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Improvement and Reconstruction of Coking Processes

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Abstract

Coke quality requirements are formulated according to the functions it performs in blast furnace smelting. The main technological methods and measures to improve the technology of coal charge preparation for coking are analysed. Particularly promising technologies for achieving high quality blast furnace coke, expanding the raw material base for coking and reducing the cost of coal charge (technology for coking a stamped charge, technology for coking a dry charge and technology for coking thermally prepared charges) are considered. These methods have a direct impact on the bulk density of the coal charge, the clinker properties and, consequently, the quality of the coke produced and the production capacity of the coke oven. It should also be noted that their implementation improves the environmental safety of coke production (by increasing the productivity of the coke oven battery, the specific emission of harmful substances to the environment is reduced). The article analyses the research into the improvement of coking processes and their practical application, which was not available to the English-speaking reader.

Keywords: *Coke; Coke functions; Blast furnace; Coal batch; Coking processes.*

1. Introduction

According to the World Steel Association, global steel production in 2021-2022 averaged 150 million tons (Mt). To produce that much steel will require around 85 Mt of coke. The predicted estimated cost of metallurgical coke in 2023 will be about 200 billion US dollars [1-3]. According to this information, the production and use of metallurgical coke is now significant. Currently, coke remains an extremely important raw material for blast furnace iron production.

Coke functions as a complex energy-technological material in the blast furnace. Primarily, coke is a reductant and heat source in the blast furnace process. A smaller part of the coke is spent on reduction processes, and the main part goes into the furnace and burns together with the fuel to CO_2, releasing the required amount of heat in the blast furnace. The formed carbon dioxide is reduced to carbon monoxide upon contact with red-hot coke.

Carbon oxide rises upward and, depending on the zone temperature, reduces metal oxides by the following equations:

$$3\,Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2 \quad (1)$$
$$Fe_3O_4 + CO \rightarrow CO_2 + 3FeO \quad (2)$$
$$FeO + CO \rightarrow CO_2 + Fe \quad (3)$$

Cast iron is the final product of such reduction. In addition to energy and reagent functions, coke as a solid material ensures uniform gas distribution over the cross-sectional area of the blast furnace unit. The above-mentioned main functions of coke cause relevant requirements for it. Coke quality is one of the main parameters determining the progress and results of blast furnace smelting.

Modern requirements for the quality of blast furnace coke are clearly formulated and remain quite high: $M_{25} \geq 88.0$-90.0%; $M_{10} \leq 6.0$-6.5%; CSR - 60.0-75.0%; CRI - 25-30.0%, +80 mm fraction content - no more than 5%; - 25 mm fraction content - no more than 5%; moisture fluctuations on both sides - no more than 0.5%.

The he quality of coke depends both on the composition of the coal charge and on the technology of preparing coal concentrates for the coking process in terms of such indicators as particle size distribution, bulk density, moisture content and initial temperature of the coal mass.

Achieving high quality coke for blast furnace smelting is possible provided an integrated, scientifically based approach to improving the technology of coal preparation for coking, which consists in the development of methods and technological measures, the main of which are:

- prediction and optimization of the charge composition, taking into account the petrographic characteristics of its components and the bursting pressure of coal concentrates [4];
- the need to switch to more efficient final grinding schemes, taking into account the petrographic characteristics of the coal charge components in combination with the screening of small classes before grinding [5];
- introduction of organized mixing of coal charge components for its homogenization [6];
- control of the degree of oxidation of coal concentrates [7-8].

Recently, technologists have focused on the introduction and application of special methods of preparation of coal raw materials for coking. The technologies that allow to significantly reduce the share of high-blowing coal in the charge, to expand the raw material base by using low-blowing, low-metamorphosed coal, and thus to reduce the cost of the coal charge are the technology of coking rammed charge, the technology of coking dry charge, and the technology of coking thermally prepared batches.

2. Discussions

Coking of stamped, dry and thermally prepared, briquetted batches is a technology that allows a significant reduction in the share of good-clinkering coal in the batch and uses batches in which rank composition is as close as possible to the balance of coal resources of a specific basin.

