (2.9)	0 (0)
Average value, %	2.1	1.9	1.3	1.6	0.7	2.0	1.3
Pipe (St20)							
Study 1	13.5	28.0	41.5	44.0	49.0	54.5	56.5
Study 2	14.0	30.0	41.5	43.0	48.0	54.5	57.5
Study 3	14.5	29.0	40.0	45.0	47.0	54.0	60.0
Determining an average value	14.0	29.0	41.0	44.0	48.0	54.0	58.0
Measurement error 1, mg/m ³ (%)	0.5 (3.6)	1.0 (3.4)	0.5 (1.2)	0 (0)	1.0 (2.1)	0.5 (0.9)	1.5 (2.6)
Measurement error 2, mg/m ³ (%)	0 (0)	1.0 (3.4)	0.5 (1.2)	1.0 (2.3)	0 (0)	0.5 (0.9)	0.5 (0.9)
Measurement error 3, mg/m ³ (%)	0.5 (3.6)	0 (0)	1.0 (2.4)	1.0 (2.3)	1.0 (2.1)	0 (0)	2.0 (3.4)
Average value, %	2.4	2.3	1.6	1.5	1.4	0.6	2.3

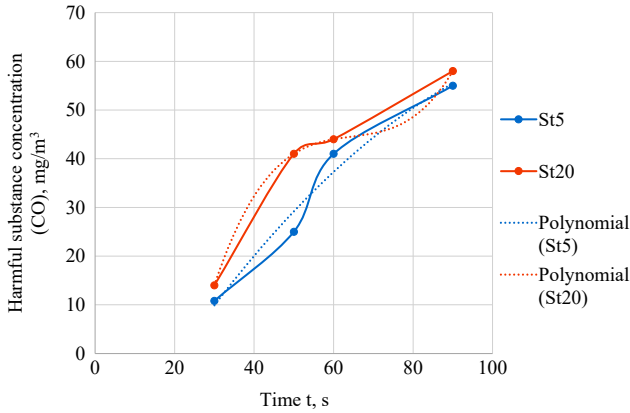


Fig. 2. Dependence of CO concentration on time in the welding zone during gas welding (steel pipes, St5 and St20)

The equation that gives the CO concentration increase (accumulation) over time was derived using the EXCEL software. The traditional interpretation of different levels of significance is $\alpha=0.05$. This value of α is recommended for small sampling (when the probability of the second-kind error is high). After processing the results of the experiment, the level of significance of each coefficient by which the equations were truncated was determined (Table 1). Only significant numbers were left after the comma, while other digits were discarded, so the equations take the following form for St5 and St20:

$$y_{St5} = -0.0003x^3 + 0.0483x^2 - 1.5529x + 21.543, \quad (1)$$

$$y_{St20} = 0.0003x^3 - 0.0699x^2 + 5.2274x - 88.976. \quad (2)$$

The polynomial dependence was chosen as a result of comparing R^2 indicators at different trend lines: linear, polynomial, logarithmic (Table 2).

Table 2

R^2 indicators obtained at different trend lines of equations (1) and (2)

Trend line	R^2	
	St5	St20
linear	0.9623	0.9186
polynomial	0.988	0.9949
logarithmic	0.9689	0.9759

It follows from Table 2 that the polynomial equation is the most acceptable.

Previous studies have shown that during electric arc welding there is a formation of CO [5]. Fig. 3 shows the plots constructed to compare the increase in CO concentration in the welding zone during gas welding and electric arc welding. The studies were carried out under the same conditions of gas and electric welding processes, that is: premises without ventilation; the same welded material; electric current of electric arc welding was 200 A.

