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Catalytic systems on a ceramic fiber carrier with deposited metals in the process of carbon monoxide oxidation

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ABSTRACT

This study explores the formation of catalytic systems for the oxidation of carbon monoxide on a ceramic fiber carrier with impregnated ferrite materials, including magnetite, copper ferrite, and chromium ferrite. The oxidation of carbon monoxide was carried out on a flow-type installation with a stationary weight of the catalyst in the temperature range of 50–450 °C and an initial concentration of 1–2 vol % of carbon monoxide in the gas mixture at the entrance to the reactor. The highest degree of conversion of 98.6% at 450 °C was ensured using chromium ferrite. The composition of the main elements of the surface samples of the ceramic fiber catalyst was confirmed by micro-X-ray spectral analysis of the surface using scanning electron microscopy, which corresponded to the specified Cr6+: Fe2+ =1:15. The results show ceramic fibers modified by ferrites, which do not require significant capital investment, can effectively clean electrode graphitization furnaces and flue gases and neutralize toxic carbon monoxide. We propose a method of fixing the modified fibrous catalyst in a metal frame, which will allow it to be easily placed over the entire surface area of the thermal insulation of the Acheson graphitization furnace to ensure full-scale CO neutralization and subsequently be dismantled after the end of the carbon electrode heat treatment campaign.

Keywords: Carbon monoxide, flue gases, purification, catalyst, oxidation, conversion, ferrite method, graphitization furnaces

1. INTRODUCTION

The most polluted industrial regions in Ukraine in terms of carbon monoxide emissions are regions with a significant concentration of mining and processing enterprises (tabure 1), namely, Dnipropetrovsk, Donetsk, and Zaporizhzhia regions (some territory is currently under occupation).

Figure 1 Emissions of carbon monoxide into atmospheric air from stationary emission sources by region in 2021 (built by the authors on the Bing platform, Geonames Tomtom)

The total amount of CO emissions in the country is 704,344,218 tons per year which in percentage terms is 31.42% of the total emissions of pollutants and greenhouse gases other than carbon dioxide of 2,242,020.75 tons per year. In particular, the concentration of ecologically hazardous industrial enterprises in Zaporizhzhia, including Ukrgrafit PJSC, resulted in a territory with significant technological influence. The emissions of Ukrgrafit PJSC contain 47.056 % of carbon monoxide. As a result of their economic activities, gaseous emissions from industrial enterprises adversely affect the environment and even worsen workers' sanitary and hygiene conditions (Panov et al., 2019; Panov et al., 2020; Ivanenko et al., 2021). The release of large amounts of poisonous CO into the atmosphere is a serious problem that must be solved at the level of industrial production.

One of the practical approaches to purifying industrial gas emissions from toxic carbon monoxide is the application of catalytic technologies due to the use of compositions based on transition metals, especially ferrite materials (Lou and Chang, 2006). Despite the relatively high initial costs, the catalytic cleaning method has many advantages, including in comparison with thermal afterburning: The operating temperature of the catalytic process is significantly lower than the temperature of thermal afterburning; less harsh working conditions of the equipment, and because of longer service life; the possibility of regeneration of the catalyst. In this case, traditional technological approaches use significant masses of carrier granules with appropriately applied active coatings as catalysts, loaded into special devices several meters high (Ivanenko et al., 2023). Simultaneously, the mass of the catalyst can reach tons. Block catalysts can also neutralize airflows (Ivanenko et al., 2021). As shown in the study Groppi and Troncon, (2005), the advantages of block catalysts compared to granular catalysts consist of lower hydraulic resistance and small reactor sizes.

However, block catalysts have inevitable disadvantages associated with heat and mass exchange in the channel of the block, a decrease in filtration capacity Matatov-Meytal and Sheintuch, (2002), which limit their use in many processes that have an environmental focus. Recently, toxic gas neutralization systems, which include glass fiber catalysts, have become widely popular

(Zagoruiko and Lopatin, 2019). These systems can be used in any industry, and their advantages include high activity, long-term stable operation in a wide temperature range, resistance of the active component to “catalytic poisons”, and low hydraulic resistance. In addition, the geometric shape of glass fiber catalysts allows the creation of optimal and economical packaging variants in various devices and reactors, which allows for the optimization of capital and operating costs during the design of technological processes.

Catalysts containing noble metals (Pt and Pd) applied to a braided glass fiber base have attracted much attention because they are characterized by high efficiency and cost (Zagoruiko et al., 2007). Possible active components may also include oxides of transition metals depending on the requirements of the target catalytic process (Lopatin et al., 2015). For the impregnation of noble metal catalysts, the fiberglass carrier was pre-treated with a hydrochloric acid solution for surface activation Kiwi-Minsker et al., (1999), which requires additional costs and necessary equipment during production. This study aimed to determine the activity of glass fiber catalysts in the CO oxidation reaction depending on the catalytically active component (ferrite material) applied without preliminary treatment.

2. MATERIALS AND METHODS

Ceramic fiber LYTX-512, manufactured by Shandong Luyang Share, China, was used as a glass fiber support for catalytic systems of oxidation of gas emissions containing CO (Figure 2). Properties of ceramic fiber LYTX-512 are given in the (Table 1). The application of the investigated fibrous catalyst is envisaged in Acheson's graphitization furnaces in producing carbon electrodes (Figure 3). As can be seen from Figure 3, a metal frame with a 2.5 cm thick modified fiber catalyst firmly fixed in it (Figure 4) is located over the entire surface area of the thermal insulation of the graphitizing furnace with a length of 12960 mm and a width of 4200 mm to ensure complete CO neutralization.