An increase in the bulk density of the coal batch occurs during its tamping (the bulk density of the batch loaded into the furnace in the «usual» way is 0.72-0.73 t/m^3 per dry mass; the bulk density of the stamped cake, formed using modern equipment, is 1.017 t/m^3 per dry mass). The greater the cake density from the same batch, the greater the strength of mechanical and capillary adhesion between the coal grains, and the greater its strength. As a rule, the volume of free intergranular space in a bulk batch is 42-43%, and in a stamped one - 19-20% [9-10].

In stamped coal batch, complicated conditions are created for the evacuation of steam and gaseous products from the plastic layer. This results in an increase in gas pressure. The higher the gas pressure, the more actively steam and gaseous products of pyrolysis participate in secondary reactions with the organic coal mass. At the same time, hydrogen saturation reactions are intensified, and free bonds of fragments of macromolecules (free radicals) are formed. This leads to an increase in the number of relatively low-molecular compounds, which, at certain temperatures, can be in a plastic state and take an active part in the clinkering process. Such a change in chemistry towards reductive depolymerization has a positive effect on the plastic state of the stamped coal batch. During coking of stamped batch, temperature and, therefore, time intervals of coal plasticity (especially low-clinkering coal) expand. Positive changes in the plastic state, along with an increase in the density of the plastic layer, make it possible to use the clinkering potential of the batch to a greater extent and to obtain coke of high mechanical strength from batches of reduced clinkering [10].

The stamping process and the strength of the coal cake depend on the characteristics of the coal raw material: degree of metamorphism; the content of mineral impurities (ash content); shapes and sizes of coal grains (small classes contribute to compaction, filling the pores between large grains and thereby increasing the bulk density); humidity (moisture acts as a binder, affects the sealing process by reducing internal friction) [9,11-13].

To study the mechanical strength of stamped coal cakes, the authors developed a special strength tester that combines the capabilities of testing compressive/tensile strength and shear strength. Based on tests of the ramming process and the effect on the strength of the cake for this coal, an empirical model was proposed [11-12] for calculating the stampability factor (K) of a coal cake with the required density and height, which is calculated as follows:

$$K = \left[\frac{HGl_{max} = 100}{HGL^{\beta} \times d'^{\delta} + n}\right]_{W=W_{apt}} + \alpha \times (W - W_{opt})^2 \qquad (1)$$

where HGL – Hardgrove grindability index, units; W- moisture content in the batch, %, $d^{/}$ – diameter of a coal particle, mm; n - RRSB distribution function; α, δ ß, W_{opt} – model parameters.

The results of laboratory modeling show [13] that DEM (discrete element method) is an appropriate tool for studying the coal stamping process. The modeling approach makes it possible to obtain additional information for empirical research on a laboratory scale. In particular, the mechanisms of movement and rearrangement of particles in stamped coal, contact forces and local differences in the porosity or density of the cake can be dynamically monitored during the stamping process (Fig. 1).

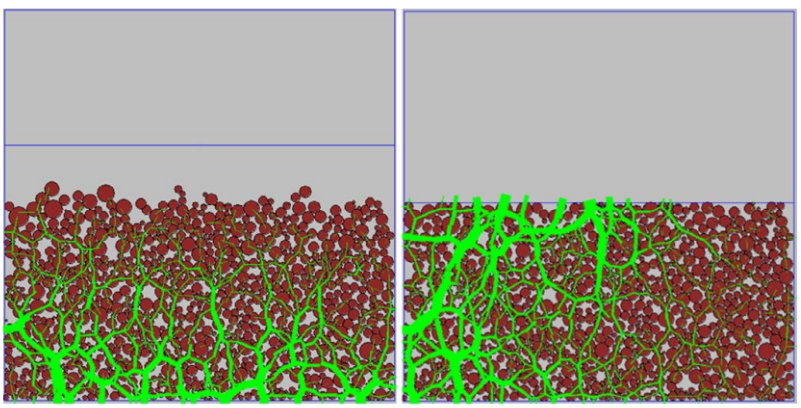

Fig.1. Contact forces between particles. Compression forces arising in coal batch under the action of gravity (left) and under the stamper impacts the coal cake (right) [13].

