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Development and implementation of technological measures to extend the campaign of blast furnace No. 5 of PJSC Severstal

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Abstract. The work presents generalized experience in the development and implementation at PJSC Severstal of technological measures to extend the campaign of blast furnace No. 5. The authors carried out an analysis, identified and described the problem areas, generalized the principles for ensuring the safety of the shaft lining, boshes and metal receiver of the blast furnace. The results of a study of the working space of blast furnace No. 5 in 2006 are also presented. The identified technological factors ensure an increase in duration of the unit campaign. Technological measures are given for: washing the blast furnace hearth, reducing chemical erosion of the carbon blocks of the hearth and flange, forming a protective skull in the blast furnace shaft, special methods for loading solid coke substitutes, and organizing an effective structure of the charge column in the blast furnace. It is necessary to use digital models integrated into the blast furnace expert system for operational control of blast furnace technology. The results of the current blast furnace campaign were compared with previous ones. It was proven that the systematic use of all elements of the developed technology makes it possible to achieve high economic indicators while exceeding the standard duration of the campaign by 1.75 times. Experience in technology development made it possible to increase the furnace campaign duration to 17.46 years, achieve a reduction in specific coke consumption by 15.9 %, and increase the specific consumption of natural gas for cast iron smelting by 46.4 %; reduce the specific carbon consumption for cast iron smelting by 6.3 %.

Keywords: blast furnace, campaign duration, PJSC Severstal, blast-furnace hearth, shaft, toterman, hearth washing, skull formation, specific consumption of natural gas, solid fuel consumption per ton of cast iron, digital model, iron ore materials, coke, CSR

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Разработка и внедрение технологических мероприятий по продлению кампании доменной печи № 5 ПАО «Северсталь»

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Аннотация. В работе представлен обобщенный опыт по разработке и внедрению на ПАО «Северсталь» технологических мероприятий по продлению кампании доменной печи № 5. Авторы провели анализ, выявили и описали проблемные зоны, обобщили принципы обеспечения сохранности футеровки шахты, заплечиков и металлоприемника доменной печи. Также представлены результаты исследования рабочего пространства доменной печи № 5 в 2006 г. Выявленные технологические факторы обеспечивают увеличение длительности кампании агрегата. Приведены технологические мероприятия по промывкам горна доменной печи, снижению химической эрозии углеродистых блоков горна и лещади, формированию защитного гарнисажа в шахте доменной печи, особым приемам загрузки твердых заменителей кокса и организации эффективной структуры столба шихты в доменной печи. Для оперативного управления технологией доменной плавки необходимо использовать цифровые модели, объединенные в экспертную систему доменной печи. Авторы провели сравнение результатов текущей кампании доменной печи с предыдущими и доказали, что системное применение всех элементов разработанной технологии позволяет достигать высоких экономических показателей при превышении нормативной продолжительности кампании в 1,75 раза. Опыт развития технологии позволил увеличить длительность кампании печи до 17,46 лет, достигнуть снижения удельного расхода кокса на 15,9 %, увеличить удельный расход природного газа на выплавку чугуна на 46,4 % и сократить удельный расход углерода на выплавку чугуна на 6,3 %.

Ключевые слова: доменная печь, продолжительность кампании, ПАО «Северсталь», горн, шахта, тотерман, промывка горна, гарнисажеобразование, удельный расход природного газа, расход твердого топлива на тонну чугуна, цифровая модель, железорудные материалы, кокс, показатель CSR

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Introduction

The current development trends of global blast furnace production are aimed, as before, at bringing down the cost of cast iron smelting by reducing coke consumption, enhancing the productivity of blast furnaces (BF) and the duration of their campaign. Increased duration of the campaign, the period between overhauls of the first category above the standard level, enables to reduce the unit cost and boost the competitiveness of the manufacturer in the world market.

