

## Use of Metal Oxide-Modified Aerated Concrete for Cleaning Flue Gases from Carbon Monoxide

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### ABSTRACT

The necessity of development of technical solutions that will allow to reduce carbon monoxide emissions of flue gases of industrial productions is substantiated. It is shown that the most rational design solution to the problem of carbon monoxide pollution during the firing of electrode blanks is the use of aerated concrete blocks with a catalyst, which can be quickly and conveniently located directly on the carbon material of the “green” electrodes pouring in the subfloor space of the firing furnaces. Modified by oxides of Mn<sup>4+</sup>, Fe<sup>2+</sup>, Fe<sup>3+</sup>, Cu<sup>2+</sup>, Cr<sup>3+</sup> -catalysts based on aerated concrete were obtained. It is shown that in an empty reactor in the temperature range 200–400 °C the degree of conversion of carbon monoxide in the absence of a catalyst is zero. It is established that on the investigated catalysts based on aerated concrete 100% oxidation of carbon monoxide is achieved at a temperature of 390 °C in the case of using a mixture of catalyst powders 30% CuO + 70% MnO<sub>2</sub>, 40% CuO + 60% MnO<sub>2</sub>, 50% Fe (Fe<sub>x</sub>Cr<sub>1-x</sub>)<sub>2</sub>O<sub>4</sub> + 50% MnO<sub>2</sub>; 50% Fe<sub>3</sub>O<sub>4</sub> + 50% MnO<sub>2</sub>. It is determined that the addition of ferrite catalyst powder in aerated concrete in a mixture or without manganese dioxide does not critically affect the mechanical properties of the products.

**Keywords:** carbon monoxide, flue gases, purification, catalyst, oxidation, conversion

### INTRODUCTION

The main air pollutants are mining and processing industries, electricity, steam and air conditioning supply, whose pollutant emissions account for more than 90% of total air emissions in Ukraine. In 2018, emissions of pollutants into the atmosphere from stationary sources of pollution amounted to 2508.3 thousand tons, which is 76.6 thousand tons (3.0%) less than in 2017 [Statistical Yearbook “Environment of Ukraine 2018”, 2019].

Of particular concern is air pollution associated with carbon monoxide from stationary and mobile sources, due to its large volumes and toxicity [Kursov, 2015].

According to statistics [Statistical Yearbook “Environment of Ukraine 2018”, 2019], the receipt of carbon monoxide from stationary sources in 2018 amounted to 744.3 thousand tons, which is 15.9 thousand tons more than in 2017 (728, 4 thousand tons). The amount of carbon monoxide pollution from mobile sources in 2017 was 557.0 thousand tons. The reason for the formation of carbon monoxide (II) is incomplete combustion of hydrocarbon fuels at insufficient temperatures or poorly adjusted air supply system [Panov et al., 2020].

As a result, large amounts of highly toxic CO emissions are released into the atmosphere. Inhalation of carbon monoxide leads, first of all, to hemic hypoxia due to the harmful effect

of reducing the oxygen capacity of the blood [Lysenko et al., 2017].

Despite the scale of air pollution with carbon monoxide, no effective methods of purification of industrial exhaust gases from this pollutant have been introduced to date. Only for vehicles, a number of methods have been proposed for the purification of exhaust gases from carbon monoxide by its catalytic oxidation [Patel et al., 2019]. This is the most effective and expensive method of combating carbon monoxide. However, for powerful industrial enterprises [Ivanenko et al., 2020] this method of waste gas purification is not suitable due to the high cost of catalysts containing precious metals and their low productivity. Therefore, other, cheaper, affordable, efficient, long-life catalysts should be developed for stationary sources of pollution.

It is known that catalytic methods allow to process gases with low initial concentrations, provide a high degree of purification and do not lead to the formation of secondary contaminants [Inglezakis et al., 2012; Panov et al., 2019].

Numerous catalytic systems for the oxidation of CO to CO<sub>2</sub> based on precious metals are currently known [Rakitskaya et al., 2011]. Mixed oxide catalysts are also widely used [Choi et al., 2016]. Ferritic materials also have good potential as catalysts for CO oxidation of exhaust gases [Kharisov et al., 2019]. It is known that ferrite materials based on magnetite, copper ferrite and chromium ferrite can be easily obtained in the process of purification from heavy metal ions of etching solutions and spent electrolytes of galvanic coatings of metallurgical industries [Radovenchik et al., 2020]. A significant advantage of ferrite catalytic materials is their ease of removal from the environment and their reusability without loss of catalytic activity.

The use of catalytic methods is often limited by the complexity of finding and manufacturing suitable for long-term operation and fairly cheap, efficient catalysts to create waste-free environmentally friendly technologies.