During the process of preparing coal batches using stamping in production conditions, the main goal is to obtain a coal cake of optimal density and strength, which will ensure its trouble-free loading into the coke chamber and guarantee the production of homogeneous coke with high physical and mechanical characteristics. Damage to the coal cake during its loading leads to operational complications and environmental problems (unorganized emissions) and reduces the productivity of the coking chamber. Based on the established parameters of the technological process (moisture and grain size), the main factor determining the mechanical strength of the coal cake is the stamping energy (cumulative energy transferred to the coal cake during the stamping process). Under the influence of the energy transmitted by the hammers at the moment of impact, the coal grains move relative to each other, gradually filling the space between the grains and creating a dense packing. The movement of particles is facilitated by surface moisture, which minimizes frictional forces between them [11,13-14]. The results showed that depending on the properties of the coal raw material, the consumption of stamping energy necessary to achieve the optimal density of the coal cake differs significantly.

A mathematical model for predicting the coal cake density and determining the required cumulative energy of stamping depending on the batch components' properties is proposed in [15]:

$$p^d = 623.95 + 53.33 \cdot \ln(E) - 3.82 \cdot V^{daf} + 8.89 \cdot A^d + +63.26 \cdot d' - 31.13 + 3.99 \cdot W_t^r \qquad (2)$$

where ρ^d – coal cake density, kg/m^3; E - cumulative tamping energy, J/kg; V^{daf} – the yield of volatile matters of the batch, %; A^d — the ash content of the batch, %; $d^/$ – diameter of a coal particle, mm; n - RRSB distribution function parameter; $W^r{}_t$ – batch moisture, %.

The developed model makes it possible to determine the level of cumulative energy, technical parameters of the equipment (mass and number of stamping hammers, height of fall), and time required for stamping. Studies have shown that an increase in the yield of volatile matters from 20 to 32% leads to a decrease in the density of the coal cake at all investigated levels of cumulative stamping energy (600-1200 kJ/kg). An increase in the cumulative energy of stamping from 600 to 1200 kJ/kg, the moisture content of the batch, and the ash content cause an increase in the coal cake density.

Coke with high cold strength M_{25} = 90% and abrasion resistance M_{10} = 5% with a rank content of 25 mm 3.5%, CRI ≤27%, and CSR ≥65% was obtained on battery No.10-bis of PJSC Alchevskkoks, where batch stamping and coke dry quenching technologies are used. At the same time, high-quality coke was obtained from batches in which the share of high-clinkering coal (without K rank coal) was 33.9%, and the share of low-clinkering coal was 66.1% [11]. Since February 2017, the coal batch stamping technology has been implemented at the new coke battery No.6 (coal cake density 1.1 t/m^3), and in 2018 – at battery No.5 of coke production of ArcelorMittal Kryvyi Rih. Analyzing the data on the composition of coal batches supplied to coke batteries No. 1–4 (coking of bulk batch), it can be noted that the average share of high-volatile coal was 47.07%; the content of medium-volatile coal - 35.27%; the content of low-volatile coal - 17.66%. Using stamping technology makes it possible to obtain blast furnace coke of a higher quality than with traditional technology. In particular, coke obtained at coke batteries (CB) No.5, 6 is characterized by lower values of ash content than at CB No.1-4 (11.4% and 11.7%), total sulfur content (0.44 and 0.52) and abrasion M_{10} at the level of 6.0% and 8.1%, while at the same time higher values of mechanical strength according to the grindability index, and are at the level of M_{25}~88.4% and 85.7% and coke strength after reactionCSR~54, 4% and 50.8%, respectively [16-18].