In accordance with equations (3) to (8), as well as for equations (1) and (2), the results obtained in the studies were processed. After processing the results of the experiment, the level of significance of each coefficient at $\alpha=0.05$ was determined. Only significant coefficients were left. It is de-

termined that the change in carbon monoxide concentration occurs follows the polynomial dependence for St5 and St20:

$$y_{St5} = -0.00024x^3 + 0.0357x^2 - 0.6x + 9.59 \quad (R^2=0.985); \quad (3)$$

$$y_{St20} = -0.0003x^3 + 0.039x^2 - 0.758x + 8.6, \quad (R^2=0.985). \quad (4)$$

Under the following conditions for electric arc welding:

$$y_{ea} = 0.0004x^3 - 0.07x^2 + 4.975x + 41.8, \quad (R^2=0.999). \quad (5)$$

Fig. 4 shows the comparison of the speed (mg/s) of CO formation during electric arc and gas welding.

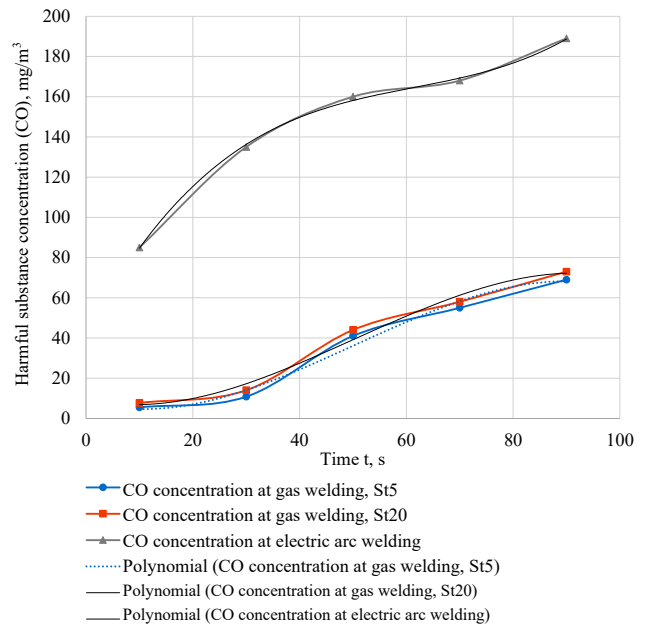


Fig. 3. The dynamics of CO concentration change dependent on time in the zone of gas and electric arc welding

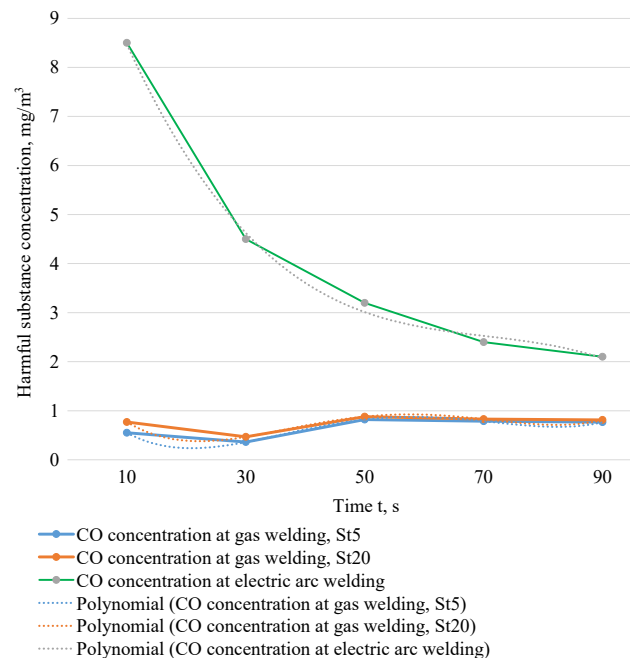


Fig. 4. Dependence of the rate of CO formation on time in the welding zone during gas and electric welding

The rate of CO formation follows the polynomial dependences for St5 ($R^2=0.997$) and St20 ($R^2=0.98$) (formulas (6) and (7)) during gas and electric arc welding ($R^2=0.998$) (formula (8)):

$$y_{St5}=0.07x^4-0.897x^3+3.99x^2-7.045x+4.65; \quad (6)$$

$$y_{St20}=0.069x^4-0.88x^3+3.881x^2-6.71x+4.2; \quad (7)$$

$$y_{ea}=-0.183x^3+2.21x^2-9.2x+15.64. \quad (8)$$

Analyzing the derived mathematical dependences (3) to (8), it is necessary to pay attention to the fact that electric arc welding is characterized by a much higher rate of CO formation from the beginning of the process (8.5 mg/s), then this speed is reduced in 20 s by 2 times (to 4.5 mg/s). After 90 s, the speed becomes almost constant, to 2 mg/s.