In Ukraine, natural sorbents are often used to treat natural and wastewater from Mn<sup>2+</sup>, Fe<sup>2+</sup>, Fe<sup>3+</sup>, Cu<sup>2+</sup>, Cr<sup>3+</sup> ions [Basaraba et al., 2014; Zashidko et al., 2017]. Due to the combination of structural-adsorption and physico-chemical properties of zeolites in combination with metal oxides, which are freely incorporated in the middle of their pores, it is possible to actively use

sorption-catalytic processes for purification of aqueous media [Inglezakis et al., 2012; Korablev et al., 2017; Tarasevich et al., 2012].

Modified by transition metal oxides, in particular MnO<sub>2</sub>, zeolite-clinoptilolite of the Sokyrnytsia deposit [Ivanenko et al., 2021] has proven to be an effective catalyst in the purification of flue gases containing carbon monoxide. When using oxide-manganese catalyst based on zeolite provides the degree of oxidation of CO at 400 °C at the level of 92.8%. The advantages of the proposed catalyst are cheapness, availability, high performance and environmental safety. The developed catalyst is proposed to be placed in containers in the fire channels of chambers heated by flue gases, multi-chamber furnaces for burning electrode blanks, which is an innovative technical solution to the problem of purification of flue gases from carbon monoxide.

Every year the requirements for construction to the operational and technical properties of materials increase. Therefore, to improve the properties of materials, such as strength, lower energy and material consumption, reliability and durability, mineral additives are increasingly used in production technologies. In particular, ground natural and man-made zeolite raw materials in the composition of composite slag-alkaline binders are proposed to be used for protection against radioactive radiation and immobilization of liquid radioactive waste of medium specific activity. The addition of zeolite impurities in the amount of 10% increases the water resistance and strength of binders up to 20%, in the amount of 20% provides binders with stone strength, and the compressive strength of binders reaches 140 MPa [Rahimov et al., 2013].

The use of so-called “geopolymers”, obtained by alkaline activation of zeolite raw materials of natural and man-made origin, is possible in the repair of runways, sidewalks, high-speed roads due to rapid curing for 4–6 hours at a compressive strength of 20 MPa, required for landing a Boeing or Airbus [Rahimov et al., 2014].

The main construction and technical properties of concrete with the replacement of up to 20% of Portland cement with finely ground zeolite tuff do not deteriorate compared to the properties of non-additive concrete [Obuzhdina et al., 2014]. In the case of using a complex limestone-zeolite composition, the properties of concrete are significantly improved, and you can use low-quality lime.

As determined [Obuzdina et al., 2013], the addition of zeolites in the production of aerated concrete reduces the setting time by 1.5 hours and increases the specific surface area of aerated concrete by 800–1900 m<sup>2</sup>t<sup>-1</sup>. Moreover, when introduced into the concrete zeolite containing heavy metals, in the amount of 17% by weight of cement, the maximum increase in strength is achieved [Makarova et al., 2013]. With a further increase in the amount of zeolite there is some decrease in strength, which is explained by the polystructural theory of composite building materials. In addition, the possibility of using pre-calcined zeolite clinoptilolite type in the production of aerated concrete, which significantly expands the range of possibilities of utilization of spent materials based on zeolite.

In view of the above, the development and application of modified metal oxides of aerated concrete for flue gas cleaning from carbon monoxide may be a promising direction, as their use directly in the chambers of the kiln does not require significant capital costs for re-equipment and construction of catalytic gas treatment plants. In addition, it should be noted that the placement of the catalyst and its replacement after testing increases the downtime at the enterprise of carbon production between firing campaigns. It can be predicted that the use of aerated concrete blocks with a catalyst, which can be quickly and conveniently located directly on the carbon material of the “green” electrodes in the basement space of the chambers of Ridgamer kilns, will reduce downtime and thus increase process productivity while reducing anthropogenic load to the environment due to the reduction of carbon monoxide emissions into the atmosphere.

The aim of the work was to create modified with metal oxides (Mn, Cu, Fe, Cr) aerated concrete for catalytic oxidation of carbon monoxide in flue gases, evaluate the efficiency of the developed catalysts, present design solutions for the use of modified aerated concrete blocks.

To achieve this goal, the following tasks were set:

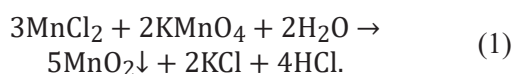
- Obtain samples of modified aerated concrete with oxides of a number of metals.
- Determine the mechanical characteristics and structural parameters of the samples.
- Evaluate the efficiency of catalytic oxidation of carbon monoxide when using aerated concrete modified with metal oxides and their mixture.