The coking technology of thermally prepared coal batches (TPC) has some advantages in comparison with coking processes of stamped batches:

- lack of special requirements for the design of typical coke ovens with a chamber height of 4.3 m and main coke machines (except coal loading wagon);
- the TPC equipment fits well into the coking unit infrastructure and can be implemented both on existing batteries and those under construction;
- the possibility of involving a wider range of low-clinkering high-volatile coal in the batches - up to 100%;
- a lower level of requirements for crushing the batch;
- makes it possible to obtain coke for various purposes (high-reaction coke for the ferroalloy and chemical industry, smokeless fuel for the energy industry, etc.);
- increases the productivity of coke ovens by 30-70%;
- allows coke batteries to be operated both on a heated batch and on a wet one [19].

The results of technology implementation [20] show that during coking of thermally prepared batches, strong coke can be obtained even from such batches, from which it is practically impossible to get it during coking by the usual method. The mechanical strength of coke from thermally prepared batches is significantly higher than that from wet batches, and this difference is even greater the more low-clinkering coal is in the batch. This technology ensures coke production with high physical and mechanical characteristics even when the batch quality fluctuates.

During the mastering of the thermally prepared batch installation at the Yasinovskiy Coke Plant, batches of different granulometric compositions were studied, in which the content of the class less than 3 mm ranged from 80 to 90%. The best results were obtained during coking batches with finer crushing, while the content of the class smaller than 0.5 mm should not exceed 45% [19].

The coking technology of thermally prepared coal batches was successfully mastered in 2006-2008, also at the research and industrial installation with a capacity of 60 t/h on a wet batch at the Yasinovskiy Coke Plant [20].

The composition of coal batches both at the basic stage (that is, wet batches on coke battery No.1) and in the experimental one (using thermally prepared batch), as well as their quality and the quality of the obtained coke, are given in Table 1.

Table 1. The composition of coal batches and the coke quality obtained at the Yasinovskiy Coke Plant

Batch variants	Composition of coal batch, %				Batch quality					Coke quality, %					
	G	Zh	K	KSN	A^d, %	V^{daf}, %	S^d, %	Y, mm	$И_o$	A^d	S^d	M_{25}	M_{10}	CSR	CRI
Basic	8.0	30.0	54.0	8.0	8.2	30.4	0.9	15.4	2.38	10.7	0.78	88.2	6.2	54.4	32.3
Experimental	35.0	10.0	40.0	15.0	7.9	31.4	1.0	11.4	2.47	10.4	0.91	90.9	4.8	44.9	42.3
Basic	10.0	30.0	50.0	10.0	8.2	29.8	1.4	15.2	3.35	10.9	1.18	87.4	6.5	42.2	39.0
Experimental	40.0	7.3	37.7	15.0	7.9	31.4	1.1	12.5	2.70	10.3	0.88	89.6	5.7	45.6	37.8

The given data show that although the share of low-clinkering coal in thermally prepared batches is 35% more than in wet ones (including coal rank G - by 27-30%), the coke obtained from them is better in terms of mechanical strength: for M_{25} – by 2.2-2.7%, and for M_{10} – by 0.8-1.4%. It should be noted that according to the M_{40} indicator, the differences between the coke types reach 4-5%, although the large coke classes from TPC are much stronger (M_{40} – 80-84%) than the traditional ones, and this is very important for maintaining gas permeability in the blast furnace [20].

The component composition of thermally prepared batches should ensure sufficient shrinkage of coke cake. From the experience of coking different composition batches, it follows that there are no complications in the coke production from thermally prepared batches, with the yield of volatile matters exceeding 30% [20].

The pre-dried batch coking technology developed by Nippon Steel and Sumitomo Metal Corporation was implemented as a CMC (Coal Moisture Control) process, then improved and implemented as DAPS (Dry-cleaned and Agglomerated Precompaction System) [9,21].