Due to the constant maintenance of a high temperature on the surface of the thermal insulation of the Acheson furnace and the prevention of air dilution of the gas flow, the developed catalytic system for the oxidation of carbon monoxide has indisputable advantages for implementation over the existing system at the enterprise, which includes exhaust ventilation of the workshop room with subsequent CO afterburning in the chimney. In addition, the metal frame with the catalyst is convenient to move with the help of a crane beam after the end of the electrode graphitization campaign.

Figure 2 The appearance of ceramic fiber felt LYTX-512 manufacturer Shandong Luyang Share, China

The proposed catalysts were studied under conditions close to actual production conditions, in which the concentration of CO at the outlet of the Acheson graphitizing furnaces is 1-2% in the gas flow at the outlet of the stove at an average of 6.1 m3/s. Taking into account that the maximum surface temperature of the top layer of the overfill of the graphitizing furnace is about 1250 °C, the use of a fibrous catalyst is quite acceptable since the working temperature of the LYTX-512 ceramic fiber is 1350 °C.

Table 1 Properties of ceramic fiber LYTX-512 with a thickness of 2.5 cm manufactured by Shandong Luyang Share, China

Basic technical characteristics	LYTX-512
Application temperature, ºC:	
Maximum	1427
Working	1350
Density, kg/m3	128
Linear shrinkage, %:	
At a temperature of 950 ºC	-
At a temperature of 1100 ºC	1.9
At a temperature of 1350 ºC	3
Breaking strength, MPa	0.08-0.12
Chemical composition:	
Al2O3	38-40
SiO2	43-47
ZrO2	15-17

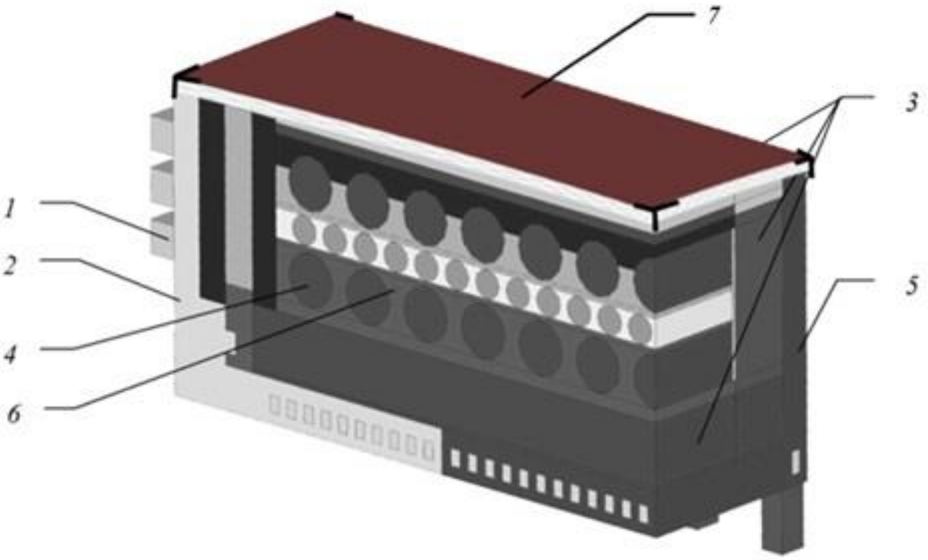


Figure 3 Scheme of laying modified LYTX-512 ceramic fiber in a metal frame on top of the thermal insulation of the Acheson graphitization furnace: 1 – conductive electrodes, 2 – end walls, 3 – heat insulating charge, 4 – core filler, 5 – side walls, 6 – blanks (electrodes), 7 – catalytic material

In addition to the oxidation of carbon monoxide, the full-scale laying of ceramic fiber on the surface of the overburden will reduce the entry of air oxygen into the porous space of the overburden and the formation of carbon monoxide, which will also contribute to the improvement of the ecological situation at the electrode production and improve the sanitary and hygienic working conditions of the personnel. The calculation of the total gas flow rate in the experimental installation considered the technological features of the electrode graphitization process at the production site.

The size of the catalyst web is S = 12.96 m · 4.2 m = 54.432 m2. Considering its thickness (2.5 cm) and specific weight (128 kg/m3), the amount of catalyst for the furnace will be 174.2 kg. At the exit from the furnace, the gas flow is 6.1 m3/s = 366 m3/min. Thus, the volumetric velocity of furnace gas per 1 kg of catalyst is

$$\omega = \frac{366^{\mathrm{M}^3}/_{min}}{174\,kg} = 2{,}1\,{}^{m^3}/_{(kg\cdot min)}.$$

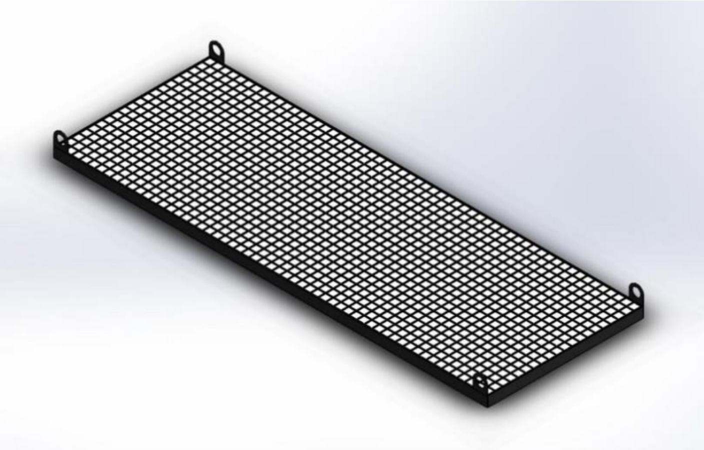


Figure 4 Appearance of the CO oxidation catalytic system

The same conditions were chosen for the study of the catalysts at the experimental plant. Indeed, 2.1 m3/(kg·min) = 2.1 dm3/(g·min). Considering that 2.5 g of catalyst was loaded into the reactor, the gas flow rate was 2.1 dm3/(g·min) · 2.5 g = 5.25 dm3/min. The total gas flow rate during the research was 5 dm3/min. The CO oxidation process was studied on a flow-type installation with a stationary catalyst weight, as shown in (Figure 5). A reactor (4) with a catalyst (8), a device for introducing the analyzed gases, including a sampler (9), and a gas chromatograph (10) are the primary units of the installation.