This work presents generalized experience in the development and implementation of technological measures aimed at extending the campaign of blast furnace No. 5 at PJSC Severstal. As previously scheduled, on April 1 – 2, 2024, PJSC Severstal performed blowingout of blast furnace No. 5 "Severyanka" with a useful volume of 5500 m^3 and tapped the salamander. The furnace was submitted for the overhaul of the first category. Blowing-out was successful, accident-free, consistent with the developed technological program. The furnace campaign lasted 17.46 years from 20.10.2006 to 02.04.2024 (hereinafter referred to as the current campaign), significantly exceeding the standard service life of blast furnaces with the similar design. Blast furnace No. 5 was first blown in on April 12, 1986 and is currently the largest cast iron production unit in Europe. The current campaign is the third in a row, the first two lasted 9 and 11 years respectively.

Theoretical background

The standard blast furnace campaign in most cases is 12 – 15 years [1; 2], but campaign durations of some furnaces, such as Hamborn No. 9 blast furnace made by ThyssenKrupp Steel Europe, can exceed 22 years [3]. The authors of [4] believe that the key technological factors ensuring the duration of the blast furnace campaign are stability and compliance of charge materials with quality standards, rational slag and blast modes, loading mode parameters ensuring the required distribution of charge components and gas flow, and technologically justified mode of melting products processing. In addition, a number of researchers [5 – 7] note that, to a large extent, durability of the flange and hearth lining, contribute, to a large extent, to achieving long-term safe and accident-free operation of the blast furnace.

The major factors affecting wear of the refractory lining are:

– abrasive effect of liquid cast iron flows;

– chemical effects of cast iron and slag;

– infiltration and thermomechanical stress in the lining [8].

While high quality iron-containing materials are required to ensure a long service life of the blast furnace shaft lining, the service life of the hearth lining is largely determined by the quality of the loaded coke. Wear-resistant hearth structures are currently non-existent [9], but the technologies aimed at extending the life of the furnace lining are continuously improving. The numerous studies were conducted by domestic and foreign researchers on blown-out and cooled blast furnaces to establish the main types of impacts destroying the lining and changes in their intensity along the blast furnace height [10 – 12].

Creation of a stable skull is one of the main measures aimed at ensuring the safety of the shaft lining, boshes and metal receiver of the blast furnace, which contributes to increasing the duration of its campaign.

The gas flow distribution along the blast furnace radius and height is controlled by a purposefully formed zone of enhanced gas permeability, the so-called vent, which can be formed by distribution of ore loads both in the axial zone of the furnace and at the periphery.

Identification of critical areas of blast furnace No. 5 requiring protection based on the results of the previous campaign

Blast furnace No. 5 was shut down for overhaul of the first category at the end of the previous campaign in 2006. After blowing-out of blast furnace No. 5, the samples of refractory lining and skull-forming masses were selected along its height. Fig. 1 features a scheme of the sampling points and the Table presents the chemical composition of the studied material samples.

The analysis of the state of blast furnace No. 5 working space in 2006 revealed the following:

– in the area of cast iron notches, the refractory thickness did not exceed 200 – 250 mm, carbon peripheral blocks of the upper flange located directly under the notches were deformed, cracks and chips emerging in some places;

– significant reduction in the thickness of the shaft lining (the upper rows were 270 – 300 mm thick) and wear of the uncooled part of the shaft were mainly caused by abrasive impact of charge materials and vapors of sublimated alkaline compounds;

– horizontal coolers of the shaft cooled part were mostly deformed and destroyed, only the upper three – four rows were in satisfactory condition;

– boshes in the upper part were mostly open, no traces of skull deposits were noticed on the coolers in this part.

– chemical analysis of the skull samples taken in the furnace hearth revealed the presence of significant amounts of alkali in it, as well as the presence of zinc oxide and even metallic zinc in the high-temperature furnace zone.