According to the CMC technology, coal is dried in a drying tube (Fig. 2), while its moisture content is reduced from 10% to 5–6% before loading into the coke furnace. Heat consumption for coking is significantly reduced when the moisture content of the batch is reduced from 10 to 6%. The application of moisture control technology reduces the moisture content of the batch by 1% and allows to reduce coking heat consumption by 62.0 MJ/t dry weight of the batch.

At a moisture content of 5%, water acts as a binder, and small coal particles either stick to the surface or stick to each other, forming conglomerates.

When coal is dried to a moisture content of 1.5% due to thermal shock, partial destruction of coal grains occurs, resulting in a large amount of coal dust. An increase in dustiness leads to the complications of coke cake issuance, the deterioration of resin quality, and the working conditions of personnel [9,21].

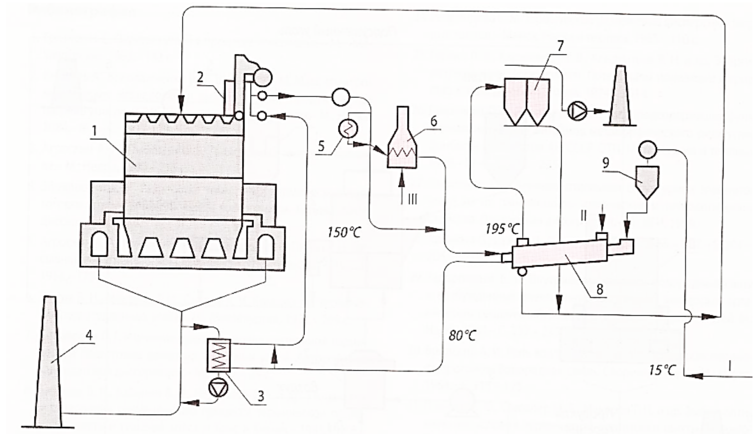

Fig. 2. Scheme of the installation for moisture control using CMC technology [9]:
1 – coke battery, 2 – riser heat exchanger, 3 – heat exchanger for gases that leave for heating furnaces, 4 – chimney, 5 – cooler, 6 – heating furnace, 7 – fabric filter, 8 – dryer, 9 – wet batch hopper. I – batches, II – air, III – coke gas

These shortcomings are eliminated when using the DAPS process (Fig. 3), which consists in decreasing the batch moisture content to 2% by drying it in a pseudo-fluidized bed. The resulting dispersed coal dust is fed to the agglomeration. Dry coarse coal and agglomerated are mixed and fed into the coke furnace.

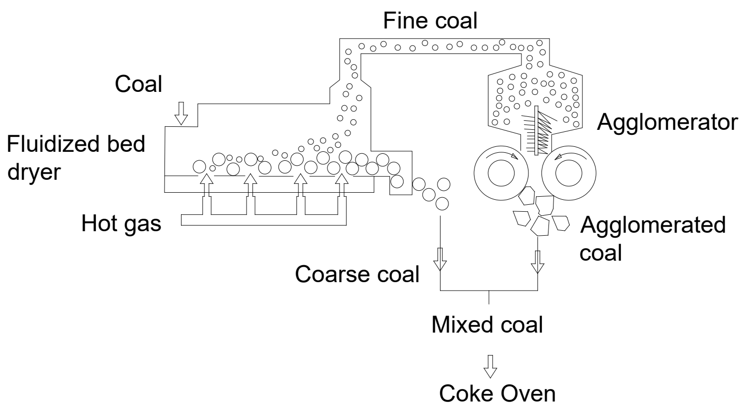

Fig.3. Scheme of the DAPS process (modified after [20]).

The decrease in coal moisture achieved in the process leads to an increase in the coal bulk density, coke furnace productivity, and higher coke strength. Thus, the M_{40} indicator increases by 1-2.5%, and M_{10} decreases by 0.5-1.5%, the reactivity (CRI) decreases by 0.5-2.5%, and the coke strength after reaction (CSR) increases by 0.2-2.5% [22].