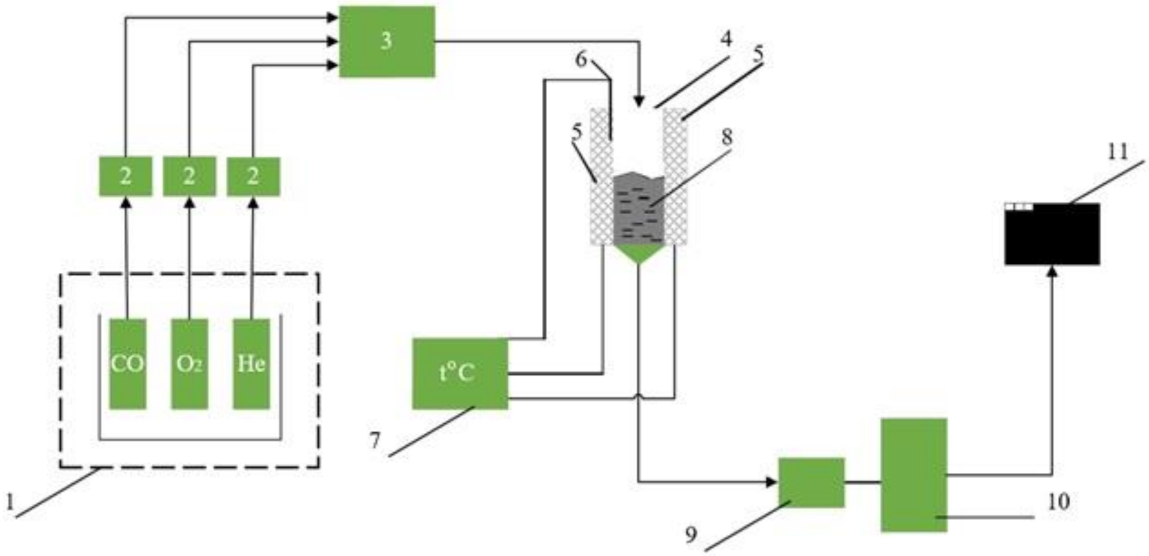


Figure 5 Scheme of the experimental installation for studying the processes of catalytic oxidation of carbon monoxide: 1 – unit with cylinders of carbon monoxide, oxygen, and helium of the brand "Extra Clean", 2 – Bronkhorst EL-FLOW F-111AC gas flow meters, 3 – gas mixer, 4 – flow-type reactor with stationary catalyst weight, 5 – electric heater, 6 – thermocouple; 7 – meter-regulator temperature, 8 – catalyst, 9 – sampler, 10 – gas chromatograph Agilent 8890 GC System CO-CO2 Analyzers, 11 – digital measurement interface

The reactor is a heat-resistant glass tube with an electric heater (5). Temperature change control was carried out using a thermocouple (6) with an accuracy of ±1.0 °C, connected to the temperature controller (7). During experiments, CO, O2, and He gases stored in cylinders (1) are fed to rotameters (2), through which the gas flow is regulated, and the mixture of gases enters the reactor (4) after mixing. A fabric filter is installed at its bottom to retain the catalyst inside the reactor. After passing through the catalyst layer (8) located in the reactor, the reaction mixture enters the sampler (9), from where a portion of it is periodically sent to the chromatographic column (10) using a dosing tap. The fuel component's oxidation degree is controlled by taking a chromatogram through the registration device (11) with the installed software.

During the experiment, a sample of the fibrous catalyst (8) weighing 2.5 g was placed in a cylindrical reactor (4) in such a way as to exclude the passage of the gas mixture past the catalyst. The dimensions of the reactor were as follows: height 220 mm, internal diameter 8 mm. The volume velocity of the gas flow was 5 dm3/min. The composition of the gas mixture at the entrance and exit from the thermal chamber was constantly monitored during the heating process. Helium was used as an inert gas, if necessary. The concentration of the reaction products was analyzed using an Agilent 8890 GC System gas analyzer, and the relative standard deviation of the repeatability of the peak area was 0.5%. Immediately before the catalytic experiment, the catalyst grain was subjected to heat treatment at 450 °C for 2 hours. Catalytic purification of the CO gas mixture was studied in the 50–450 °C range. The concentration of carbon monoxide in the initial gas mixture at the entrance to the reactor was varied in the range of 1 – 2 vol. %.

The carbon monoxide conversion was calculated according to the following formula:

$$X_{CO} = \frac{C_{CO}^{in} - C_{CO}^{out}}{C_{CO}^{in}} \cdot 100\%, \qquad (1)$$

де C_{CO}^{in} – mole fraction of CO at the entrance to the reactor, C_{CO}^{out} – mole fraction of CO at the exit from the reactor.

To obtain ferrite catalysts, six samples of LYTX-512 ceramic fiber with a size of 10 cm × 10 cm were immersed in a reaction mixture with a total concentration of 16.76 g/dm3 of iron (II), iron (III), copper (II), chromium (VI) ions according to the methods discussed later (Figure 6). In the future, a 10% solution of NH4OH was added to the reactor with stirring until pH 8 was reached because further addition of alkali, according to previous studies, contributed to the mechanical destruction of ceramic fiber during heat treatment.