- Provide a design solution for the location of catalytic aerated concrete blocks for the oxidation of carbon monoxide.

## MATERIALS AND METHODS

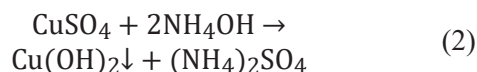
### Obtaining catalyst powders

To obtain MnO<sub>2</sub> powder, 1 dm<sup>3</sup> of 0.475 M MnCl<sub>2</sub> and 0.316 M KMnO<sub>4</sub> solutions were prepared, drained, and a suspension of manganese dioxide particles was prepared according to the reaction (1):



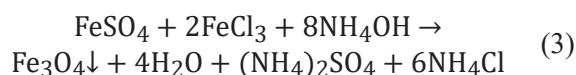
The suspension was allowed to stand in the mother liquor for 1 hour, the solid MnO<sub>2</sub> particles were separated from the liquid phase by decantation, washed, air dried to constant weight and ground to form 20 μm particles.

To obtain CuO powder, 1 dm<sup>3</sup> of a 1,000M CuSO<sub>4</sub> solution was prepared and the precipitate was precipitated with 25% cold NH<sub>4</sub>OH solution. Treatment of the solution gave a suspension of copper (II) hydroxide particles according to the reaction (2):



The suspension was maintained in the mother liquor for 1 hour, the precipitate Cu(OH)<sub>2</sub> was separated from the liquid phase by decantation, washed, dried in air to constant weight, kept at 70 °C for 5 hours in an oven to obtain CuO, which was ground to form particles size of 20 microns.

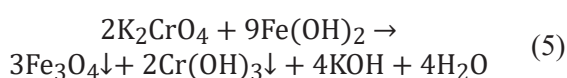
To obtain Fe<sub>3</sub>O<sub>4</sub> powder with a ratio of ion concentrations  $K = [\text{Fe}^{2+}]/[\text{Fe}^{3+}] = 1/2 = 0.5$ , 1 dm<sup>3</sup> of 1,000M FeSO<sub>4</sub> and 2,000M FeCl<sub>3</sub> solutions were prepared, drained and precipitated with 25% NH<sub>4</sub>OH solution (pH = 9,5–10). The result was a suspension of magnetite particles according to the reaction (3):



According to this method, samples of magnetite with a concentration ratio of  $K = 0.1; 0.3; 0.5; 0.7; 0.9; 1.1; 1.3; 1.5; 1.7; 1.9; 2.1; 2.3$ . The

suspension was maintained in the mother liquor for 1 hour, the solid particles of magnetite were separated from the liquid phase by decantation, washed until neutral, dried in air to constant weight. To obtain a modified aerated concrete, the air-dry powder was ground to form particles with a size of 20  $\mu\text{m}$ .

To obtain Fe powder ( $\text{Fe}_x\text{Cr}_{1-x}$ ) $_2\text{O}_4$  ( $[\text{Cr}^{6+}] / [\text{Fe}^{2+}] = 1/15$ ) 1 dm<sup>3</sup> solutions of 0.135M  $\text{K}_2\text{Cr}_2\text{O}_7$  and 1.600M  $\text{FeSO}_4$  were poured into one container and precipitated with 25%  $\text{NH}_4\text{OH}$  solution (pH = 9.5 – 10) by reactions (4), (5):



The resulting suspension was allowed to stand for 1 hour, the solid particles of chromium ferrite were separated from the liquid phase by decantation, washed until neutral, air dried to constant weight and ground to form 20  $\mu\text{m}$  particles.

### Obtaining modified aerated concrete

Samples of the catalyst for the oxidation of carbon monoxide from gaseous emissions were obtained by forming a mixture for the production of aerated concrete with the addition of powders of catalysts obtained by the above methods, without mixing or mixing the components in certain proportions:

1.  $\text{MnO}_2$ ;
2. 70%  $\text{MnO}_2$ , 30%  $\text{CuO}$ ;
3. 60%  $\text{MnO}_2$ , 40%  $\text{CuO}$ ;
4.  $\text{Fe}(\text{Fe}_x\text{Cr}_{1-x})_2\text{O}_4$ ;
5. 50%  $\text{Fe}(\text{Fe}_x\text{Cr}_{1-x})_2\text{O}_4$ , 50%  $\text{MnO}_2$ ;
6.  $\text{Fe}_3\text{O}_4$ ;
7. 50%  $\text{Fe}_3\text{O}_4$ , 50%  $\text{MnO}_2$ ;
8. 50%  $\text{Fe}(\text{Fe}_x\text{Cr}_{1-x})_2\text{O}_4$ , 50%  $\text{Fe}_3\text{O}_4$ ;
9. 25%  $\text{Fe}(\text{Fe}_x\text{Cr}_{1-x})_2\text{O}_4$ , 25%  $\text{Fe}_3\text{O}_4$ , 50%  $\text{MnO}_2$ .