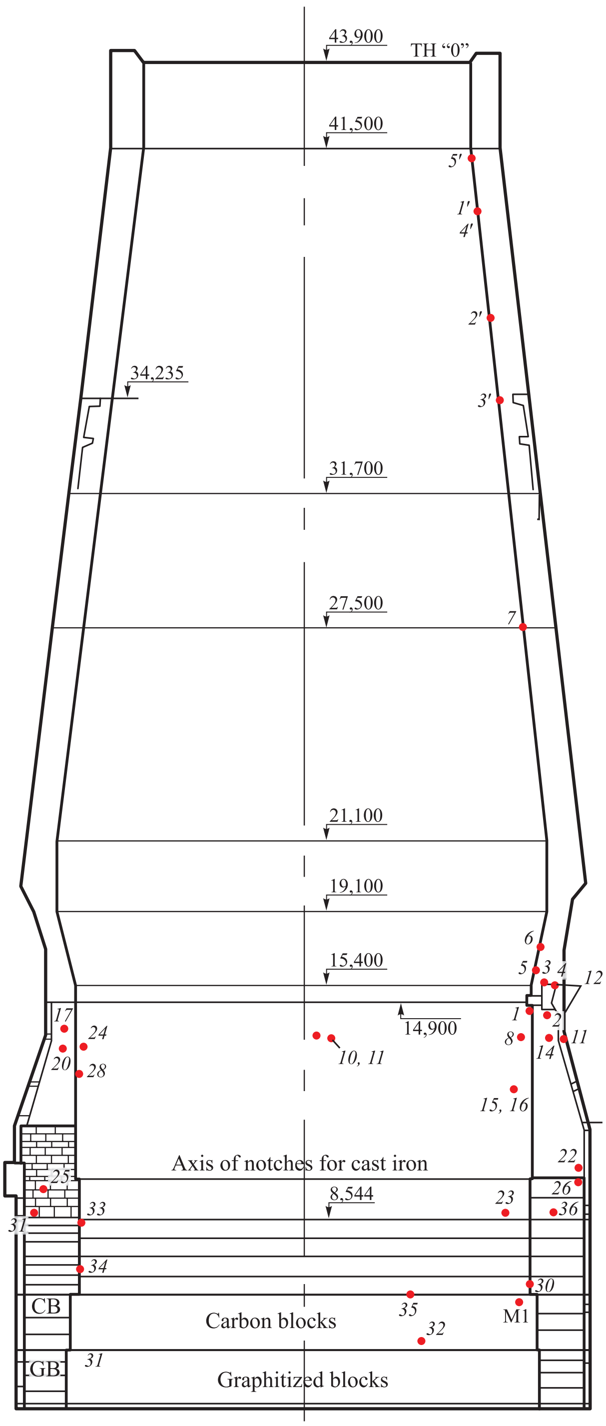

Fig. 1. Location of sampling points for refractory materials and skull from the working space of blast furnace No. 5 after blowing-out of the furnace in 2006

Рис. 1. Расположение точек отбора проб огнеупорных материалов и гарнисажа из рабочего пространства ДП № 5 после выдувки печи в 2006 г.

During the 2006 overhaul, the furnace shell was partially replaced and the lining was replaced completely. The hearth structure was reinforced within the dimensions of the furnace shell. On the steel leveled surface of the furnace bottom, the graphite blocks, 800 mm high, were vertically installed and carbon blocks, 1100 mm high, were vertically placed on them. On the periphery, the blocks were stacked horizontally in the following order: two 400-mm graphite and two 550-mm carbon ones. Above, on the periphery of the furnace, seven rows of ring carbon blocks supplied by NDK were laid. The bottom two rows of those were made of BS-8SM2 grade microporous blocks and the top five rows were made of BS-8SR grade super microporous blocks. The internal volume of the five lower rows was laid with high-aluminous MLLD-62 blocks, 550 mm high, thus the value of the “dead” layer in the hearth increased from 1500 to 2050 mm.

Copper coolers were installed in the under-notch area, three coolers under each notch. The cooling channels were made by drilling holes in the cast and rolled copper plate. A pumping station of chemically treated water was built to supply these twelve coolers. The combined cooling by smooth plate coolers, 120 mm thick, in combination with horizontal 100-mm thick coolers installed in the inner recess, was provided in the furnace belly and shaft at about 65 % of its height. The uncooled portion of the shaft was lined with chamotte.