The technology of coke production, according to the SCOPE 21 project [20] (Fig. 4), deserves attention and involves solving the following tasks: effective use of coal resources with an increase in the share of low-clinkering coal in the batch for coking up to 50%; increasing the coke oven productivity to reduce capital costs; reducing environmental impact and energy consumption.

Coal (coal batch) goes to the dryer-classifier, where the batch drying and division into two classes, fine and coarse. Coarse coal is rapidly heated to 350ºC in a pneumatic heater. After the dryer-classifier, fine coal enters two-roll presses and undergoes hot briquetting, then combines with coarse coal and loaded into a coke oven at a temperature of 250ºC [21-22].

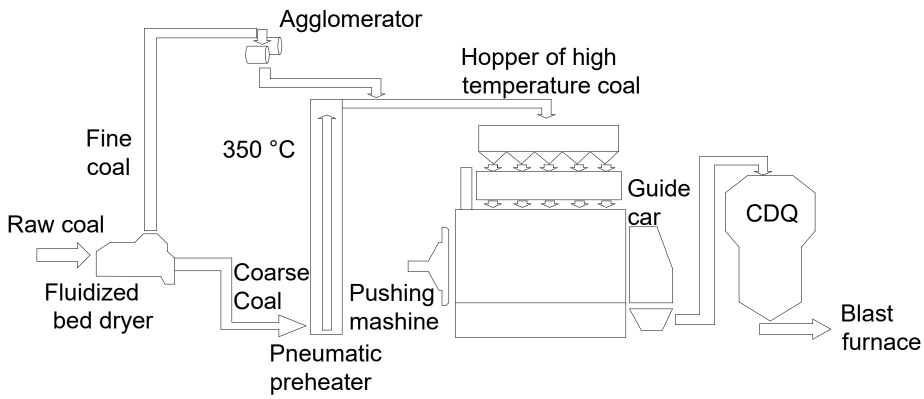

Fig. 4. Coke production technology, according to the SCOPE 21 project (modified after [21]).

The SCOPE 21 technological process has the following main advantages:
- reduction of coking time to 13 hours;
- reduction of energy consumption for coking;
- increasing coke strength to DI 86.5%;
- provides an opportunity to more fully use raw materials and increase the share of low-clinkering coal in batches from 20% to 50% [21-22].

The technology of thermal batch preparation before coking makes it possible to obtain coke from batches with a high content of highly volatile low-clinkering coal, which is superior in terms of mechanical strength to low-reaction coke from better coal batches [23].

The mechanical strength of coke from thermally prepared coal batches is significantly higher than from wet coal batches, and this difference is even greater the more poorly clinkering components the batch contains.

In [24], the study results of the heating rate influence during carbonization on the mechanical strength and reactivity of cokes and, therefore, on their mechanical strength after the reaction are given. The coal chosen for the study covered a wide range of volatile matter content (20.4–33.4 wt. %) and characterized by a low ash and sulfur content, the carbon content was in the range from 79.3 to 81.8%, the Gieseler maximum fluidity (F_{max}) of it varied from 192 to 25418 divisions/min. The Free Swell Index (FSI) was between 6 and 8 ½. Increasing the heating rate resulted in cokes with a higher coke strength after reaction CSR. Spectral analysis showed that an increase in the heating rate in the temperature ranges of 300-400, 400-500, and 500-750°C, which coincide with the pre-plastic, plastic, and post-plastic stages of the coking process, led to an increase in the degree of the structure orderliness, and, accordingly, led to obtaining cokes with higher coke strength after reaction CSR. An increase in the heating rate at the stage of the plastic state increases the coal plasticity, which improves coal particle adhesion and has a favorable effect on the formation of structures that form less reactive forms of carbon, which leads to coke production with a higher CSR.

