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DEVELOPMENT OF CATALYTIC MATERIALS BASED ON NANOSTRUCTURED INTERMETALLICS FOR SOLVING ENVIRONMENTAL PROBLEMS OF THE COKE-CHEMICAL INDUSTRY

Belokon K.V.
Zaporizhzhia National University
Universytetska St., 66, 69600, Zaporizhzhia
kv.belokon@gmail.com

The paper presents the results of the development and testing of highly efficient polymetallic Fe-Al catalysts designed for the deep oxidation of hydrocarbons in industrial emissions. The relevance of the study is driven by the necessity to replace noble metal-based catalysts in catalytic units with more affordable and thermally stable analogues. Intermetallic precursors of the stoichiometric composition $FeAl_3$ were synthesized using the thermal self-ignition method. The activation of the precursors was carried out via aluminum leaching, which ensured a significant increase in the specific surface area, reaching 74.3 m^2/g. The introduction of nickel into the precursor composition promotes the formation of a more finely dispersed microstructure, directly resulting in an increased specific surface area and enhanced corrosive and thermal stability of the catalytic system. In the processing of resins or organic emissions (benzene, phenol, naphthalene), iron often triggers coke formation; however, nickel facilitates the gasification of carbon deposits, thereby extending the catalyst's service life. It was established that the addition of cobalt (15 wt. %) radically enhances catalytic activity, ensuring 95% hydrocarbon conversion at a temperature of 350°C. Manganese alloying determines the formation of a nanostructured surface in the form of hexagonal plates and star-shaped clusters, which significantly increases the accessible active surface area and intensifies the catalytic process. It was established that doping with copper (3 wt. %) and zirconium (1 wt. %) ensures the stabilization of the microstructure and inhibits crystallite growth, resulting in increased mechanical strength and an extended service life of the catalyst in aggressive gas environments. It has been experimentally confirmed that the developed catalyst composition, Fe-Ni-Co-Mn-Cu-Zr (41-33-15-12-3-1 wt. %), ensures high detoxification efficiency of toxic components under the actual gas environment conditions of coke-chemical production. Pilot-scale tests conducted under the actual conditions of a tar distillation shop confirmed the high efficiency of the development. At high inlet concentrations of pollutants (specifically benzene – 40.38 mg/m^3, phenol – 15.38 mg/m^3, and naphthalene – 179.56 mg/m^3), the detoxification efficiency for phenol, benzene, and naphthalene reached 99.0-99.8%. The obtained results comply with the maximum permissible emission standards, allowing for the recommendation of the developed catalyst for implementation at enterprises within the coke-chemical and metallurgical industries. *Key words:* intermetallic catalysts, iron-aluminum alloys, thermal self-ignition method, leaching, specific surface area, nanostructure, deep oxidation, hydrocarbons, environmental safety, coke-chemical production, gas emissions, phenol, benzene, naphthalene.

Розробка каталітичних матеріалів на основі наноструктурованих інтерметалідів для вирішення екологічних проблем коксохімічного виробництва. Бєлоконь К.В.

