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Study of the Flow of Burden Materials and their Distribution on the Furnace Top of a Modern Blast Furnace

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The main results of investigations carried out before blowing blast furnace №3 at PJSC "Yenakiieve Iron and Steel Works" equipped with modern bell-less charging device are shown.

Keywords: BLAST FURNACE, BURDEN MATERIALS, LOADING, BELL-LESS CHARGING DEVICE, PRE-START RESEARCH, BURDEN DISTRIBUTION

Introduction

An important way to increase the efficiency of blast furnace (BF) is the rational use of technological capabilities of the charging system by improving methods of distribution of charge materials in the furnace in conjunction with the choice of rational parameters of the blast and gasdynamic melting modes [1].

To control the formation of portions of the charge materials, loading and distribution in the furnace it is necessary to have reliable information on the nature of the movement of materials along the highway feeder and their distribution on the surface of the stockline of the charge. Such data can be obtained through pre-launch studies of the charge-conveying mechanisms and BLT, the distribution of charge materials on the furnace top [2, 3].

Results and Discussion

In October 2011, after a major overhaul of I-th category modern BF № 3 at PJSC "Yenakiieve Iron and Steel Works" of 1719 m^3 was commissioned. The furnace is equipped trough bell-less top (BLT) of the firm "Paul Wurth", stationary thermobeams located above the stockline, two radar level transmitters , flue gas probe, infrared camera. BLT of the company "Paul Wurth", set on BF № 3, on a number of key parameters and design features is unique in Ukraine. Applicable unit is a single cycle BLT, providing the ability to download the charge materials with temperatures up to 400 ° C.

The ISI staff, together with representatives of PJSC "Yenakiieve Iron and Steel Works" performed research on the distribution of the first batch of the BF № 3 before blowing and studies of the change boot options, blast mode and gas distribution during blowing in, blowing, and the furnace yield for top performance. Use of received information to improve the loading mode of the furnace burden materials, increasing the use of heat and reduction energy of furnace gases in combination with executed during repair activities for the reconstruction of refractory glass of the hearth and hearth bottom, increase the resistance of the metal reservoir lining will extend the campaign up to 15 years.

Before blowing the BF № 3, the following studies were carried out:

- determination of flow characteristics of charge gate (CG) of the bunker BLT;
- determination of the trajectories of the charge materials in the flue space of BF and implementation in the ACS angles of the tray BLT;
- measurement of the surface and stockline of charging materials after their load into the furnace;
- study of the flow parameters of charge materials and research on the distribution portion of the mixture components of sinter and pellets along the radius of the furnace top.

Determination of flow characteristics of charge gate of the hopper BLT

At run time of the primary investigations the flow characteristics of charge gates of BLT unload iron components and coke are determined. The results are shown in Figure 1. Relatively high correlation coefficients (for iron components r = 0.940, for coke r = 0.871) show that the dependence of the volume flow rate of charge materials (and at constant mass flow time portions and materials from the hopper BLT) on the degree of opening of the charge gate can be used in ACS software for automated control of unloading portions of the charge.

It should be noted that the obtained relationships should be clarified in the course of operation of the furnace, which is provided by project management algorithms. Initially, the furnace blowing was recommended for the unloading time of portions of the charge of the BLT to support materials for iron at 80 seconds, 90 seconds for coke. At the same time during the study, these values correspond to the following time of unloading values of the degree of opening charge gate for iron materials 33%, 40% for coke. One month after blowing in of the furnace due to the need to ensure system throughput of charge conveying at 8 feeds per hour (working with ore load 3.95 t / t), it was recommended to reduce the time to unload iron ore materials to 70 seconds, and coke up to 80 s, what corresponded to the degree of opening of the charge gate 37% for iron materials and 44% for coke.

As the experience of the development of blast furnace equipped with BLT, increasing the time of unloading portions of charge materials promotes the rational distribution of materials on the radius and circumference of furnace top and should be the best possible for the conditions of the required intensity of the heat, which determines the rate of descent of the charge and the rate of loading furnace [4]. The unloading portion of the charge is given in accordance with the flow characteristic charge the charge gate BLT, which is determined by the results of pre-launch research.