Figure 6 The appearance of the received wet ferrite catalysts on a ceramic fiber carrier

Ceramic fiber samples were treated with a mixture of FeSO4·7H2O and Fe2(SO4)3·9H2O with concentrations of iron ions of 5.59 and 11.17 g·dm-3 (16.76 g·dm-3 of iron ions), respectively, for 1 hour to obtain a ferrite catalyst (Fe3O4 with a ratio of concentrations of iron (II) and iron (III) ions [Fe2+]:[Fe3+]=1:2 Dovholap et al., (2023) on a fibrous carrier:

FeSO4·7H2O + Fe2(SO4)3·9H2O + 8NH4OH → Fe3O4↓ + 4(NH4)2SO4 + 20H2O. (2)

To obtain a copper-ferrite catalyst ((FexCu1-x)Fe2O4 (x=0.60-0.65) with a concentration ratio of copper (II) and iron (II) ions [Cu2+]:[Fe2+]=1:4 Ivanenko et al., (2021) on a fibrous carrier, ceramic fiber samples were treated with a mixture of CuSO4·5H2O and FeSO4·7H2O solutions with concentrations of copper and iron ions of 3.35 and 13.41 g·dm-3, respectively (a total of 16.76 g·dm-3 of copper and iron ions) during 1 hour, after which the copper ferrite residue was precipitated with an NH4OH solution according to the following reaction:

2CuSO4·5H2O + 8FeSO4·7H2O + 20NH4OH + O2 → 2CuFe(FeO2)3↓ + 10H2O + 10(NH4)2SO4. (3)

To obtain a chromium-ferrite catalyst (Fe(FeyCr1-y)2O4 (y=0.91 – 0.92) with a ratio of concentrations of chromium (VI) and iron (II) ions [Cr6+]:[Fe2+]=1:15 Ivanenko et al., (2021) on a fibrous carrier, ceramic fiber samples were treated with a mixture of K2Cr2O7 and FeSO4·7H2O solutions with concentrations of chromium and iron ions, respectively, 1.05 and 15.71 g·dm-3 (a total of 16.76 g·dm-3 of chromium and iron ions) for 1 hour, after which the chromium ferrite residue was precipitated with NH4OH solution according to the following reactions:

Cr2O72- + 2OH- → 2CrO42- + H2O, (4)

2K2CrO4 + 9Fe(OH)2 →3Fe3O4↓+ 2Cr(OH)3↓ + 4 KOH + 4H2O. (5)

To obtain combined catalysts, 50% Fe3O4, 50% Fe(FeyCr1-y)2O4; 33.3% Fe3O4, 33.3% (FexCu1x)Fe2O4, 33.3% Fe(FeyCr1-y)2O4; 50% Fe3O4, 50% (FexCu1-x)Fe2O4 were mixed according to the percentage content of the components of the metal salt catalyst with the indicated ratios according to reactions (2) – (5). After impregnation with ferrites for 24 hours, the samples of modified ceramic fiber were separated from the aqueous phase and dried in air to a constant weight.

Therefore, the samples of the formed ferrite catalysts on solid ceramic fiber supports were removed from the solutions and, without wringing, were placed on metal grids until completely dry for further use (Figure 6). The composition of the main elements of the modified ceramic fiber samples after heat treatment at a temperature of 1000 ºC for 2 hours was determined by micro-X-ray spectral analysis of the surface of the ceramic fiber, performed using scanning electron microscopy using the PEM-106I equipment (SELMI, Ukraine).

3. RESULTS AND DISCUSSION

The obtained temperature dependences of the conversion of carbon monoxide with a concentration of 1% (12500 mg/m3) on the studied catalysts on a ceramic fiber carrier showed that 100% conversion of carbon monoxide is not achieved even at a temperature of 450 ºC in the case of using the obtained catalysts (Figure 7, 8). In the case of using a mixture of ferrites 50% Fe3O4, 50% (FexCu1-x)Fe2O4, the degree of CO conversion is 97.17% at a temperature of 300 ºC. 97.17% carbon monoxide oxidation efficiency is achieved even at a temperature of 450 ºC in the case of using chromium ferrite Fe(FeyCr1-y)2O4 and a mixture of ferrites 50% Fe3O4, 50% Fe(FeyCr1-y)2O4 and 33.3% Fe3O4, 33.3% (FexCu1-x)Fe2O4, 33.3% Fe(FeyCr1-y)2O4. At the exact time, the residual concentration of CO in the gas reaches 354 mg·m-3. When using magnetite Fe3O4 and copper ferrite (FexCu1-x)Fe2O4, the degree of CO conversion is 39.81% and 74.80%, respectively, with initial concentrations of 7524 and 3150 mg·m-3.

When comparing the activity of catalysts in the conversion of 1% (12500 mg·m-3) and 2% (25000 mg·m-3) of carbon monoxide, a high efficiency of using a mixture of magnetite and copper ferrite 50% Fe3O4, 50% (FexCu1-x)Fe2O4 is observed, which is 96.14% at a temperature of 300 ºC (Figure 9) and stably ensures CO neutralization until the degree of conversion of CO is 98.27% at a temperature of 450 ºC and a residual concentration of 433 mg·m-3 (Figure 10).

At a temperature of 450 ºC, when using chromium ferrite Fe(FeyCr1-y)2O4, the highest degree of conversion can be inevitable, which is 98.62% and provides 345 mg·m-3 of the initial CO concentration. However, the specified chromium-ferrite catalyst at a temperature of 400 ºC provides an oxidation efficiency of 86.79%; that is, it has fewer advantages for use with inevitable fluctuations in the temperature of gases in industrial conditions. As for other catalysts, mixtures of ferrites 50% Fe3O4, 50% Fe(FeyCr1-y)2O4 and 33.3% Fe3O4, 33.3% (FexCu1-x)Fe2O4, 33.3% Fe(FeyCr1-y)2O4 provide 97.73% purification at a temperature of 450 ºC (residual CO concentration 568 mg·m-3).