У роботі представлено результати розробки та випробування високоефективних поліметалевих Fe-Al каталізаторів, призначених для глибокого окиснення вуглеводнів у промислових викидах. Актуальність дослідження зумовлена необхідністю заміни каталізаторів на основі дорогоцінних металів в каталітичних установках на більш доступні та термічно стійкі аналоги. Були синтезовані сплави методом теплового самозапалювання, що дозволило отримати інтерметалідні прекурсори стехиометрического состава $FeAl_3$. Процес активації прекурсорів здійснювався шляхом вилуговування алюмінію, що забезпечило суттєве зростання питомої поверхні до 74,3 м^2/г. Введення нікелю до складу прекурсора сприяє формуванню більш дисперсної мікроструктури, що безпосередньо зумовлює зростання питомої поверхні та підвищує корозійну і термічну стабільність каталітичної системи. У процесах переробки смол або органічних викидів (бензол, фенол, нафталін) залізо часто провокує утворення коксу. Нікель сприяє газифікації вуглецевих відкладень, подовжуючи термін служби каталізатора. Встановлено, що введення кобальту (15% мас.) радикально підвищує каталітичну активність, забезпечуючи 95% конверсії вуглеводнів при температурі 350°C. Легування марганцем обумовлює формування наноструктурованої поверхні у вигляді гексагональних пластин та зірчастих кластерів, що суттєво збільшує площу доступної активної поверхні та інтенсифікує каталітичний процес. Встановлено, що легування міддю (3% мас.) та цирконієм (1% мас.) забезпечує стабілізацію мікроструктури та інгібує ріст кристалітів, що обумовлює підвищення механічної міцності та подовження терміну експлуатації каталізатора в агресивних газових середовищах. Експериментально підтверджено, що розроблений склад каталізатора Fe-Ni-Co-Mn-Cu-Zr (41%-33%-15%-12%-3%-1%) забезпечує високу ефективність знешкодження токсичних компонентів в умовах реального газового середовища коксохімічного виробництва. Дослідно-промислові випробування, проведені в реальних умовах смолоперегінного цеху, підтвердили високу ефективність розробки. При високих вхідних концентраціях забруднювачів (зокрема бензол – 40,38 мг/м^3, фенол – 15,38 мг/м^3, нафталін – 179,56 мг/м^3) ступінь знешкодження фенолу, бензолу та нафталіну склав 99,0-99,8%. Отримані результати відповідають нормативам гранично допустимих викидів, що дозволяє рекомендувати розроблений каталізатор для впровадження на підприємствах коксохімічної та металургійної галузей. *Ключові слова:* інтерметалідні каталізатори, залізоалюмінієві сплави, теплове самозапалювання, вилуговування, питома поверхня, наноструктура, глибоке окиснення, вуглеводні, екологічна безпека, коксохімічне виробництво, газові викиди, фенол, бензол, нафталін.

Problem statement. The issue of environmental protection has remained a matter of paramount importance for all industrial enterprises over recent years. Coke-chemical production remains one of the most technologically burdened segments of the metallurgical cycle. Despite the strategic importance of coke as a reducing agent for blast furnace production, the industry is a source of emissions of more than 200 types of toxic compounds, including carbon monoxide (CO), nitrogen oxides (NO_x), benzene, phenols, and fine particulate matter [1]. For large industrial centers such as the city of Zaporizhzhia, the reduction of pollutant emissions at coke-chemical plants is exacerbated by the high density of enterprises and their proximity to residential areas. Under current technologies for coke production, as well as the recovery and processing of chemical coking products, the emission sources at coke-chemical plants vary significantly both in terms of emission volumes and the composition of chemical pollutants; consequently, each source requires specific technical solutions and substantial capital investment to improve the environmental situation. Existing gas cleaning systems often demonstrate insufficient efficiency, leading to the accumulation of toxicants in the surface layer of the atmosphere. The situation is further complicated by the necessity of post-war industrial recovery, which must align with the stringent standards of the European Green Deal.

Relevance of the study. Toxic organic substances generated during coke-chemical production represent a complex mixture with concentrations of polycyclic aromatic hydrocarbons (PAHs) significantly exceeding maximum permissible limits. Many of these compounds possess pronounced carcinogenic and mutagenic properties [2]. Stringent modern environmental requirements for industrial emissions necessitate the implementation of advanced detoxification technologies characterized by high energy efficiency and the utilization of unconventional and alternative energy sources [3]. Thermocatalytic treatment of gaseous emissions to remove toxic components is among the most effective methods, often achieving near-absolute purification levels [4].

Analysis of recent research and publications. The primary approaches for detoxifying emissions from coke-chemical production include electrostatic precipitation, thermal and thermocatalytic oxidation, as well as adsorption methods.

Electrostatic precipitation of tarry substances is considered the most common method for treating gases containing PAHs. The advantages of this method include its technical simplicity, relative cost-effectiveness, and ease of maintenance. However, the residual concentration of toxic organic substances in the purified gases discharged into the atmosphere remains significant, failing to meet current sanitary standards [5].

The high-temperature thermal method for PAHs detoxification is quite effective but entails significant energy consumption. Thermal incineration of contaminated gases may be viable for small exhaust gas volumes or when a plant possesses a high potential for waste heat recovery [1].

The adsorption method lacks sufficient efficiency; its application is primarily advisable when the spent adsorbent can be recycled or utilized within the plant's own production processes [6].