Thus, in the 2006 – 2024 campaign, the basic technical solutions for the design of blast furnace No. 5 hearth and shaft were retained in the classical form, with necessary adjustments in problem areas based on the experience of the first two campaigns of 1986 – 1995 and 1995 – 2006. To maximize the duration of the current furnace campaign, certain technological measures were applied as a priority.

Chemical composition of the samples of refractory materials and skull extracted during dismantling of the refractory lining of blast furnace No. 5 in 2006

Химический состав проб огнеупорных материалов и гарнисажа, извлеченных при разборе огнеупорной футеровки ДП № 5 в 2006 г.

Place of sampling	Material	Content of chemical compounds, wt. %				
		Fe_2O_3	Al_2O_3	Na_2O	K_2O	ZnO
1'	ShPD – 39 (chamotte engineering domain bricks)	1.34	38.7	–	–	–
2'	ShPD – 42 (chamotte engineering domain bricks)	1.33	43.4	–	–	–
3'	Skull	–	–	0.23	0.81	0.110
4'	ShPD – 42 (chamotte engineering domain bricks)	4.07	38.7	–	–	–
5'	ShPD – 42 (chamotte engineering domain bricks)	1.89	42.8	–	–	–
22	Skull (ChL 3 (cast iron))	–	–	0.22	3.80	30.500
23	Skull	–	–	0.08	0.20	0.045
24	Refractory material	–	–	0.28	0.79	1.200
25	Skull (ChL 2 (cast iron))	–	–	0.07	0.36	40.000
27	Skull (ChL 4 (cast iron))	–	–	0.30	2.70	1.000
29	Skull (ChL 1 (cast iron))	–	–	0.17	0.40	0.035

Place of sampling	Material	Content of chemical elements, wt. %					
		C	S	P	Si	Mn	Zn
M1	Metal in carbon block joints	0.69	0.060	0.057	0.25	0.29	95.00
GB	Graphite block of the first row	98.2	0.450	–	–	–	–

Development and implementation of technological measures aimed at extending the campaign of blast furnace No. 5 in 2006 – 2024

The series of investigations of the 1995 – 2006 campaign results (see the Table, Fig. 1) revealed low residual thicknesses of refractory materials and the absence (or small amount) of protective skull and enabled to determine critical zones of blast furnace No. 5 that require protection and adjustment of smelting technology in the current campaign: the hearth, the bottom part of the shaft and the top of the boshes.

First of all, to increase the durability of the hearth lining, the development of abrasive action of liquid cast iron flows in the near-wall zone should be prevented, i.e., it is necessary to ensure intensive filtration of liquid melting products through the toterman and to achieve good gas permeability in the central furnace zone. In real conditions of blast furnace operation, the toterman porosity can significantly decrease due to fluctuations of coke quality characteristics, water ingress into the hearth from defective elements of the cooling system, localized masses of refractory components of blast furnace charge entering the hearth, even an area can form impermeable for flows of liquid melting products in the hearth, as well as for countercurrent flows of gases and liquids above the tuyere level.

The results of experimental studies at blast furnace No. 9 at the metallurgical plant Krivorozhstal proved that it is possible to form a dense, poorly permeable layer on the toterman's surface [13; 14]. Since this furnace has about the same parameters as blast furnace No. 5 at PJSC Severstal, the experience gained from its operation was taken into account by the authors when the technological process at "Severyanka" was arranged. First of all, the above experience proved that gas permeability in the central furnace zone and the condition of the toterman should be systematically controlled.

It is extremely difficult to control the toterman size in an operating furnace. Temperatures of melting products in the hearth reach 1500 °C and in the tuyere zones, the gas temperature can exceed 2000 °C. In such conditions, physical sounding without bulky equipment is complicated and remote methods are not yet sufficiently developed. To assess the toterman permeability and control its geometry at blast furnaces of PJSC Severstal, a scheme was proposed of systematic probing of the blast furnace hearth during short-term shutdowns for planned preventive maintenance. A metal slice bar, 10 m long, with a diameter of 28 mm, served as a probe. The probe was plunged into the furnace until it became obvious that the front of the slice bar reached the hard-to-penetrate zone. The toterman was probed systematically, at least once a quarter during normal furnace operation and more often if the charge conditions changed or signs of impurity content in the hearth emerged.