A new approach to the thermal preparation of low-clinkering coal using ultrahigh-frequency irradiation is promising. According to the authors' conclusions [25-26], heating coal to 200-250ºC by ultra-high-frequency radiation, the temperature inside the coal grain due to electron-relaxation, migration, and ion-relaxation polarization reaches approximately 300-350 ºC, resulting in the formation of liquid-plastic and steam-gas products, which upon further heating to 400-450°C create high pressure, due to which the plastic mass erupts with the destruction of coal grains and a significant change in the thermochemical properties of the coal organic mass. This leads to the temperature range expansion of the existence of the plastic mass of heat-treated gas coal, the improvement of clinkering conditions and coke formation, which makes it possible to obtain from the poor clinkering batches a more homogeneous by size coke with increased strength characteristics (M_{25}, M_{10}) and thermochemical properties (CSR and CRI). Thus, the results of laboratory coking proved that the thermally treated gas coal addition to the composition of stamped batches increases the obtained coke quality characteristics (abs.%): the coke yield increases by 1.3; the large pieces yield increases by 16; strength increases by 2.0 and reactivity decreases to 2.0.

Preliminary briquetting/partial briquetting of the batch is another direction of the coking raw material base due to the inclusion of low-clinkering or non-clinkering coal in the composition of coal batches. The technology is used for processing non-condensing coal to obtain energy fuel, its semi-coking to obtain agglomerated smokeless fuel, and production of metallurgical coke from partially briquetted batch.

Research on the production of briquettes with different binders was conducted in many countries (China, USA, Hungary, Japan). A review of scientific sources shows that coal briquetting can be carried out without a binder [2,27], 8the binder can be of petroleum or coal origin [29-30], synthetic materials and modified various chemical reagents [31-33] or molasses are also used in a mixture with coal tar pitch after appropriate modification [34]. The binder has the following requirements: good binding capacity, low carcinogenicity, low adhesion to structural materials (especially metals), high cohesiveness, availability and economic feasibility [31].

In Ukraine, there is a shortage of petroleum products; available coal pitch resources are limited due to its use in the electrode industry. Therefore, it is of interest to study the possibilities of using non-traditional binders for briquetting. For example, work [35] presents the study results on the briquetting of fine coke and anthracite using a mixture of coal tar pitch and molasses (a by-product of sugar beet and sugar cane processing during sugar production) as a binder after its appropriate modification. The briquette production process involves blowing coal pitch with air and mixing it with molasses and hardeners. Then, the binder is mixed with crushed anthracite or coke fines, briquetting at a pressure of 140 MPa, and the briquettes are kept at 200°C for 2 hours for hardening. Ammonium carbonate, ammonium nitrate and nitric acid in different amounts were added to the molasses as hardeners. The best results among the tested hardeners were obtained with 2.5% ammonium nitrate. The briquettes obtained using a mixed binder (coal tar pitch + molasses) with a hardener were highly water-resistant and water-impermeable, and their tensile strength was sufficiently high (35 MPa). The authors [30] also claim that briquettes, after solidification, can be directly loaded into the blast furnace without prior coking and can partially replace coke in the blast furnace.

The results presented in [36] on the briquetting of low-clinkering coal with semi-coke obtained from the same coal for highly reactive coke production are promising. The mixture components (low-clinkering coal, high-clinkering coal, semi-coke and hard coal pitch) were taken in the following ratio of 10:20:44:8, respectively. The coarseness of the coal components was less than 2 mm; semi-coke was ground to a particle less than 0.178 mm, and coal pitch to <0.150 mm. Coal briquetting was carried out in a press under a pressure >200 kN/cm^2. The size of the obtained briquettes was 2.8 × 2.5 × 8.0 cm. Compared to the quality of other traditional metallurgical cokes, briquette coke had lower porosity, graphitization degree and crystallite size. In addition, the isotropic structure prevailed in the optical structure of the briquettes. Isotropic carbon layers are arranged chaotically with randomly oriented microcrystallites. Since non-clinkering coal practically does not form a plastic mass during pyrolysis, the briquettes preserve up to 60% of the fusinite and fine fragmental structure of the coal raw material. These factors cause the high reactivity of briquettes. Using microscopic studies, it was established that the structural matrix of briquette coke is very dense; it is dominated by pores with thicker walls of an elliptical or rod-shaped shape, the size of which is <100 μm. The peculiar structure of the pore wall can be caused by high pressure on low-clinkering coal during its briquetting. This is quite different from the porous structure of ordinary blast furnace coke, which is characterized by mainly large round or rod-shaped pores >100 μm in size. The established structural features, namely the presence of mostly small-sized pores with thicker walls and the increased internal specific surface of the briquette matrix due to this, cause higher compressive strength and coke strength after reaction CSR_{25} briquettes (according to the method [37]) compared to traditional coke samples.