The main characteristics of the mixture are shown in Table 1. In the process of preparation of the mixture for the production of aerated concrete, sand with a size of 8  $\mu\text{m}$  was used, in which water, cement, lime, gypsum were added in portions, stirred, aluminum paste was added and a final mixing was performed.

To obtain samples of the catalyst to 1 dm<sup>3</sup> of the finished mixture to obtain aerated concrete was added 100 g of catalyst powder. The components were thoroughly mixed and the mixture was poured into molds measuring 100×100×100 mm. Next, the molds were kept at a temperature of 50 °C for 5 hours, after which the molds were transferred to an autoclave and kept at a temperature of 180 °C for 10 hours. As a result of the described process, samples of the catalyst for the oxidation of carbon monoxide were obtained.

Determination of mechanical characteristics and structural parameters of the samples was performed according to the method described in [Ivanenko et al., 2021].

The content of micropores was calculated by the formula:

$$V_{\mu\%} = \frac{V_{\mu}}{V_{\Sigma}} \cdot 100 \%, \quad (6)$$

The efficiency of the presented catalysts was determined in the temperature range 200–400 °C by calculating the conversion of carbon monoxide due to the change of concentrations of this gas at the outlet and inlet to the reactor. The conversion of carbon monoxide was calculated by the formula:

$$X_{\text{CO}} = \frac{c_{\text{CO}}^{\text{in}} - c_{\text{CO}}^{\text{out}}}{c_{\text{CO}}^{\text{in}}} \cdot 100 \%, \quad (7)$$

where:  $c_{\text{CO}}^{\text{in}}$  – molar fraction of CO at the inlet to the reactor,  
 $c_{\text{CO}}^{\text{out}}$  – molar fraction of CO at the reactor outlet.

**Table 1.** Chemical composition and characteristics of a typical mixture for the production of aerated concrete

№	Parameter	Unit of measurement	Value
1	Density	kg·dm <sup>-3</sup>	1,69
2	Dry matter content	kg·dm <sup>-3</sup>	460,0
3	Binder content:	%	31,4
4	- including concrete ALL 500	%	76,6
5	- including quicklime CaO	%	23,4
6	Gypsum content $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	%	3,78
7	The content of aluminum paste (aluminum content in the paste 70%)	%	0,14
8	Sand content	%	64,68



## RESULTS AND DISCUSSION

As a result of the conducted researches 9 samples of catalysts on the basis of aerated concrete which differed in the chemical composition were developed. Subsequently, the mechanical characteristics of the modified aerated concrete were determined according to the method described in the work [Ivanenko et al., 2021] (Table 2).

As can be seen from the above results, samples of catalysts modified with chromium ferrite and magnetite in a mixture with or without manganese dioxide, showed satisfactory results. When adding 100 g of catalyst powder per 1 dm<sup>3</sup> of aerated concrete mass, the decrease in the strength of the cubes obtained from them was 1.67–10.33%. When adding chromium-ferrite catalyst, there was an increase in strength by 6.33%.

Interesting was the fact that the addition of only manganese dioxide or hopkalite significantly reduces the strength of the catalyst samples, while adding a mixture of chromium ferrite and MnO<sub>2</sub> in aerated concrete there is a significant improvement in its mechanical properties (Fig. 1).

Thus, the addition of ferritic catalyst powder in aerated concrete with or without manganese dioxide does not critically affect the properties of the products, the products will not be destroyed during long-term operation in the electrode production.

Studies of the porous properties of the obtained catalysts according to the method described in [Ivanenko et al., 2021], showed that the adsorption isotherms obtained for heat-treated and not heat-treated aerated concrete samples modified with chromium ferrite powder, magnetite and dioxide refer to isotherms of the IV type (Fig. 2–4). Isotherms of this type have an initial region similar to type II isotherm, which indicates

the passage of polymolecular adsorption, and a region indicating the presence of capillary condensation in mesopores [Gavrilova et al., 2015]. Confirmation of capillary condensation and the presence of micropores is the mismatch of the isotherms of adsorption (lower branch) and desorption (upper branch) in the range of relative pressures from 0.55 to 0.995. Thus, type IV isotherms are inherent in mesoporous adsorbents, which is confirmed by the results of calculating the parameters of the porous structure of the modified aerated concrete, shown in Table 3.