The possible range of volumetric flow of charge materials during providing sufficient accuracy for distributing them in the furnace top for the conditions of BF № 3 is: for coke 0.124-0.337 m^3/s and 0.160-0.337 m^3/s for ferrous materials. The value of flow rate 0.337 m^3/s is sufficient for the maximum load capacity of the system in the mode "measure fitting". Smaller volume flow can be given in cases where in the boot cycle portions there is a reserve time for extended unloading portions. The lower limit of the above range of volume flow (0.124 m^3/s for coke and 0.160 m^3/s for ferrous materials) is set from the experimentally defined conditions of "burning" charge materials.

Calculation of sound composition and the choice of the mode of loading blowing charge are factors which largely determine the success of the work of blowing and BF operation during the blowing-in period [5].

During the program development of the first burden loading, it is necessary to note that when you load the lower levels one must prevent damage of the furnace lining shafts, steam out, shoulders and lances by feeding material and, where possible, to minimize the crushing of charge materials. Also, when loading charge containing slag along with coke and iron materials, one should ensure the required distribution of components over the cross section of the furnace. Obviously, for the correct choice of the angular positions of the tray that is used when loading blowing burden of the furnace at different levels, it is necessary to refine the calculated trajectories of the charge materials after the withdrawal from the distribution tray over the entire height of the working space of the blast furnace [1, 5].

In the calculations of the parameters of the distribution of burden materials movement of material flow in the furnace throat is usually characterized by the trajectory of its central part. In developing programs for loading horizontal section of furnace top equipped with BLT is divided usually into 10 equal in size annular zones according to the number of main working angular positions of the tray (except for adjustment provisions and provisions designed for unloading the charge materials directly under the wall of the furnace top and the axis of the furnace). Rational values of angles tray in working position, shall be crossing the center of the flow path of the charge from the center line of the corresponding annular zone of the furnace top. It should be noted that with the level of the grist, the coordinates of the intersection points of the trajectories of the fall of the charge flows to the surface of the grist change too. Therefore, in modern management systems of BLT inclination angle matrices of the tray provide the ability to set angles for different levels of the grist defined by increments 0.10-0.25 m. Changes of the implemented number of angles of the tray may take place automatically when you change set of the stockline level [1].

The calculation of the trajectories of the centers of gravity of the charge flow in the working space of the furnace was carried out using refined mathematical model of Iron and Steel Institute. The results of calculations made it possible to determine the value of working angles of the tray for loading ten furnace top annular zones and two additional angular positions for loading charge materials directly under the wall of the furnace top and the axis of the furnace.

To assess and refine the results of calculation angles of inclination of the tray and flow parameters of charge materials discharged from the tray of BLT to the stockline surface of the charge, the vertical and horizontal boundaries of sections were determined by instrumental measurements of the flow of the meeting points with plates of blast furnace protection (**Figure 2a**), the surface of the radial gas sampling probes (**Figure 2b**) [3] (level of the charge surface is 3.6 m), as well as wooden beam set obliquely on the surface of charge stockline (**Figure 2c**).

General borders of the flow were defined to take into account peculiarities of the material flow through the distribution tray, reflection of the part of the coke flow from the front tray buckle, stationary thermal beam surface and its subsequent dispersal at movement in the furnace to the level of gas sampling probes. Measurements of the movement borders of material heavy flow were subsequently used to specify the initial data of modeling trajectories of the charge materials in the working space of the furnace.

The results of the measurements of the parameters of flow movement of coke and ferrous materials made it possible to refine the design trajectory of charge materials in the working space of the furnace and determine angles of inclination of the tray giving the required control range of the distribution of charge materials for the furnace top. Calculated values of the angles of inclination of the tray determined on the basis of experimental data for different levels of the grist in increments of 0.1 m were introduced in the matrix of the control system of BLT BF № 3.