When using magnetite Fe3O4 and copper ferrite (FexCu1-x)Fe2O4, the degree of conversion of CO is 35.20% and 67.19%, respectively, and a decrease in the activity of catalysts is observed in comparison with the conversion of 1% of CO (39.81% and 74.80% in accordance). Previously conducted studies of the use of a block catalyst on an aerated concrete carrier determined Ivanenko et al., (2021) that when using a mixture of magnetite and chromium ferrite in a ratio of 1:1, the degree of oxidation reached 85.2% and provided better efficiency than when using chromium ferrite with an efficiency of 70.6%.

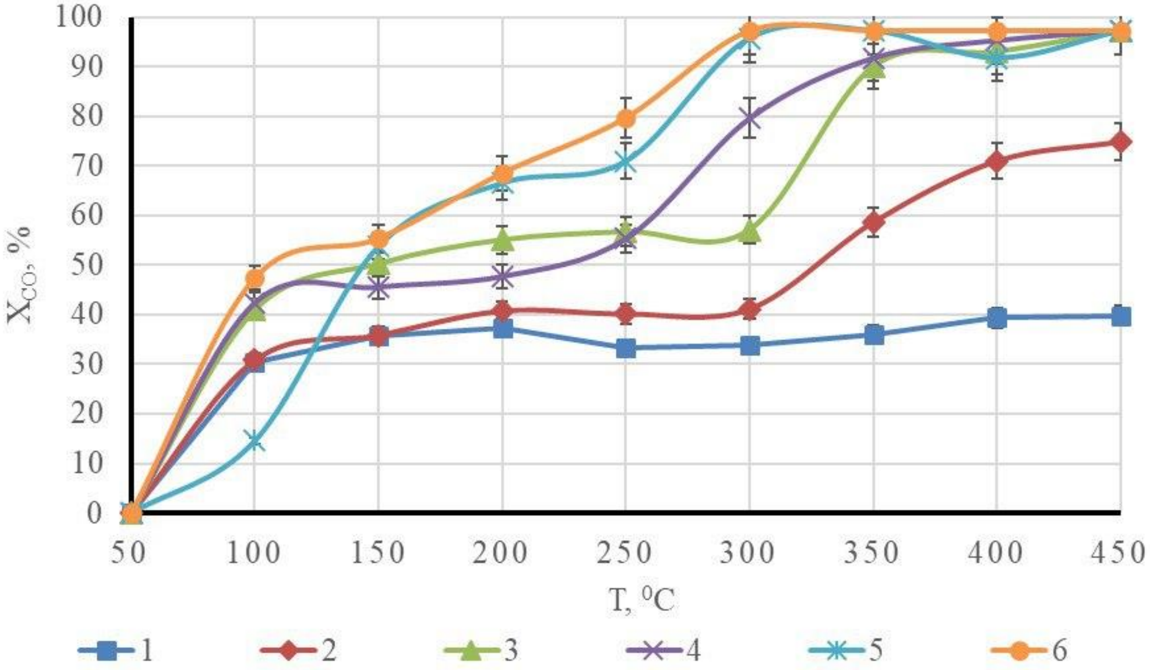


Figure 7 Temperature dependence of the degree of conversion of carbon monoxide with 1% initial concentration on catalysts on a ceramic fiber carrier: 1 - Fe3O4; 2 - (FexCu1-x)Fe2O4; 3 - Fe(FeyCr1-y)2O4; 4 - 50 % Fe3O4, 50 % Fe(FeyCr1-y)2O4; 5 – 33.3 % Fe3O4, 33.3 % (FexCu1-x)Fe2O4, 33.3 % Fe(FeyCr1-y)2O4; 6 - 50 % Fe3O4, 50 % (FexCu1-x)Fe2O4