The method of thermocatalytic detoxification of toxic organic compounds is the most promising across all indicators due to its relatively low energy consumption. The development of modern high-efficiency catalysts, capable of achieving near-complete neutralization of organic substances at temperatures of 350-450°C (compared to thermal incineration, which occurs at temperatures around 1000°C), ensures high treatment efficiency at significantly lower costs. For this reason, the thermocatalytic oxidation method was selected for the treatment of toxic organic compounds in gaseous emissions from coke-chemical production [1].

However, traditional catalysts based on noble metals (Pt, Pd) are characterized by high costs and low resistance to poisoning by sulfur compounds, which are typical for coke oven gas [6]. At the same time, the use of more affordable oxide systems fails to provide the required conversion levels at low temperatures. There is a pressing scientific and practical need for the development of new, thermodynamically stable, and economically accessible materials – specifically intermetallic systems (based on Ni-Al, Fe-Al, Co-Al), that could ensure deep purification of coke-chemical emissions from carbon-containing components within the «green metallurgy» paradigm.

Scientific novelty. The challenge of environmental protection in coke-chemical production lies in the necessity of transitioning from traditional treatment methods to integrated, environmentally safe technologies. The current state of the industry demands the development of high-efficiency catalytic systems capable of stable operation within the corrosive environments of coke-chemical plants, while simultaneously ensuring minimal energy consumption and compliance with international environmental standards.

Scientific novelty. The scientific novelty of this work lies in the substantiation and development of catalytic gas purification systems for removing PAHs using intermetallic catalysts under the specific conditions of tar distillation production.

To achieve the stated objective, the following tasks were performed:

1) comprehensive analysis: based on analytical and experimental studies, the qualitative and quantitative

composition of pollutants generated during the technological processes of the tar distillation shop was determined.

2) development of new materials: intermetallic catalysts of the Fe-Ni-Co, Fe-Ni-Co-Mn, Fe-Ni-Co-Mn-Cu, and Fe-Ni-Co-Mn-Cu-Zr systems were synthesized; the elemental composition of the synthesized phases providing the highest catalytic activity was experimentally substantiated.

3) validation of efficiency: the physicochemical and catalytic properties of the obtained samples were investigated in the deep oxidation reactions of polycyclic aromatic hydrocarbons. It was established that the proposed catalyst with the composition Fe-Ni-Co-Mn-Cu-Zr (41%-33%-15%-12%-3%-1%) ensures a high degree of detoxification of toxic components under the specific conditions of coke-chemical production.

Presentation of the main material. Coking is a method of coal processing by heating at temperatures of 1000-1200°C without air access. During coking, the fuel decomposes, forming volatile substances (up to 25%) and a solid residue. The primary products of coke chemistry include coal coke (76-78%), coke oven gas (14-15%), and various chemical products (5-6%): dust, nitrogen oxides, sulfur dioxide, carbon monoxide, ammonia, phenol, benzene, benzopyrene, naphthalene, hydrogen sulfide, hydrogen cyanide, and graphite. Consequently, the concentrations of pollutants in the air of the working zones of coke-chemical plants exceed the maximum permissible concentrations (MPC) several times over. Coal dust concentrations reach 8 MPC and above, while harmful gases reach up to 3-4 MPC, with the exception of carbon monoxide, whose concentration in some cases exceeds the MPC severalfold.

The primary shops include coal preparation, coking, recovery of chemical coking products, coke oven gas desulfurization (hydrogen sulfide removal), tar distillation, crude benzene rectification, pitch coking, phthalic anhydride production, and fine chemicals shops.

Let us consider the tar distillation shop. This facility handles the processing of coal tar and the production of coal-based oils and electrode pitch. The shop consists of the following units: a tar storage facility; a tar distillation department; an electrode pitch production unit; a pitch storage yard; pitch granulation and road tar preparation units; an oil storage facility; a reagent storage and oil washing unit; emission control systems (a catalytic incineration unit); and a biochemical treatment plant.

The raw material for tar processing production is coal tar – a byproduct of coal coking. The primary stages of the coal tar processing cycle include: tar preparation for processing at the storage facility, where heating to temperatures of 70–80°C, preliminary dehydration, and homogenization of the coal tar are performed, along with the sedimentation of tar decanter sludges (foots); tar distillation; processing of fractions obtained through distillation; extraction of phenols from coal-based oils; final product manufacturing; and the production of coal-based electrode pitch in both liquid and granulated forms.