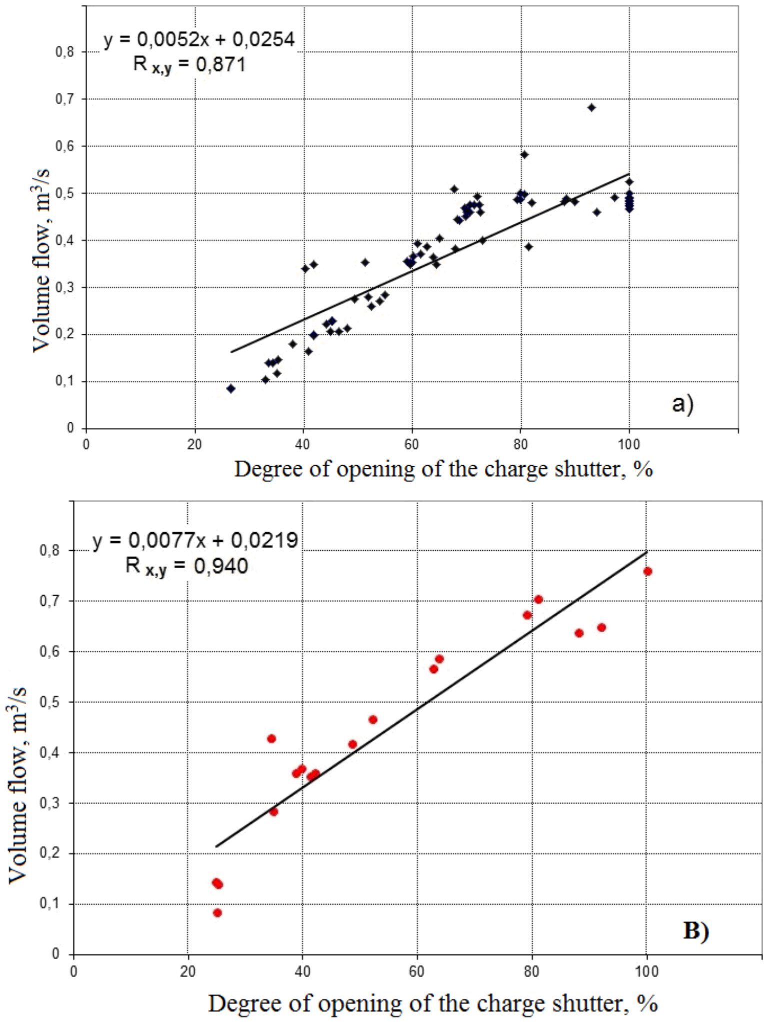

Figure 1. Dependences of volume flow on the extent of charge preparation to open the shutter for coke (a) and iron ore materials (b) at discharge from the hopper bell-less top