To clean the hearth from refractory flux residues and fine coke fractions, technological provisions were developed for complex washing of the blast furnace hearth. The procedures were proposed for forming a washing portion consisting of a mixture of a sinter, pellets, lump iron ore and converter slag, as well as the mass of this portion depending on the mass of the working portion of iron ore materials. Consumption of charge materials in the washing portion was determined based on obtaining primary slag melt with FeO content in the range from 35 to 55 %, which was calculated by the equation

$$FeO_{psm} = 29.73 - 1.43CaO + 3.27SiO_2 - \\ - 10.18MgO + 1.36Al_2O_3 - 0.58FeO,$$

where FeO_{psm} is FeO content in the primary slag melt, %; CaO, SiO_2, MgO, Al_2O_3 and FeO represent the content of these components in the washing feed, %.

The efficiency of the developed procedures for complex washing was controlled by means of toterman probing. Its results showed that systematic washing helped to maintain high level of the coke head permeability. The area of the hard-to-penetrate zone at the tuyere level shrank by 47.8 rel. % compared to the previous (before complex washing) measurements.

In addition to the traditional methods of assessing the condition of the lining based on the data of heat removal by the hearth and flange cooling system and embedded thermocouples installed at different levels, new nondestructive inspection methods were applied in the current campaign. The purpose of the survey was to determine the condition of the refractory materials and the thickness of the residual lining, as well as to detect anomalies in the refractory materials such as cracks, delaminations and unfilled mortar joints in brickwork. The work was carried out using the technique of supersonic sounding using the echo method (AU-E). The scope of the survey included periodic monitoring of the condition of the furnace refractory lining from the metal receiver to the tuyere level, as well as determining the trend of the refractory lining wear in various zones.

To reduce chemical erosion of carbon blocks of the hearth and flange due to non-equilibrium chemical compositions of cast iron, the method was developed to control the technological process through monitoring the ratio of the actual carbon content in cast iron C_f to the saturated content C_s by regulating the flow rate of natural gas blown into the furnace. The indicated C_f/C_s ratio was maintained in the range of 0.92 – 0.98. When the C_f/C_s ratio dropped below 0.92, the natural gas consumption was increased by 2.0 – 10.0 m^3/t of cast iron, and when the C_s/C_s ratio rose above 0.98, the natural gas consumption was reduced by 0.2 – 2.0 m^3/t of cast iron while maintaining the oxygen content in the blast. The applied method enabled to significantly (from 5.8 to 1.4 % of the total number) reduce the number of tappings aggressive to carbon lining. During 12 months of the use of the claimed method, the increment of heat loads on the cooling system coolers in the metal receiver decreased on average twice compared to the previous similar period. The effectiveness of the applied method can also be evaluated by the results of supersonic sounding using the echo method. Its use enabled us to record the fact that the average thickness of the unchanged lining did not alter significantly during 2019 – 2021, probably because the skull layer that protected the underlying lining was preserved. The average thickness of the residual intact lining of the hearth wall measured by the AU-E method was 540 mm or about 21 % of the initial lining thickness.

To ensure self-renewal of the protective skull in the blast furnace shaft, the previously developed method [15] was used, which involves cyclic loading of charge materials, including the skull-forming mixture consisting of iron ore and sinter, which enables to obtain from it the primary slag melt in the amount of 20 – 25 %, the proportion of ferrous oxide in this melt not exceeding 15 %. In addition, the requirements for enhancing the economic efficiency of cast iron smelting made it necessary to develop the methods for industrial use of small substandard fractions of iron ore materials. The mass fraction of 3 – 5 mm of the sinter loaded into the near-wall zone was determined depending on the index of sinter strength during the reduction-heat treatment of its oversize fraction by the following formula

$$M = KM_h \frac{100 - A(100 - R)}{100},$$

where M – mass of undersize fraction of the 3 – 5 mm sinter in the loaded iron ore portion, t; K – empirical coefficient equal to 0.10 – 0.25; M_h – mass of the sinter in the head part of the loaded iron ore portion, t; A – share of the sinter in iron ore portion, units; R – index of the sinter strength during reduction-heat treatment of the sinter oversize fraction, %.