The tar storage facility is equipped with a warehouse (cargo shed) for heating and unloading coal tar arriving in railway tank cars from the recovery shop. Tar storage is managed within five above-ground vertical cylindrical tanks, each with a capacity of 2,000 tons. For raw material reception directly from the discharge bays, underground storage units with a volume of 150 m^3 each are provided. During the operation of the facilities, the following pollutants are emitted into the atmosphere (mg/m^3): hydrocyanic acid – 21, hydrogen sulfide – 40.30, benzene – 40.38, phenol – 15.38, and naphthalene – 179.56.

The transfer of coal tar from the storage facility to the distillation department is performed by a pumping station, the operation of which is accompanied by atmospheric emissions of the following pollutants (mg/m^3): benzene – 252, phenol – 185, and naphthalene – 840.

Inside the enclosed warehouse, in addition to unloading operations, the process of tank steaming is carried out, which is accompanied by atmospheric emissions of the following substances (mg/m^3): benzene – 128, hydrocyanic acid – 140, phenol – 235, and naphthalene – 341.

The storage tanks of the tar farm and the enclosed warehouse are equipped with a common collector system for transporting gaseous substances to the catalytic incineration unit. Prior to entering the catalytic reactor, the gas emissions are partially diluted with atmospheric air; subsequently, within the apparatus containing the catalyst, they undergo oxidation to carbon dioxide and water at temperatures of 400-450°C. The heating of the gas-air mixture within the unit is facilitated by tubular electric heating elements (TEHs). Before reaching the fan, the purified gases are cooled (diluted) with atmospheric air to a temperature of 75°C (Fig. 1). The annual operating time of the unit is 8,760 hours. The emissions of pollutants are discharged through a stack with a diameter of 0.4 m at a height of 30.0 m. The following substances are released into the atmosphere: nitrogen dioxide, sulfur dioxide, carbon monoxide, hydrocyanic acid, hydrogen sulfide, benzene, phenol, and naphthalene. Monitoring of the detoxification efficiency for organic substances was conducted by determining the concentrations of phenol, benzene, and naphthalene in samples of both contaminated and purified air.

To investigate the feasibility of using more cost-effective contacts within the emission control system (the catalytic incineration unit), polymetallic iron-based catalysts doped with transition metals (cobalt, nickel, manganese, copper, and zirconium) were developed. The selection of these additives was based on several considerations, including: the elimination of noble metals; high activity in deep oxidation processes typical for the coke-chemical industry; high mechanical strength and thermal stability, which are critical for catalysts operating in gas emission purification systems; and their wide-

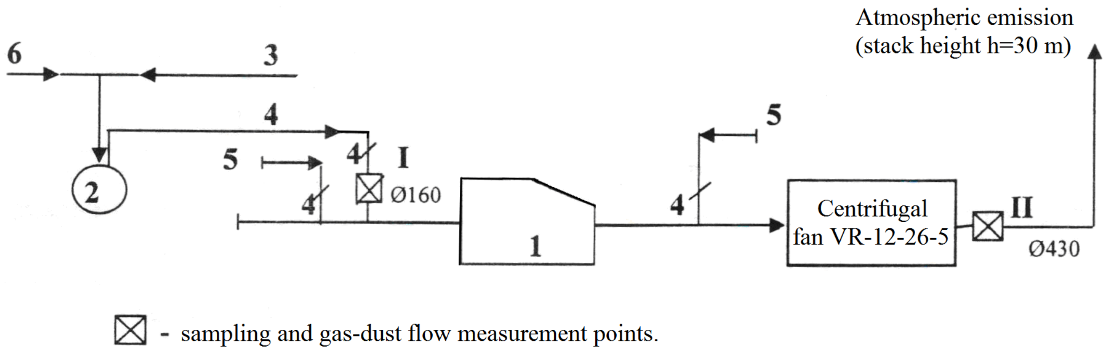

Fig. 1. Process flow diagram of the catalytic detoxification unit: 1 – catalytic reactor (apparatus); 2 – scrubber (washer); 3 – gas emissions from the warehouse (cargo shed); 4 – control valves (dampers); 5 – atmospheric air inlet (for dilution); 6 – gas emissions from the tar storage farm; I, II – sampling points and gas-dust flow parameter measurement locations.

spread industrial application alongside a robust manufacturing base for the mass production of polymetallic catalysts [7-9].