The paper [38] presents the results of studying the behavior of coal briquettes of different component compositions and the assessment of their influence on the volume of coal loading in the coking chamber. Two versions of the experimental batches were composed of low-, medium-, and highly metamorphosed coal in the ratio of 70:20:10 and 20:70:10. Coking was carried out in a laboratory installation. Coking of batches was carried out in a mixture with two types of briquettes: 1) had the same composition as coal batches; 2) were made from highly metamorphosed coal with the addition of 2 wt.% coal pitch (CTP), 2 wt.% low-density polyethylene (LDPE) and 2 wt.% polypropylene (PP). It was found that the addition of 1 type briquettes (the same composition as the batch) contributes to an increase in the volume of coal loading at the swelling stage near the heating wall. This can cause a dangerous increase in the expansion pressure. The addition of briquettes made from a mixture of highly metamorphosed coal with the above additives to the two variants of coal batches reduces the volume of coal loading at the swelling stage. Briquettes with the specified additives act as moderators and inhibit the increase in the batch volume, which contributes to reducing the created expansion pressure. These additives interacted with volatile products during the thermal destruction of the batch organic mass. The gas phase (volatile products of pyrolysis) amount and its composition significantly affect the swelling intensity, texture and porosity of highly metamorphosed coal briquettes. Studies have shown that the composition of the volatile phase has practically no effect on coal briquettes with an additive of 2 wt. % polypropylene. Briquettes with the addition of 2 wt.% of low-density polyethylene were the most susceptible to the gasification process. Briquettes with the addition of 2 wt.% coal pitch tended to increase in size under the influence of more volatile decomposition products.

3. Conclusions

The functionality of coke in a blast furnace is conditioned by its chemical, physicochemical and physical properties. At the same time, its quality depends crucially on the properties of coal raw materials and the efficiency of its preparation.

Taking into account that according to the decision of the European Commission dated September 3, 2020, coking coal is included in the updated list of critical raw materials - strategic from the point of view of the European Union's functioning and economic development [39], it is necessary to ensure the economy and efficiency of coke production while optimizing the consumption of scarce raw materials. To expand the raw material base of coking coal, it is necessary to introduce promising technologies such as coal front cleaning, batch modification using additives, coking of stamped batches, the technology of coking dry batch, the technology of coking thermally prepared batches, coking of partially briquetted batches.

These methods directly affect the bulk density of coal batch, clinkering properties, and, therefore, the quality of the obtained coke and the production capacity of coke chambers. It should also be noted that their implementation increases the environmental safety of coke-chemical production (due to the increase in productivity of the coke battery, the specific emission of harmful matters into the environment decreases).

Symbols

M_{10}, M_{25} – indices of resistance of coke abrasion and crushability, respectively, %;
>80 mm, 80-60 mm, 60-40 mm, 40-25 mm, <25 mm – content of particles in coke accordingly, %;
CRI, CSR – coke reactivity index and coke strength after reaction, %
HGL – Hardgrove Grindability Index, units;
ρ^d – coal cake density, kg/m^3;
E - cumulative tamping energy, J/kg;
V^{daf} – the yield of volatile matters of the batch, %;
$W^r{}_t$ – water content of the coal batch (or coke), %;
A^d – ash content of the coal batch (or coke) in the dry state, %;
$S_t{}^d$ – sulphur of the coal batch (or coke) in the dry state, %;
Y, mm – plastometric parameters (thickness of the plastic layer);
$И_o$ - basicity index, units.

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