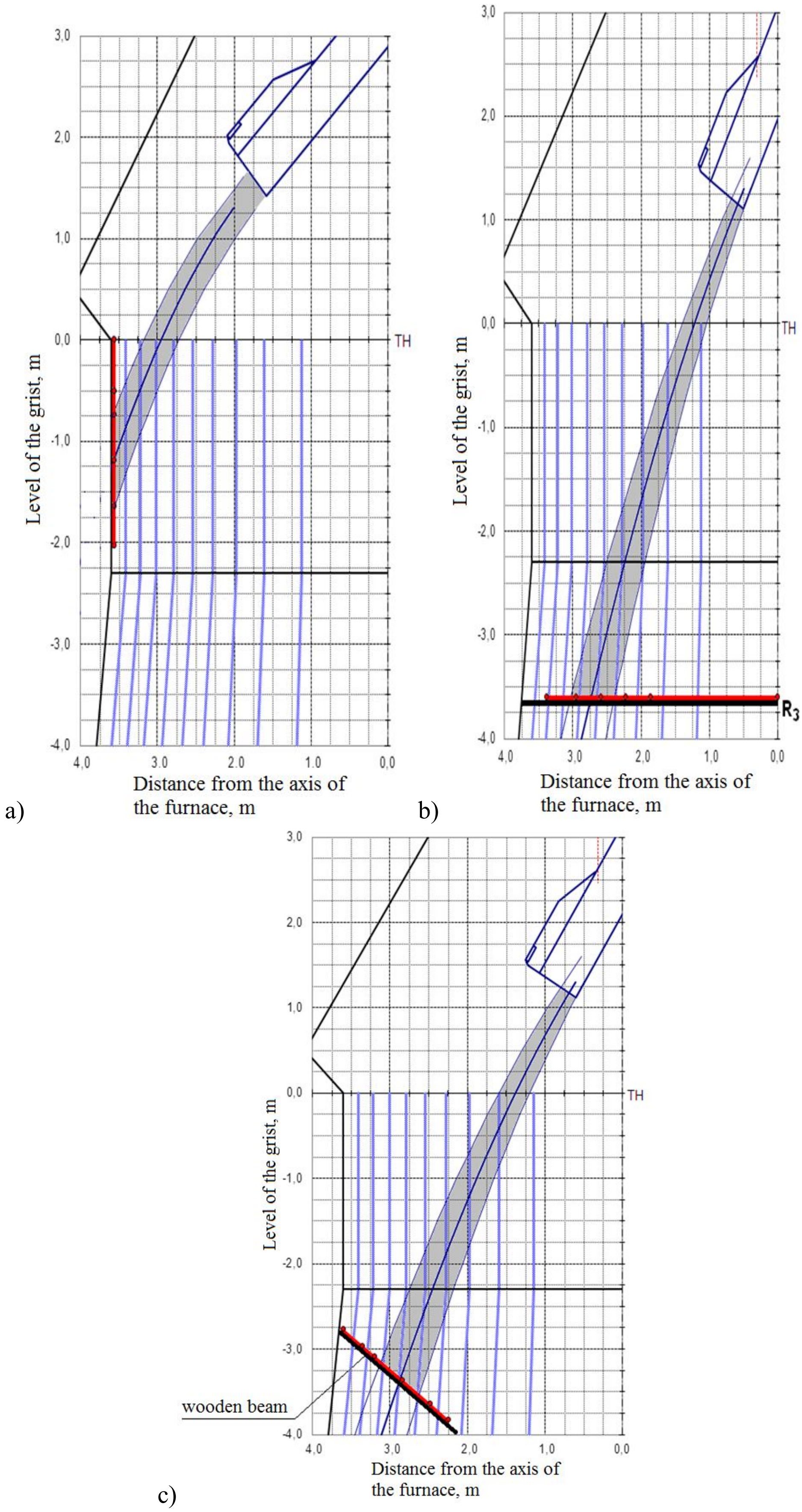

Figure 2. Borders of vertical section of the flow of charge materials (a), horizontal section of the flow (b), and flow borders determined by measurements of points of meeting flow with a wooden beam set obliquely on the surface of the grist of the charge (c)

Study of the formation of the charge grist surface profile

The shape of the surface of the grist, the geometrical arrangement of the ridge of the profile after unloading portions of charge materials, in addition to their physical and mechanical properties significantly affect the level of grist, angle of inclination of the tray, the opening value of the BLT hopper gate, and profile settings after unloading the previous portion of the charge (original profile of the grist). [1]

Evaluation of surface formation of the charge grist was performed by level measurements of the charge surface at 60 points directly on the surface of the grist after unloading the last eight portions of the blowing charge (№ 103-110). Test results are shown in Figure 3.

Mode of unloading research portions № № 103-110 of charge materials into the furnace was performed as specified below.

Portion № 103 – coke – $M_к$ = 5.4 t, angle of inclination of the tray 49.0°, unloading time 128 s, degree of opening the hopper gate ($α_{шз}$) 26,7 %, tray rotation counterclockwise.

Portion № 104 – coke – $M_к$ = 2.8 t, angle of inclination of the tray 37.5°, unloading time – 11 s, $α_{шз}$ – 67.7 %, tray rotation in a clockwise direction.

Portion № 105 – coke – $M_к$ = 10.7 t, angles of inclination of the tray 28.1 and 21.6°, unloading time 146 s, $α_{шз}$ – 35.4 %, tray rotation counterclockwise.

Portion № 106 – sinter (A)+slag (Ш)+ore (P) – $M_п$ = 31,6 t (A–24,62 t, Ш–4,31 t, P–2,67 t), angles of inclination of the tray 38.4, 29.3 and 21.8°, unloading time 121 s, $α_{шз}$ – 24,8 %, tray rotation in a clockwise direction.

Portion № 107 – coke – $M_к$ = 10.2 t, angle of inclination positions 8-4, unloading time 147 s, $α_{шз}$ – 34.3 %, tray rotation in a clockwise direction.

Portion № 108 – A+ pellets (O)+Ш–$M_п$ = 34,4 t (A–19.46 t, O–12.97 t, Ш–1.97 t), angle of inclination positions 9-4, unloading time 25 s, $α_{шз}$ – 81 %, tray rotation counterclockwise.

Portion № 109 – coke – $M_к$ = 10.2 t, angle of inclination of the tray 8-4, unloading time 240 s, $α_{шз}$ – 26.7 %, tray rotation counterclockwise.

Portion № 110 – A+O+Ш – $M_п$ = 34,0 t (A–12.82 t, O–19.23 t, Ш–1.94 t), angle of inclination positions 9-4, unloading time 40 s, $α_{шз}$ – 34,4 %, tray rotation in a clockwise direction.