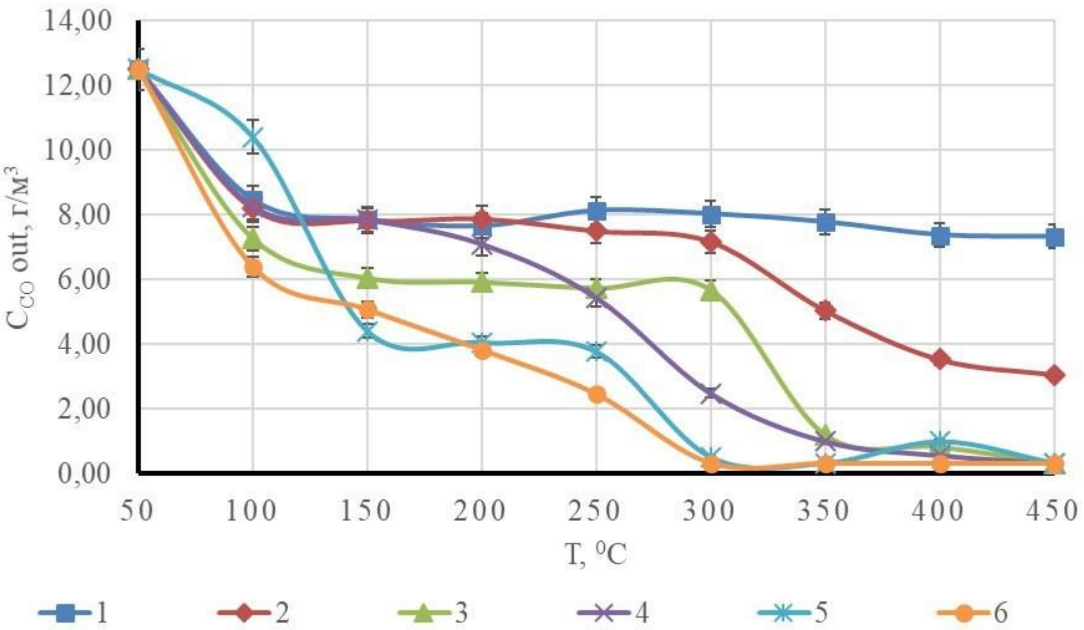


Figure 8 Change in the concentration of carbon monoxide with an initial concentration of 1% depending on the temperature of the catalysts on the ceramic fiber carrier: 1 - Fe3O4; 2 - (FexCu1-x)Fe2O4; 3 - Fe(FeyCr1-y)2O4; 4 - 50 % Fe3O4, 50 % Fe(FeyCr1-y)2O4; 5 – 33.3 % Fe3O4, 33.3 % (FexCu1-x)Fe2O4, 33.3 % Fe(FeyCr1-y)2O4; 6 - 50 % Fe3O4, 50 % (FexCu1-x)Fe2O4

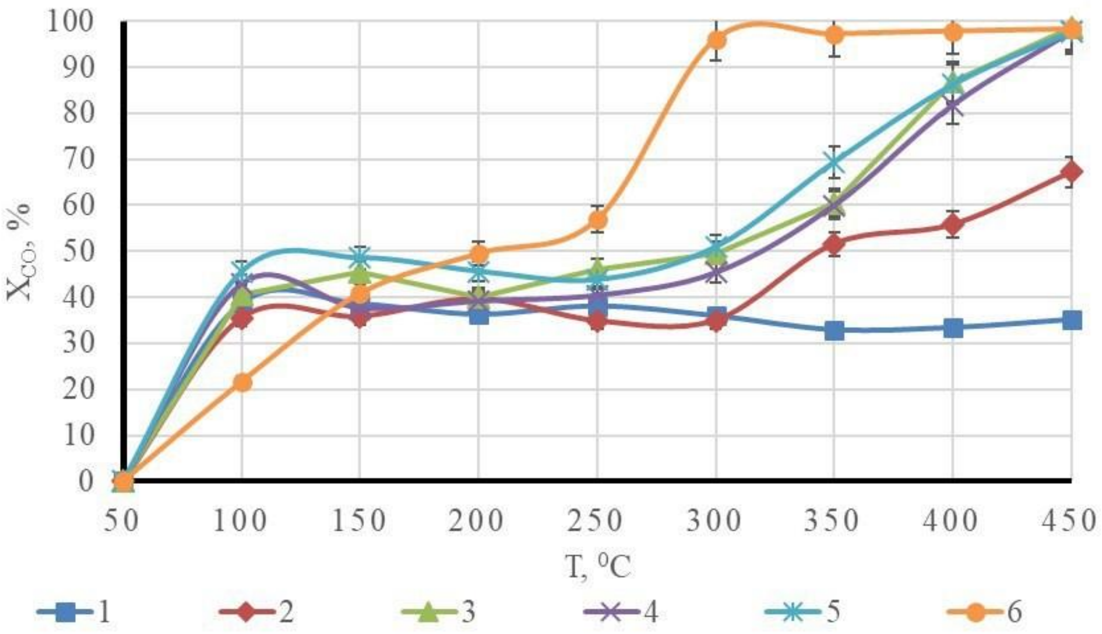


Figure 9 Temperature dependence of the degree of conversion of carbon monoxide with 2% initial concentration on catalysts on a ceramic fiber carrier: 1 - Fe3O4; 2 - (FexCu1-x)Fe2O4; 3 - Fe(FeyCr1-y)2O4; 4 - 50 % Fe3O4, 50 % Fe(FeyCr1-y)2O4; 5 – 33.3 % Fe3O4, 33.3 % (FexCu1-x)Fe2O4, 33.3 % Fe(FeyCr1-y)2O4; 6 - 50 % Fe3O4, 50 % (FexCu1-x)Fe2O4

The exact correlation can be observed in these studies. At a temperature of 400 ºC, when using a mixture of magnetite and chromium ferrite in a ratio of 1:1, the degree of conversion of 1% of CO at 95.22% of chromium ferrite is 92.98%. In addition to the specified catalysts, these studies show a consistently high efficiency of using a mixture of magnetite and copper ferrite 50% Fe3O4, 50% (FexCu1-x)Fe2O4 at different concentrations of carbon monoxide in the temperature range of 300 – 450 ºC. Let's consider that the ferrite particles themselves can be obtained from spent solutions of etching and copper plating of galvanic production. This catalyst will be recommended for decontaminating CO flue gases using modified ceramic fiber in graphitizing furnaces.

To confirm the modification of ceramic fiber, which provides the highest degree of conversion, a micro-X-ray spectral analysis of the surface of samples of modified Fe(FeyCr1-y)2O4 ceramic fiber was carried out after heat treatment at a temperature of 1000 ºC for 2 hours. To obtain Fe(FeyCr1-y)2O4, solutions of iron (II) sulfate and potassium dichromate were used, as confirmed by the results of micro-X-ray spectral analysis of the surface of the modified Fe(FeyCr1-y)2O4 ceramic fiber after heat treatment (Figure 11, 12).

As can be seen from (Figure 11, 12), on the surface of the modified Fe(FeyCr1-y)2O4 ceramic fiber after heat treatment, all the chemical elements of compounds for obtaining chromium ferrite using iron (II) sulfate and potassium dichromate are present. In addition, the ratio of chromium to iron in sample 1 (Cr: Fe = 2.29:34.31 = 1:14.98) and sample 2 (Cr: Fe = 1.94:29.13 = 1:15.02) corresponds to the Cr6+:Fe2+ =1:15 ratio. Therefore, the obtained results show the resistance of the catalyst to the action of high temperatures in the case of its industrial use in Acheson furnaces.