To achieve the given number of closed cycles of the chute, the fraction of the 3 – 5 mm sinter was distributed in the furnace working space using a bell-less top depending on the bulk weight of undersize fractions of iron ore materials.

Due to the need to use cheaper fuel for smelting cast iron, in the second part of the campaign the specific consumption of various solid substitutes for skip coke considerably increased. Both substandard fractions of metallurgical coke (less than 25 mm) and anthracite served this purpose. In the final third of the furnace campaign, an innovative carbon-containing product (ICCP) was additionally used. It was obtained in the process of laminar coking of the coal charge, consisting of 60 – 100 % of coals of one or several grades tentatively suitable for coking.

The results of earlier theoretical studies and industrial experience revealed [16 – 19] that effective replacement of skip coke with various substitutes (natural gas, pulverized coal fuel, anthracite, substandard coke fractions) is only possible if the quality of the bulk of coke and iron ore materials is high. Therefore, to use solid coke substitutes with relatively low-quality characteristics in significant quantities, which includes the charge containing solid fuel with reduced hot strength reaching almost 50 %, special methods of its loading and distribution over the cross-section of the furnace mouth had to be preliminarily developed and applied. The solid fuel with reduced strength before reaction (CSR) was loaded into the intermediate zone of the blast furnace in portions at a distance of 0.1 – 0.5 of the furnace mouth radius from the furnace wall, and the ore load in the axial zone of the furnace mouth was maintained in the range from 0.8 to 3.2 depending on the difference in the index (CSR) of high and low quality solid fuel. Smaller ore load in the furnace axis corresponds to a larger difference of the CSR characteristic for the two solid fuels.

The escalating environmental challenges associated with the climate change and the prospect of carbon regulation call for a continuous search for new ways to reduce CO_2 emissions in the course of steel production [20]. Technologically, in the production chain "blast furnace – converter", carbon dioxide emissions are reduced by cutting the specific consumption of solid carbon fuel for smelting cast iron and increasing the consumption of hydrocarbon coke substitutes blown into the blast furnace.

The approach to building an effective structure of the charge column in the blast furnace had to be reconsidered and a set of procedures was developed to regularly wash the hearth from coke waste and flux residues, maintain a stable self-renewing skull in the lower part of the shaft, effectively distribute various types of solid fuel over the furnace cross-section and develop the technology of ultra-high specific consumption of natural gas during cast iron smelting. As a result, we, on a permanent basis, used the system of charge material distribution over the height and cross-section of blast furnace No. 5, which includes the specified distribution of ore load over the furnace cross-section [21], as well as the cyclic use of axial, prewashing and washing portions, providing a central operating mode of the blast furnace under variable charge and gas blowing conditions [22]. Fig. 2 shows the structure of the charge distribution used on a permanent basis in the working space of blast furnace No. 5. The efficiency of the applied system of charge materials distribution was evaluated during the final third of the current furnace campaign, when, despite significant changes in charge conditions and transition to a technology of high (more than 170 m^3/t of cast iron) specific consumption of natural gas, stable operation of the furnace could be achieved. The presence of protective skull in the lower part of the blast furnace shaft was established when the furnace was disassembled during the overhaul of the first category, and the condition of the horizontal coolers of the furnace shaft cooling system and their recesses, which have not lost their initial geometry, indicates that the cooling system operates under protection of the sufficient layer of stable self-renewing skull.