As can be seen from Table 3, heat-treated and not heat-treated aerated concrete modified with magnetite and heat-treated aerated concrete modified with chromium ferrite have approximately the same insignificant content of micropores, which is 5.22–5.85%. At the same time, heat-treated aerated concrete modified with chromium ferrite has a 2 times higher content of micropores. This fact can be explained by the fact that the synthesized magnetite by water condensation has a more ordered crystalline structure than chromium ferrite. Even in the case of the optimal ratio of Cr<sup>6+</sup>: Fe<sup>2+</sup> = 1:15 [Radovenchik et al., 2020], the formation of an amorphous phase of iron hydroxide around crystalline particles of chromium ferrite with a high content of hydrated water, which did not evaporate even as a result of heat treatment in an autoclave at 180 °C for 10 hours. The reduction in this case by almost 2.5 times the size of the micropores indicates the formation of a more ordered crystalline structure of chromium ferrite under elevated temperature, which is also confirmed by some decrease in the specific surface area of the aerated concrete sample modified with chromium ferrite.

In the case of manganese dioxide, there is a significant increase in the size of the micropores,

**Table 2.** Dependence of compressive strength of the obtained aerated concrete cubes on the chemical composition of the catalyst powder

№ of catalyst powder	Chemical composition of catalyst powder	Strength of cubes, MPa
Without catalyst	–	3.00
1	MnO <sub>2</sub>	1.31
2	70% MnO <sub>2</sub> , 30% CuO	1.22
3	60% MnO <sub>2</sub> , 40% CuO	1.33
4	Fe(Fe <sub>x</sub> Cr <sub>1-x/2</sub> ) <sub>2</sub> O <sub>4</sub> (Cr:Fe=1:15)	3.19
5	50% Fe(Fe <sub>x</sub> Cr <sub>1-x/2</sub> ) <sub>2</sub> O <sub>4</sub> (Cr:Fe=1:15), 50% MnO <sub>2</sub>	3.27
6	Fe <sub>3</sub> O <sub>4</sub>	2.95
7	50% Fe <sub>3</sub> O <sub>4</sub> , 50% MnO <sub>2</sub>	2.88
8	50% Fe(Fe <sub>x</sub> Cr <sub>1-x/2</sub> ) <sub>2</sub> O <sub>4</sub> (Cr:Fe=1:15), 50% Fe <sub>3</sub> O <sub>4</sub>	2.69
9	25% Fe(Fe <sub>x</sub> Cr <sub>1-x/2</sub> ) <sub>2</sub> O <sub>4</sub> (Cr:Fe=1:15), 25% Fe <sub>3</sub> O <sub>4</sub> , 50% MnO <sub>2</sub>	2.16

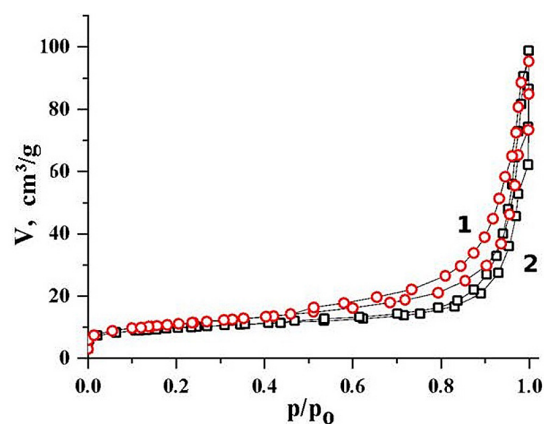


**Fig. 1.** The appearance of the obtained aerated concrete cube when adding powder 50% Fe ( $\text{Fe}_x\text{Cr}_{1-x})_2\text{O}_4$  (Cr:Fe=1:15), 50%  $\text{MnO}_2$

which is 8.7 times higher than that of chromium ferrite. This result may be an explanation for the deterioration of the mechanical properties, namely, the compressive strength of the obtained catalysts.

In the second stage, the efficiency of catalytic oxidation of carbon monoxide was evaluated using aerated concrete modified with metal oxides and their mixture.