Taking into account the high efficiency and stability at high temperatures of the modified Fe(FeyCr1-y)2O4 ceramic fiber, as well as the possibility of obtaining chromium ferrite during the disposal of harmful chromate-containing effluents from chrome-plating processes, which contributes to increasing the environmental safety of the engineering industry, an industrial study of the specified catalyst was carried out at Acheson furnaces on the enterprise PJSC "Ukrainian Graphite", Zaporizhzhia, Ukraine. As a result of the full-scale test of the catalytic system, which includes the modified Fe(FeyCr1-y)2O4 ceramic fiber, the stability of its use during the entire duration of the graphitization campaign, which is 10 hours, was confirmed. At the same time, the catalyst did not lose its activity.

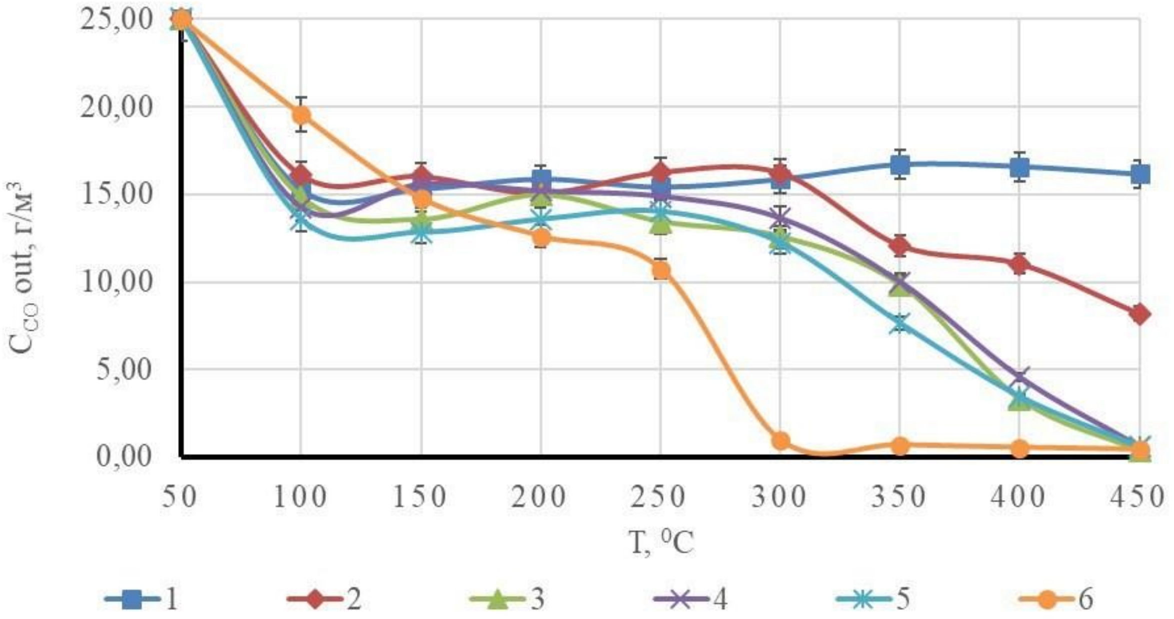
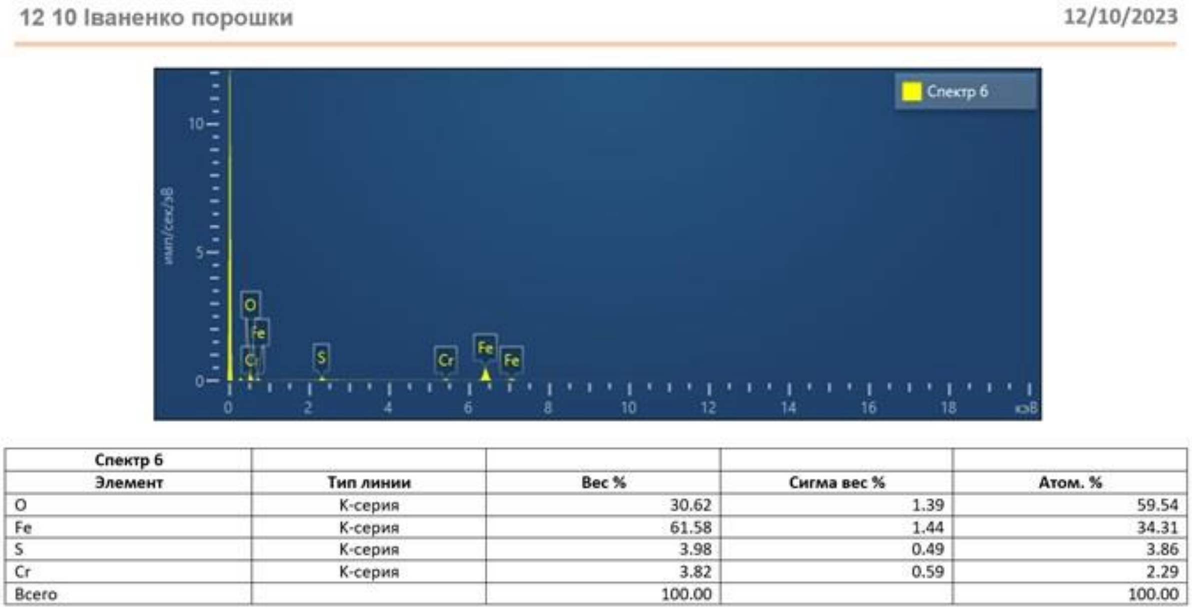