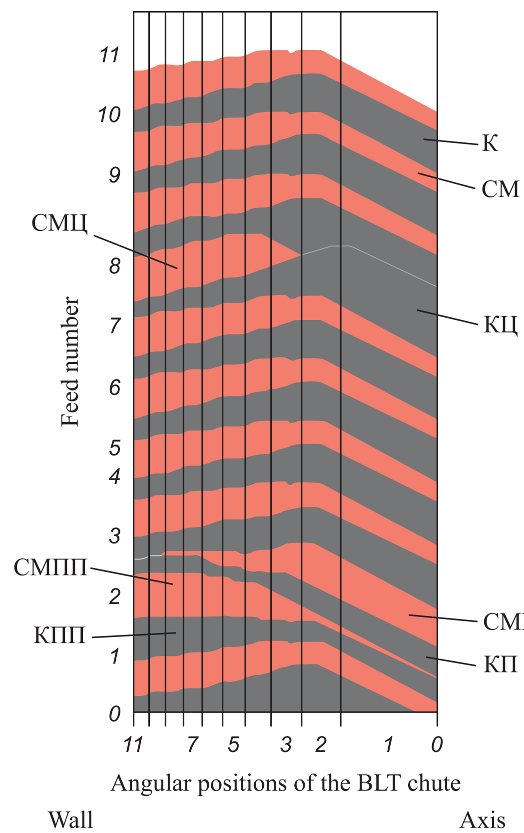

Fig. 2. Structure of the charge column from 11 feeds including axial, pre-washing and washing portions:
К – portion of coke, positions of the BLT (Bell Less Top) chute (*9 – 3*); СМ – portion of the iron ore mixture, position of the BLT chute (*11 – 3*); КЦ – central (axial) portion of coke, position of the BLT chute (*8 – 2*); СМЦ – portion of iron ore mixture for feeding with axial coke, position of the BLT chute (*10 – 5*); КПП – pre-washing feed coke, position of the BLT chute (*10 – 3*); СМПП – portion of iron ore mixture of the pre-washing feed, the position of the BLT chute (*11 – 5*); КП – washing feed coke, position of the BLT chute (*9 – 3*); СМП – a portion of the iron ore mixture of the washing feed, the position of the BLT chute (*7 – 3*)

Рис. 2. Структура столба шихты из 11-ти подач, включающая осевые, предпромывочные и промывочные порции:
К – рабочая коксовая порция, положения лотка БЗУ (*9 – 3*); СМ – рабочая порция железорудной смеси, положения лотка БЗУ (*11 – 3*); КЦ – центровая (осевая) порция кокса, положения лотка БЗУ (*8 – 2*); СМЦ – порция железорудной смеси для подачи с осевым коксом, положения лотка БЗУ (*10 – 5*); КПП – кокс предпромывочной подачи, положения лотка БЗУ (*10 – 3*); СМПП – порция железорудной смеси предпромывочной подачи, положения лотка БЗУ (*11 – 5*); КП – кокс промывочной подачи, положения лотка БЗУ (*9 – 3*); СМП – порция железорудной смеси промывочной подачи, положения лотка БЗУ (*7 – 3*)

It should be noted that the application of a set of measures aimed at extending the campaign of blast furnace No. 5 under conditions of frequent changes in the quality characteristics of iron ore raw materials, as well as the increased use of solid and gaseous coke substitutes, requires constant monitoring of both the smelting parameters and the effectiveness of the applied technological solutions. At the coke-and-sinter production of PJSC Severstal, this task is solved, among other things, by using operational control of blast-furnace smelting technology involving on-line digital assistants [23], united in a blast furnace expert system (ES). The blast furnace expert system is a proprietary development of PSJC Severstal. It is a system for optimizing, monitoring and managing the cast iron smelting process. It is based on highly efficient technological models, special application software, graphical end-user interfaces and many years of practical experience of domainers.