As the investigated catalyst for the oxidation of polycyclic aromatic hydrocarbons, an iron-based system with the stoichiometric composition $FeAl_3$ was used, synthesized via the thermal self-ignition method [10]. To enhance the catalytic activity, the $FeAl_3$ intermetallic was modified with varying amounts of transition metals.

Following synthesis, the material is a bilayer product consisting of oxide and metallic phases. The target metallic phase is separated from the oxide phase, after which it undergoes crushing and fractionation. A precursor fraction of 0.1-0.3 mm was utilized to obtain the catalyst. Both alkalis and acids can be used to dissolve the aluminum; however, in industrial practice for the production of Raney metals, NaOH and KOH solutions of various concentrations are most commonly employed.

Leaching of the samples was performed using a 20% NaOH solution. The amount of removed aluminum was monitored based on the sample weight loss. Hereafter, the catalyst composition will be characterized by numerical values representing the mass ratio of transition metals incorporated into the initial intermetallic charge. Losses across all synthesis stages do not exceed 5%.

X-ray diffraction (XRD) studies of the reaction products were carried out using a DRON-3 diffractometer. The content of active components was determined via atomic absorption spectroscopy. The surface area of the catalysts was measured using the BET method (thermal desorption of argon).

The activity of the synthesized catalysts was studied in hydrocarbon oxidation reactions using a flow-type unit with chromatographic analysis of the reaction products (Porapak Q).

The unit consists of a cylindrical flow reactor with a catalyst bed, a thermocouple for temperature control within the reactor, a chromatograph, a flow meter, and a cylinder containing a model gas mixture. The catalyst is heated primarily by the flow of the model gas mixture, which is preheated at the outer walls of the reactor. The reaction products were passed through a desiccant to remove water formed during the process. Experiments were conducted in the temperature range of 100 to 500°C, depending on the catalyst activity, with intervals of 25-100°C. The catalytic activity was characterized by the temperature of 100% hydrocarbon conversion ($T_{100\%}$).

The catalysts derived from iron-based intermetallic precursors exhibited a reasonably high catalytic activity. However, the oxidation process on these catalysts displays several characteristics distinct from those of other catalyst systems. These materials possess a higher specific surface area and, according to X-ray diffraction (XRD) data, consist primarily of oxides.

Let us examine the hydrocarbon oxidation process over the developed catalysts. The Fe (100%) sample initiates activity only at 200°C, reaching 80% hydrocarbon conversion at 500°C. The addition of nickel to the iron-based intermetallic catalyst significantly alters its physicochemical and operational characteristics. Instead of a pure iron phase, more complex structures are formed. This modification changes the electron density at the active sites, thereby enhancing catalytic activity in hydrocarbon oxidation reactions.

Nickel influences the temperature and velocity of the combustion front during alloy synthesis, allowing for precise control over the material's porosity. Furthermore, the nickel additive promotes the formation of a more highly dispersed structure, directly contributing to an increased specific surface area of the catalyst. While pure iron catalysts are prone to rapid irreversible oxidation and subsequent loss of activity, nickel enhances the corrosion and thermal stability of the system.

In the processing of tars or organic emissions (such as benzene, phenol, and naphthalene), iron frequently triggers coke formation. Nickel facilitates the gasification of carbon deposits, thereby extending the catalyst's service life. Consequently, nickel acts as a potent modifier, transforming the iron catalyst into a high-performance material capable of operating under the rigorous conditions of metallurgical production.

The addition of nickel and cobalt to the catalyst composition results in a sharp increase in catalytic activity. With the addition of 5 wt.% cobalt, a 90% hydrocarbon conversion is achieved at 450°C. The sample containing 15 wt.% cobalt shows the best result, with 95% hydrocarbon conversion reached at 350°C.

Since the addition of manganese significantly enhances the activity of intermetallic catalysts, it was decided to incorporate it into the sample composition. All catalysts underwent pretreatment with hydrogen peroxide. In these samples, the cobalt content remained constant at 15 wt.%, while the manganese content varied from 5 to 15 wt.%.