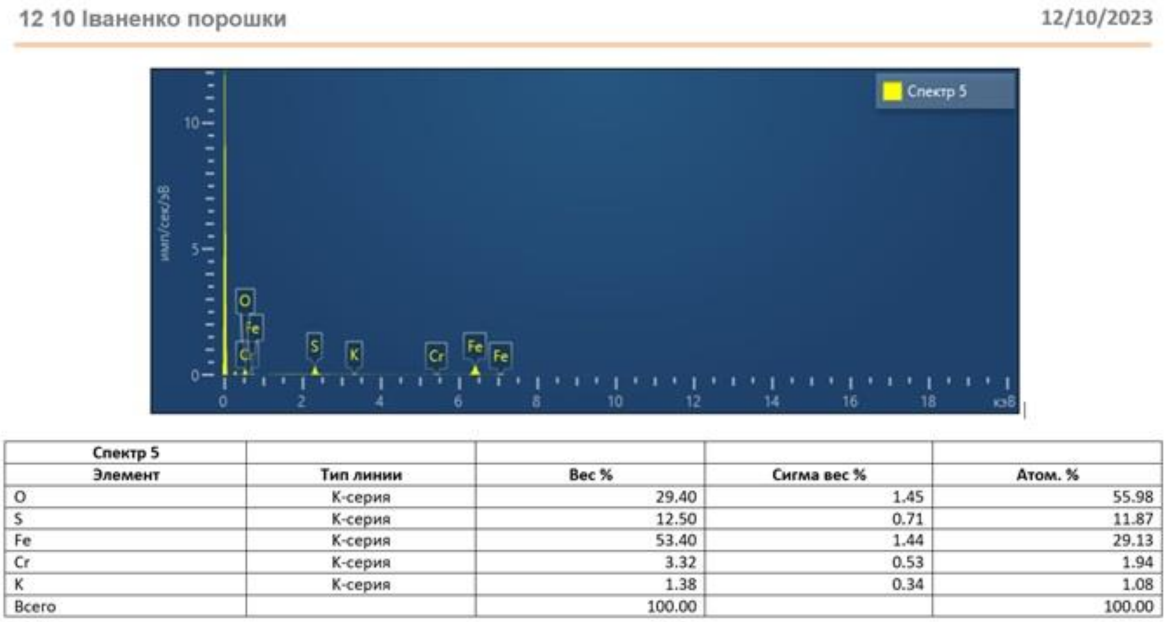
Figure 10 Change in carbon monoxide concentration with 2% initial concentration as a function of temperature on catalysts on a ceramic fiber carrier:1 - Fe3O4; 2 - (FexCu1-x)Fe2O4; 3 - Fe(FeyCr1-y)2O4; 4 - 50 % Fe3O4, 50 % Fe(FeyCr1-y)2O4; 5 - 33,3 % Fe3O4, 33,3 % (FexCu1-x)Fe2O4, 33,3 % Fe(FeyCr1-y)2O4; 6 - 50 % Fe3O4, 50 % (FexCu1-x)Fe2O4



12 10 Іваненко порошки 12/10/2023

Спектр 6				
Элемент	Тип линии	Вес %	Сигма вес %	Атом. %
O	К-серия	30.62	1.39	59.54
Fe	К-серия	61.58	1.44	34.31
S	К-серия	3.98	0.49	3.86
Cr	К-серия	3.82	0.59	2.29
Всего		100.00		100.00

Figure 11 Results of micro-X-ray spectral analysis of sample 1 of the surface of the modified Fe(FeyCr1-y)2O4 ceramic fiber after heat treatment


12 10 Іваненко порошки 12/10/2023

Спектр 5				
Элемент	Тип линии	Вес %	Сигма вес %	Атом. %
O	K-серия	29.40	1.45	55.98
S	K-серия	12.50	0.71	11.87
Fe	K-серия	53.40	1.44	29.13
Cr	K-серия	3.32	0.53	1.94
K	K-серия	1.38	0.34	1.08
Всего		100.00		100.00

Figure 12 Results of micro-X-ray spectral analysis of sample 2 of the surface of the modified Fe(FeyCr1-y)2O4 ceramic fiber after heat treatment

4. CONCLUSIONS

The research showed that ceramic fiber modified with chromium ferrite could effectively and stably purify flue gases from electrode graphitization furnaces, particularly neutralizing toxic carbon monoxide. Obtaining LYTX-512 ceramic fiber modified with ferrite material does not require significant capital investments, as it is based on using liquid waste from etching and chrome plating of galvanic production in the engineering industry. Laying ceramic fiber on top of the thermal insulation of the Acheson graphitization furnaces will also reduce the ingress of oxygen into the porous space and the formation of carbon monoxide, contributing to improving the ecological situation in electrode production.

The proposed method of fixing the modified fibrous catalyst in a metal frame will allow it to be placed without difficulty over the entire surface area of the thermal insulation of the Acheson graphitization furnace to ensure complete CO neutralization. Subsequently, after the heat treatment campaign of carbon electrodes ends, remove the frame with the catalyst for further use in the next campaign without regeneration. The fibrous catalyst can be easily replaced with a new one in mechanical destruction. In the future, research is planned to determine the effect of covering the thermal insulation surface with modified ceramic fiber on the temperature state of the Acheson graphitization furnace.

Authors Contribution

Olena Ivanenko - Research concept and design
Andrii Trypolskyi - Critical revision of the article
Serhii Dovholap - Collection and assembly of data
Olga Didenko - Final approval of the article
Serhii Ivaniuta - Critical revision of the article
Yuliia Nosachova - Writing the article
Oleksandr Nazarenko - Data analysis and interpretation
Peter Strizhak **-** Critical revision of the article

Ethical approval

Not applicable.

Informed consent

Not applicable.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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