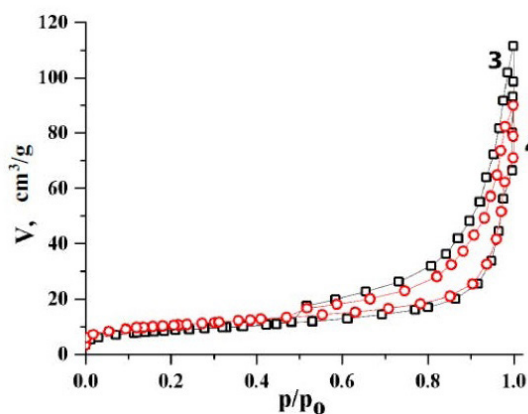
In the study of the process of CO oxidation in a gas mixture in an empty reactor in the temperature range of 200 – 400 °C, the degree of conversion of carbon monoxide in the absence of a catalyst was zero. In the case of the developed



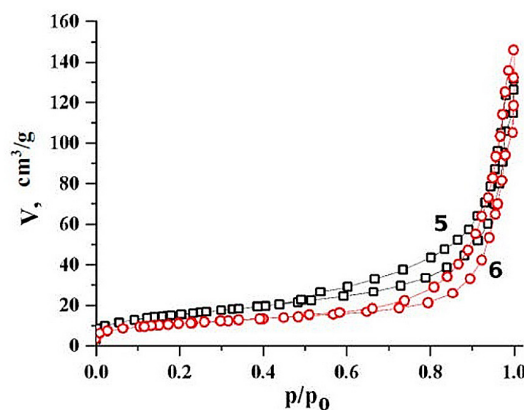
**Fig. 2.** Isotherms of adsorption and desorption of nitrogen on samples of unburned (1) and calcined (2) aerated concrete modified with chromium ferrite

catalysts, the conversion of carbon monoxide was observed. The degree of conversion of carbon monoxide depended on the chemical composition of the modified aerated concrete and on the temperature regime of the process.

From the temperature dependences of carbon monoxide conversion on the investigated aerated concrete catalysts shown in Figure 5, it is seen that 100% oxidation of carbon monoxide is achieved at a temperature of 390 °C in the case of using a mixture of catalyst powders 30%  $\text{CuO}$  + 70%  $\text{MnO}_2$ ; 40%  $\text{CuO}$  + 60%  $\text{MnO}_2$ ; 50% Fe ( $\text{Fe}_x\text{Cr}_{1-x})_2\text{O}_4$  + 50%  $\text{MnO}_2$ ; 50%  $\text{Fe}_3\text{O}_4$  + 50%  $\text{MnO}_2$ . As can be seen, the mixture of all these powders includes manganese oxide (IV), although the use of only  $\text{MnO}_2$  powder guarantees 92.7% conversion of CO to  $\text{CO}_2$ . Although at a temperature of 280 °C catalysts based on aerated concrete modified only with  $\text{MnO}_2$  and a mixture



**Fig. 3.** Isotherms of adsorption and desorption of nitrogen on samples of unburned (3) and calcined (4) aerated concrete modified with magnetite



**Fig. 4.** Isotherms of adsorption and desorption of nitrogen on samples of unburned (5) and calcined (6) aerated concrete modified with manganese dioxide

**Table 3.** Structural parameters of samples of modified (heat-treated and heat-treated) aerated concrete obtained using a sorbometer Sorptomatic 1990 (Italy)

Exemple <sup>1</sup> – not heat treated <sup>2</sup> – heat treated	Specific surface S, m <sup>2</sup> g <sup>-1</sup> (BET method)	The specific surface of the mono-molecular layer, m <sup>2</sup> g <sup>-1</sup>	The total pore volume V <sub>Σ</sub> , cm <sup>3</sup> g <sup>-1</sup>	The volume of micropores V <sub>μ</sub> , cm <sup>3</sup> g <sup>-1</sup>	The content of micropores V <sub>μ</sub> %, %	Distribution of pores by size, nm	
						BJH dV (r), nm	
						r micro-pores	r meso-pores
Aerated concrete <sup>1</sup> , modified with chromium ferrite	39,312	15,947	0,1020	0,0057	5,58	3,92	28,97
Aerated concrete <sup>2</sup> , modified with chromium ferrite	34,795	10,916	0,082	0,0095	11,58	1,65	46,81
Aerated concrete <sup>1</sup> , modified with magnetite	31,258	14,145	0,0881	0,0046	5,22	4,05	25,40
Aerated concrete <sup>2</sup> , modified with magnetite	37,892	15,390	0,1282	0,0075	5,85	4,00	27,14
Aerated concrete <sup>1</sup> , modified with manganese dioxide	55,971	27,488	0,1638	0,0052	3,17	4,20	26,61
Aerated concrete <sup>2</sup> , modified with manganese dioxide	39,927	19,012	0,1436	0,0076	5,29	14,35	34,47

of 50% Fe (Fe<sub>x</sub>Cr<sub>1-x</sub>)<sub>2</sub>O<sub>4</sub> + 50% MnO<sub>2</sub>, provide the highest degree of oxidation among all these catalysts, which is 76 and 80%, respectively.