These samples exhibit activity in hydrocarbon oxidation starting as low as 100°C, which is uncharacteristic of other intermetallic catalysts. On the optimal sample, containing 12 wt.% manganese, a 99% hydrocarbon conversion is achieved at 300°C.

Investigations into the catalytic activity of samples doped with Cu revealed significant differences compared to previously studied catalysts. The copper content was varied from 1 to 5 wt.%.

Iron-based samples exhibit activity in the hydrocarbon oxidation process at lower temperatures. For the majority of these samples, hydrocarbon conversion initiates as early as 100°C. However, this high initial activity negatively impacts the stability of these catalysts. The developed catalyst systems with various cobalt and manganese contents lose their activity in hydrocarbon oxidation reactions after only the tenth experiment, stabilizing at approximately one-third of their initial activity level.

Additional alloying of the catalysts with copper leads to the formation of strong bonds between the catalyst grains, which enhances the ultimate strength of the catalyst and extends its service life in gas purification systems. During the first twenty experiments, their activity in hydrocarbon oxidation remains unchanged; this is followed by a gradual, slow decline of 5-8%, after which the activity reaches a stable value.

The physicochemical properties of the precursors and their production method significantly influence the characteristics of the resulting catalysts. The synthesis conditions of the intermetallic are decisive not only for the microstructure of the precursor itself but also for the catalyst's microstructure, surface morphology and composition, and specific surface area, thereby exerting a major influence on the catalytic properties. The mechanical properties of the catalyst are directly dependent on the phase composition of the precursor. The addition of zirconium stabilizes the intermetallic structure, increasing the specific surface area of the catalyst. The zirconium content was varied from 1 to 3 wt.%.

The primary phase forming the precursor is Fe_4Al_{13}. All aluminide phases formed by iron contain a sufficient amount of aluminum for rapid and complete leaching. In combination with iron, cobalt forms aluminides with the composition Co_4Al_{13}, which also exhibit good leachability. As the Co content increases, the composition of the iron aluminide phases undergoes slight modification. The manganese-containing phase is difficult to identify on the X-ray diffraction pattern due to peak overlap.

Figure 2 shows an electron scanning microscopy image of the surface of the Fe-Ni-Co-Mn-Cu-Zr (41%-33%-15%-12%-3%-1%) catalyst. Regular hexagonal plates are preserved as the main structural element. The surface of the iron-based catalyst is covered with hematite Fe_3O_2 octahedra. The catalyst does not form a dense structure; however, hexagonal plates are present on the surface alongside hematite crystals.

Scanning electron microscopy (SEM) also enables point-to-point elemental analysis of the surface composition. A high concentration of manganese and oxygen was detected at all investigated structural points, suggesting that the plates are likely composed of manganese oxides. Cobalt, nickel, copper, and iron were also identified, which can be attributed to the composition of the substrate material upon which the structure forms.

A nanostructure consisting of hexagonal plates with a diameter of approximately 2 μm and a thickness of 100-200 nm forms on the surface of the manganese-containing sample. The plates are predominantly oriented perpendicular to the substrate surface on which they grow, frequently coalescing at the edges to form star-shaped clusters. Areas where the plates fuse along their faces to form extended columnar structures are also observed.

One of the reasons for the low catalytic activity of the precursors is their low specific surface area. During the preparation of catalysts through the leaching of aluminum, the specific surface area increases substantially. The addition of manganese to the iron-based precursor leads to the formation of a nanostructure on the catalyst surface, which enhances its specific surface area.

Despite its small percentage, the zirconium additive acts as a classic micro-dopant that inhibits crystallite growth, thereby helping to maintain the nanostructured state of the intermetallics. The specific surface area of the Fe-Ni-Co-Mn-Cu-Zr (41%-33%-15%-12%-3%-1%) catalyst was found to be 74.3 m^2/g.

Pilot-scale studies were conducted under actual conditions at a tar distillation shop using a laboratory-scale unit equipped with the developed catalyst, through which contaminated air was passed. The composition of the contaminated air at the reactor inlet (mg/m^3) was as follows: phenol – 5.4; benzene – 15.0; and naphthalene – 829.0. The tests demonstrated that the detoxification efficiency of organic compounds over the developed catalyst reached 99.0-99.8%, ensuring compliance with maximum permissible emission (MPE) standards for phenol, benzene, and naphthalene. Consequently, the catalyst is recommended for operation in coke-chemical production and similar technological processes.