Analysis of experimental data showed the following tendencies of formation surface of the grist after loading studied portions.

Unloading eight investigated portions was accompanied by lowering of the level of surface grist of the charge on radii МЛ (mounting hatch) at 0.50 m on average and the ГО-4 (flue №4) at 0.48 m on average, while at the radius РУ2 (radar transmitter) lowering of the grist was 0.13 m and on radius ГО-3 0.22 m. Presence of circumferential irregularity of the grist levels was caused by working off in random mode the beginning of opening the hopper gate of unloading portions of the charge. The uneven distribution of the charge in a circle due to the influence of the thermal probe was also noted, which led to the formation of cavities with the difference between the charge levels with value 0.57 m in the area of installation at an average level of the grist 3.19 m with an average grist level of 1.95 m, this difference decreased to 0.33 m. Influence of thermal probes on the formation of irregularity the surface grist of the charge is shown in Figure 4.

After unloading the portion of coke № 103 weighing 5,4 t with an inclination angle of the tray 49.0 °, the measured surface profile of the grist is characterized by the formation of a horizontal "shelf" on the periphery with width of 0.5 m.

The surface of the grist formed after unloading the portion of coke № 104 weighing 2.8 tons with an inclination angle 37.5 ° of the tray to the level of 4.38 m was characterized by the presence of the annular area on the periphery 0.5-0.8 m wide with an inclination angle of the surface of this area to the center of the furnace ≈ 20°.

After unloading portions of coke № 105 weighing 10.7 tonnes with inclination angles of the tray 28.1 ° and 21.6 ° to the level of the grist 4.24 m we recorded formation "ridges" on the radiuses МЛ, ГО-4and ГО-3 at a distance 1.0 m from the wall of the furnace with a maximum angle of inclination of the surface of the grist from the "ridge" to the wall of the furnace 10 ° and from the "ridge" to the furnace axis 12 °. Specified location of the "ridges" corresponded to coordinates of the meeting point of the center of the flow of charge materials discharged from the 5th angular position with the surface of the grist.

After unloading portions of ferrous materials № 106 weighing 31.6 tons with inclination angles of the tray 38.4 °, 29.3 ° and 21.8 ° to the level of the grist 3.67 m we recorded formation of expressed "ridges" on the radiuses РУ-1 , ГО-4 and GO-3 at a distance of 1.0 m from the wall of the furnace with a maximum angle of inclination of the surface of the grist from the "ridge" to the wall of the furnace 12 ° and from the "ridge" to the furnace axis 20 °. Specified location of the "ridge" is also corresponded to the coordinates of the meeting point of the center of the flow of charge