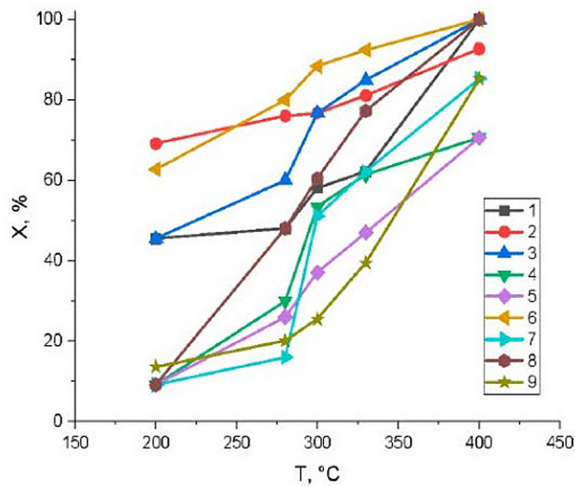
When using only magnetite or chromium ferrite at a temperature of 390 °C, 85.3 and 70.6% conversion, respectively, is achieved. When mixing magnetite and chromium ferrite in a ratio of

1:1, the degree of oxidation is 85.2%, but the conversion in this case CO is significantly reduced compared to magnetite at a temperature of 330 °C almost 2 times. When adding manganese dioxide to a mixture of magnetite and chromium ferrite in the ratio 2: 1: 1, the degree of oxidation of CO at a temperature of 330 °C increases from 39.4 to 46.9%, but at a temperature of 390 °C the conversion of carbon monoxide is as in the case of chromium ferrite.

Thus, based on the obtained results, we can conclude that at a temperature of 200 – 300 °C the highest efficiency of catalytic oxidation is provided when using only MnO<sub>2</sub> and a mixture of 50% Fe (Fe<sub>x</sub>Cr<sub>1-x</sub>)<sub>2</sub>O<sub>4</sub> + 50% MnO<sub>2</sub>. At a temperature of 300–400 °C, the mixture of chromium ferrite and manganese dioxide, hopcalite 40:60 and a mixture of magnetite and manganese dioxide are characterized by the best catalytic properties.

The use of aerated concrete for fixing CO conversion catalysts can significantly simplify the design of the carbon monoxide disposal system, in comparison, for example, with the proposal to place a tank with a catalyst in the kilns of electrode products in the fire channels of chambers heated by flue gases.

For the constructive solution of the problem of carbon monoxide emissions of electrode production it is economically expedient to use aerated concrete blocks of industrial production with standard dimensions of 600 × 200 × 100 mm, with concrete class B strength 2.5 density 400 kg m<sup>-3</sup>.



**Fig. 5.** Temperature dependences of the degree of carbon monoxide oxidation on catalysts based on aerated concrete, modified: 1 – 70% MnO<sub>2</sub>, 30% CuO; 2 – MnO<sub>2</sub>; 3 – 60% MnO<sub>2</sub>, 40% CuO; 4 – Fe(Fe<sub>x</sub>Cr<sub>1-x</sub>)<sub>2</sub>O<sub>4</sub> (Cr:Fe=1:15); 5 – 25% Fe(Fe<sub>x</sub>Cr<sub>1-x</sub>)<sub>2</sub>O<sub>4</sub> (Cr:Fe=1:15), 25% Fe<sub>3</sub>O<sub>4</sub>, 50% MnO<sub>2</sub>; 6 – 50% Fe(Fe<sub>x</sub>Cr<sub>1-x</sub>)<sub>2</sub>O<sub>4</sub> (Cr:Fe=1:15), 50% MnO<sub>2</sub>; 7 – Fe<sub>3</sub>O<sub>4</sub>; 8 – 50% Fe<sub>3</sub>O<sub>4</sub>, 50% MnO<sub>2</sub>; 9 – 50% Fe(Fe<sub>x</sub>Cr<sub>1-x</sub>)<sub>2</sub>O<sub>4</sub> (Cr:Fe=1:15), 50% Fe<sub>3</sub>O<sub>4</sub>