Having information on the rate of formation of CO, it is possible to calculate the time when the concentration of dangerous gas would begin to exceed MPC during gas welding. That is, at a speed of 0.5–0.7 mg/s after 5–6 minutes in a room with a volume of 8 m³, the concentration of CO in a working area would exceed MPC=20 mg/m³ in the absence of air movement.

6. Discussion of results of studying the formation of carbon monoxide in the processes of electric arc welding

The concentration of CO increases during gas welding, when the wire SV08G2C is added (effective GOST since 1973). All the results of our study, obtained and given, proved that the process of burning of welding gas in a burner is not a source of CO formation (less than 1 mg/m³ per 90 s) and has a possible negative impact on humans. These findings are not listed in the present paper given their small values.

It was established that the formation of carbon monoxide is associated with the wire used in welding, as well as the welded material. All the polynomial dependences shown in Fig. 2, 3 indicate the effect of the welding wire on the increase in CO in the air of a working area. Previous studies of electric welding [5] proved that the type of electrode chosen for welding significantly affects the number of gas emissions during welding.

The obtained dynamic characteristics of changes in the rate of CO formation over time (Fig. 4) indicate the risks of more likely carbon monoxide poisoning in electric welders than in gas welders. Therefore, it is necessary to take into consideration the widespread use of electric welding operations and require justification for the use of this type of welding, rather than gas welding, which, according to the indicators from our research (Fig. 4), is less dangerous.

Thus, analyzing the study results illustrated in Fig. 2–4, it can be assumed that by changing the types of welding wires used in gas welding and taking into consideration the type of material that needs to be welded (including its period of use),

it is possible to influence the volume of harmful CO emissions entering the working area and the worker's respiratory zone. It is necessary to take this into consideration in further studies with various welding wires and reduce the indicators of CO formation to the minimum possible.

Given the contamination of metal pipes, various conditions for their actual use, it is also necessary to plan experiments with various materials for steel pipes, beams with different terms of their use, and metal fatigue. It is worth noting that workers engaged in welding work pay attention to the deterioration of health when welding metal products that have a significant service life (more than 25–30 years).

The main protection against the negative impacts of welders' workflows is a change in technology. Our study has proven that there is a need to certify welding wires by the number of CO emissions. This may be the direction of further research and amendments to state standards regarding welding operations.

For comparison, earlier studies have shown that with electric arc welding in a closed volume, CO air saturation occurs much faster than during gas welding, starting on second 10 from the beginning of the process.

The disadvantages of our study include the following:

- no substantiation of the size of the umbrella concentrator in terms of the capture and analysis of welding gas, CO, has been performed;

- it was necessary to determine the number of welding wires of at least 3 and to systematize them in accordance with the probability of carbon monoxide poisoning;

- it was necessary to determine the risk of workers' poisoning with CO when performing gas welding work, taking into consideration the experience of Megan McConville [17].

Possible areas of further research may include:

- identification of gases and ingredients in emissions formed during welding, which theoretically accompany the processes of combustion, melting, and heating of materials to high temperatures;

- determining the risks of the impact of welding emissions on the health of welding workers and others;

- analysis of existing and search for more environmentally friendly metal welding technologies that could replace existing costly and environmentally hazardous ones to humans and the environment, etc.

7. Conclusions

It has been proven that carbon monoxide is formed during gas welding; the dynamics of its formation follow polynomial dependences. It was established that the increase in the concentration of carbon monoxide in a working area is affected by the welding wire. It has been determined, when comparing the results of studies of gas welding with electric arc welding, that in terms of the formation of electrolysis gases (carbon monoxide), the latter is more dangerous, and, therefore, the risk of carbon monoxide poisoning is greater.

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