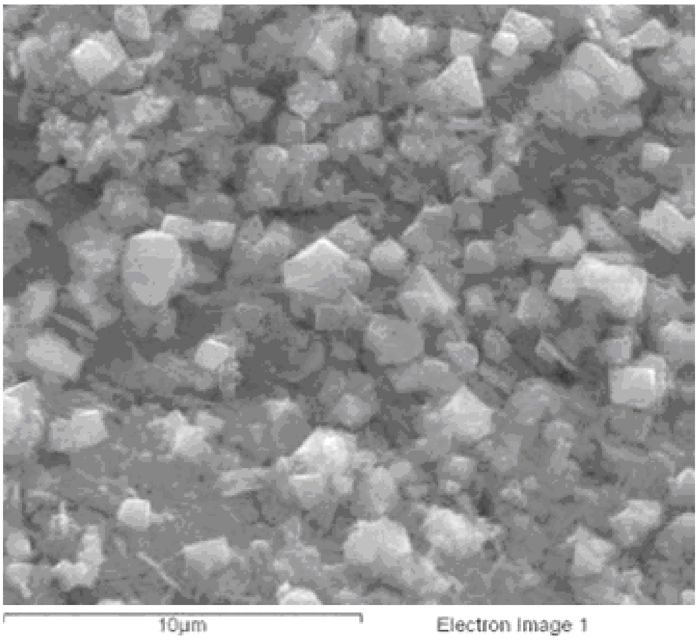

Fig. 2. Microphotograph of the surface of the Fe-Ni-Co-Mn-Cu-Zr (41%-33%-15%-12%-3%-1%) catalyst

Conclusions. Coke-chemical production is one of the most environmentally hazardous segments of the metallurgical cycle. This study identifies the composition of pollutants generated during the technological processes of a tar distillation shop, specifically: hydrocyanic acid, hydrogen sulfide, benzene, phenol, and naphthalene. To utilize more economically viable contacts in emission control systems (catalytic afterburning units), new polymetallic iron-based catalysts were developed. Intermetallic precursors of the stoichiometric composition $FeAl_3$ were synthesized using the thermal self-ignition method, which ensures the formation of a specific double-layer precursor structure where the predominant phase is Fe_4Al_{13}. To enhance catalytic activity, the precursors were modified with various amounts of transition metals, specifically by adding nickel (Ni), manganese (Mn), cobalt (Co), copper (Cu), and zirconium (Zr) in concentrations ranging from 1% to 35 wt. %. A technique for catalyst preparation was developed, which included a stage of additional sample stabilization with hydrogen peroxide. Treatment with H_2O_2 enables the removal of chemisorbed hydrogen from the precursor surface during leaching, facilitating the production of skeletal catalysts with a highly developed specific surface area, which reaches 74.3 m^2/g for the optimal composition. Nickel and cobalt significantly enhance catalytic activity by altering the electron density at the active sites. The addition of 15 wt. % cobalt allows for achieving 95% hydrocarbon conversion at a temperature as low as 350°C. Manganese promotes the formation of a unique surface nanostructure, which is critical for increasing the active surface area of the catalyst. Alloying with manganese enables a reduction in the 100% hydrocarbon conversion temperature by 100-150°C compared to unmodified analogues. Copper alloying ensures mechanical strength and activity stability, while zirconium acts as a micro-dopant that inhibits crystallite growth and preserves the nanostructured state of the system.

The developed systems exhibit activity starting from 100°C, which is atypical for standard intermetallic systems. It was established that the optimal catalyst composition, Fe-Ni-Co-Mn-Cu-Zr (41-33-15-12-3-1 wt. %, respectively), ensures a high degree of detoxification of toxic components under the conditions of coke-chemical production. Pilot-scale tests in a tar distillation shop confirmed the purification efficiency for phenol, benzene, and naphthalene at the level of 99.0-99.8%. The developed catalyst ensures full compliance with maximum permissible emission standards and is recommended for wide-scale implementation at coke-chemical and related industrial enterprises.

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