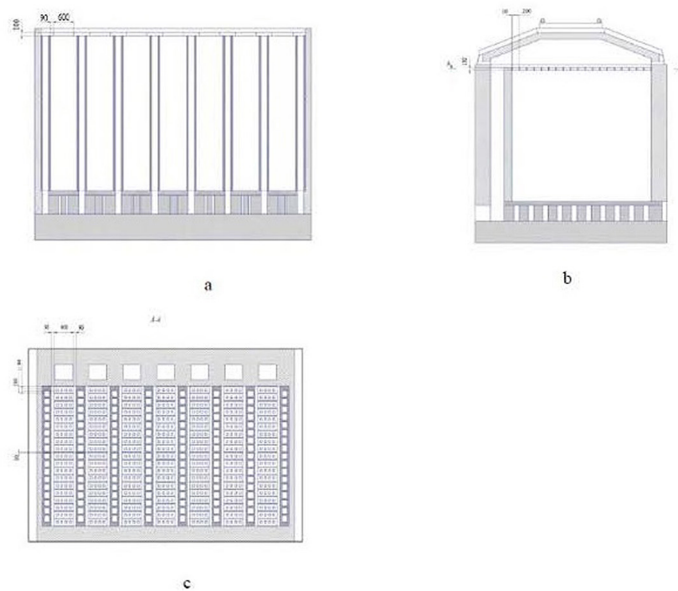
In this case, in the manufacture of aerated concrete blocks with a catalyst, they can be laid directly on the thermoanthracite pouring “green” blanks in the kilns of firing electrode products (Fig. 6).

Concrete blocks are adjacent to each other at a distance of 10 mm. The presence of a sufficient number of holes in the blocks of square or circular shape provides the necessary for the technological process of firing the movement of the gas mixture inside the chamber.

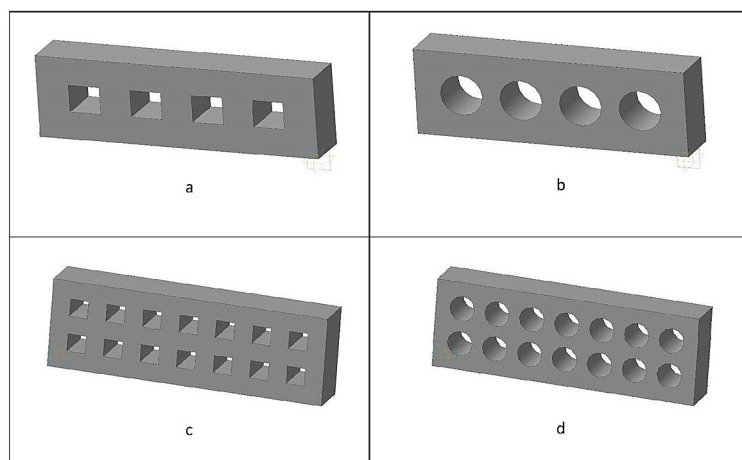
The design of the aerated concrete blocks can be represented by several variations with 4 and 14 square and log-shaped holes (Fig. 7).

The blocks can be made with 4 holes with a size of  $66 \times 66$  mm (Fig. 7 a) and a diameter of 90 mm (Fig. 7 b), and with 14 holes with a size of  $40 \times 40$  mm (Fig. 7 c) and a diameter 55 mm (Fig. 7 d). In the case of using 4-hole units, greater strength of aerated concrete blocks during operation is provided, and in the case of using 14-hole units, the specific contact surface of the catalyst with CO-containing flue gases is increased.

In addition, circular holes in the gas blocks can be easily made with a rotary hammer. In the case of square holes, the process will be complicated by the need to use special forms or a saber saw with a limited length of the cutting part.



**Fig. 6.** Placement of aerated concrete blocks with a catalyst directly on the surface of the pouring of the electrode blanks in the kilns: a – front view, b – side view, c – top view.



**Fig. 7.** Structural solutions of aerated concrete blocks: a – with square holes  $66 \times 66$  mm; b – with circular holes with a diameter of 90 mm; c – with square holes  $40 \times 40$  mm; d – with circular holes with a diameter of 55 mm.



## CONCLUSIONS

As a result of the research, catalysts based on aerated concrete modified with metal oxides (Mn, Cu, Fe, Cr) were developed.

In terms of mechanical properties, the best strength indicators are provided by catalysts based on aerated concrete, modified with chromium ferrite and magnetite in the presence or absence of manganese dioxide. The presence of chromium-ferrite catalyst in the composition of aerated concrete increases the strength of the products by 6.33% compared to the standard sample of aerated concrete. Heat-treated aerated concrete modified with chromium ferrite contains the largest number of micropores. The content of micropores for this sample is 11.58%.

Studies have shown that aerated concrete catalysts modified with a mixture of chromium ferrite and magnetite powders in combination with manganese dioxide provide the highest efficiency of purification of flue gases of multi-chamber furnaces for firing electrode blanks from carbon monoxide.

The proposed method of fixing catalyst particles in aerated concrete blocks allows to build fundamentally new schemes of carbon monoxide neutralization when placing modified blocks directly on the loading of electrode products, which significantly simplifies the conversion process and its management system.

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