The task of the blast furnace expert system is to develop controlling technological influencing factors affecting the blast furnace melting process adequate to the current conditions due to unambiguously interpreted results of processing the heterogeneous source data. Thus, to prevent fluctuations in the thermal state of the furnace, related to the inertness of traditional methods of fuel consumption operational control through changing the mass of coke in the feed, a digital model of the melting hourly heat balance is used, as well as monitoring of the specific consumption of solid and blown fuel and a model for calculating the minimum theoretical value of coke consumption. To prevent the phenomenon of spontaneous skull descent, the following models are used: models of skull accumulation, charge materials distribution in the furnace working space, charge descent with controlled feed position in the working space, gas-tuyere model with the estimated oxidation and circulation zones depths. The models of melting products accumulation in the hearth, tapping control and slag viscosity are applied to arrange effective melting products processing. The source data for the above models are the values of technological parameters, chemical compositions of raw materials and melting products, the amount of raw materials and fuel consumed per unit of time, etc., coming into the system and processed automatically, without involving the technical team.

The use of the calculation results, recommendations of the blast furnace expert system enables to reduce the influence of human factor in the evaluation and interpretation of controlled process parameters, thereby decreasing the number of deviations of the blast furnace operation parameters from the optimal range, to achieve the most stable specified chemical composition of melting products and minimum fuel consumption, as well as to minimize the negative impact on the refractory lining of the furnace.

Main production results of blast furnace No. 5 campaign in 2006 – 2024

Due to implementation of the above-mentioned developed technological measures on a permanent basis, the furnace worked in the campaign for 17 years 5 months and 13 days (17.46 years). The standard duration of the campaign was exceeded 1.75 times or by 74.6 %.

During the current campaign, the furnace smelted 75,180,099 tons of cast iron, which is ~1.6 mln tons more than the total cast iron production for the first two campaigns of blast furnace No. 5 (a total of 73,582,218 tons of cast iron were smelted during the previous two campaigns in the periods 12.04.1986 – 03.07.1995 and 26.10.1995 – 19.06.2006).

The productivity and duration of the current campaign increased due to a radical change in blast furnace smelting technology and practically 1.5 times growth in coke replacement with natural gas. Moreover, the negative factors caused by hydrocarbons that are additionally blown into the furnace hearth (reduced theoretical combustion temperature, redistribution of temperatures over the height of the furnace, significant fluctuations in the furnace thermal state, etc.) were successfully compensated by the developed technological measures. The fuel efficiency was improved during the current campaign (hereinafter the comparison is made between the first full year of operation of blast furnace No. 5 after in 2006, it was blown in and in 2024, full capacity was achieved with the final three months of the campaign):

– specific coke consumption was reduced from 417.3 to 351.1 kg/t of cast iron, i.e., by 66.2 kg/t of cast iron or by 15.9 %;

– specific consumption of natural gas for cast iron smelting was increased from 118.0 to 172.7 m^3/t of cast iron, i.e., by 54.7 m^3/t of cast iron or by 46.4 %;

– specific carbon consumption for cast iron smelting, defined as the ratio of total carbon input into the blast furnace with solid and gaseous fuel, as well as with components of iron ore charge to the amount of smelted cast iron was reduced from 428.9 to 401.7 kg/t of cast iron, i.e., by 27.2 kg/t of cast iron or by 6.3 %.

Conclusion

The use of a systematic scientific approach aimed at maximum extension of blast furnace No. 5 campaign based on the analysis of the previous campaigns results, identification of problem areas and ways to improve cast iron smelting technology, development of technological measures taking into account the accumulated experience and prospects for further development enabled to increase the service life of the unit by 1.75 times and achieve its highly efficient operation during the entire 2006 – 2024 campaign.

The results were obtained at the blast furnace of "classical" design without principal capital-intensive changes in refractory lining of the blast furnace shaft and hearth only by developing new methods of maintenance, control and adjustment of cast iron smelting technology.

The system for optimizing, monitoring and managing the cast iron smelting process based on in-house developed digital assistants is the most promising direction for further development. It provides stabilization of smelting results at significant fluctuations of incoming parameters, maximum efficiency of the developed scientific and technological measures during long time spans due to reduction of human factor impact during the process operational control.

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O. A. Kal'ko – analysis of the results of previous campaigns, determination of the physical and chemical principles of obtaining melts of a given composition.
A. A. Kal'ko – analysis of the results of previous and current campaigns, comparative calculations of the specific carbon consumption for cast iron smelting during different periods of blast furnace operation.

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