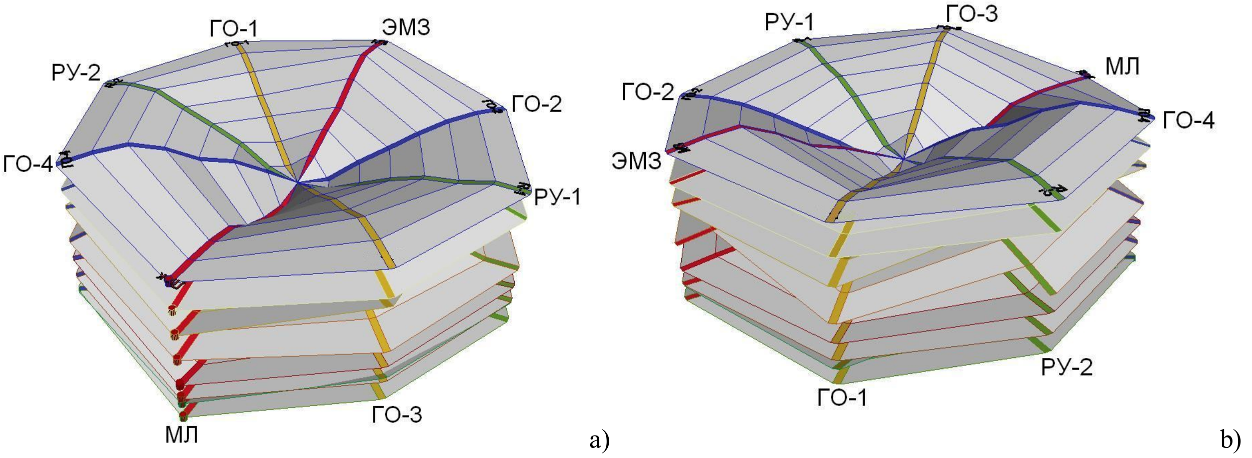

Figure 3. Surface of the grist of charge materials formed after unloading the last seven portions of the blowing charge (side-view МЛ (a), side-view ГО-1 (b)): ЭМЗ - electromechanical probes, ТЗ-1, ТЗ-2 - stationary thermal probes, РУ-1, РУ-2 - radar level gauges, ГО-1-ГО-4 - flue, МЛ - mounting hatch

materials discharged from the 5th angular position with the surface of the grist. On the other radii denoted in **Figure 3** we failed to fix the "ridges" because of the grist surface distortion.

Figure 4. Influence of the thermal probe on the formation circumferential irregularity of the surface of the grist charge (surface of charge grist after unloading portion № 104, the level of the grist 4.1-4.4 m)

With the unloading the four research portions №№ 107-110 depth of the axial hopper of the surface of the grist charge on average in eight radii increased from the minimum value after unloading portions № 107, which was 0.11 m to 0.45 m after unloading portion № 108, 0 .97 m after the discharge of portion №109 and reached a value of 1.06 m after unloading portion № 110.

Investigation of granulometric and component composition of the layer of ferrous materials along the radius of the furnace top

Optimization of blast furnace charging equipped with BLT includes rational distribution of both ore loads in annular zones of the furnace top section and the mixture composition of high- basic ore components, in particular, sinter and pellets. The latter should exclude local concentration of arrays of low-basic pellets in some areas of the furnace, especially near the wall

Figure 5. Installation of cylindrical samplers on the surface of coke before unloading iron ore research portion АОШ 9-4 (№ 1 - axis; № 4 - wall)

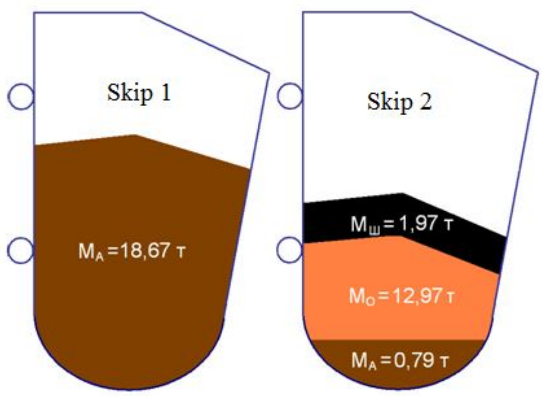

Figure 6. Structure of the research iron ore portion АОШ 9-4 (order of the components setting into skips)

area because of their negative impact on the lining life and wall accretion formation in the shaft. Increasing the number of pellets in the peripheral zone reduces the material basicity, formation of aggressive oxide melts with low flow, depleting the refractory masonry of the furnaces, as well as to increase the proportion of carbon monoxide of iron in the primary slag, which causes erosion and slumping of wall accretion, erratic heating and turn of the furnace, burning of tuyeres.

One of the limitations of technological methods of getting pellets into the furnace wall area developed in the Institute of Ferrous Metallurgy is the formation of mixed iron portions with the head part, consisting of sinter [6]. In loading systems with skip delivery of charge on furnace top the head part of iron ore portion is formed of sinter, loaded to the top of the first skip. In some cases, the first skip is loaded only by the material making up the head of the portion and all other components are loaded to the second skip.

A quantitative assessment of the impact of the mass of the head of the mixed portion on distribution of sinter and pellets along the radius of the furnace top is made using telescopic cylindrical sampler consisting of two close in size vertical sections. Samplers were installed on a layer of coke before unloading research ferrous portion АОШ 9-4 ($M_А$ = 19.46 t – 56.57 %, $M_О$ = 12.97 t – 37.70 %, $M_Ш$ = 1.97 t – 5.73 %) along the radius of the furnace top, located in the sector of the installation of the radar transmitter РУ1 from the inclined bridge at an average distance of 1.2 m from each other (**Figure 5**). АОШ portion structure, formed in the research process, is shown in **Figure 6**. Distribution of sinter and pellets along the radius of the furnace top after unloading this portion is shown in **Figure 7**.

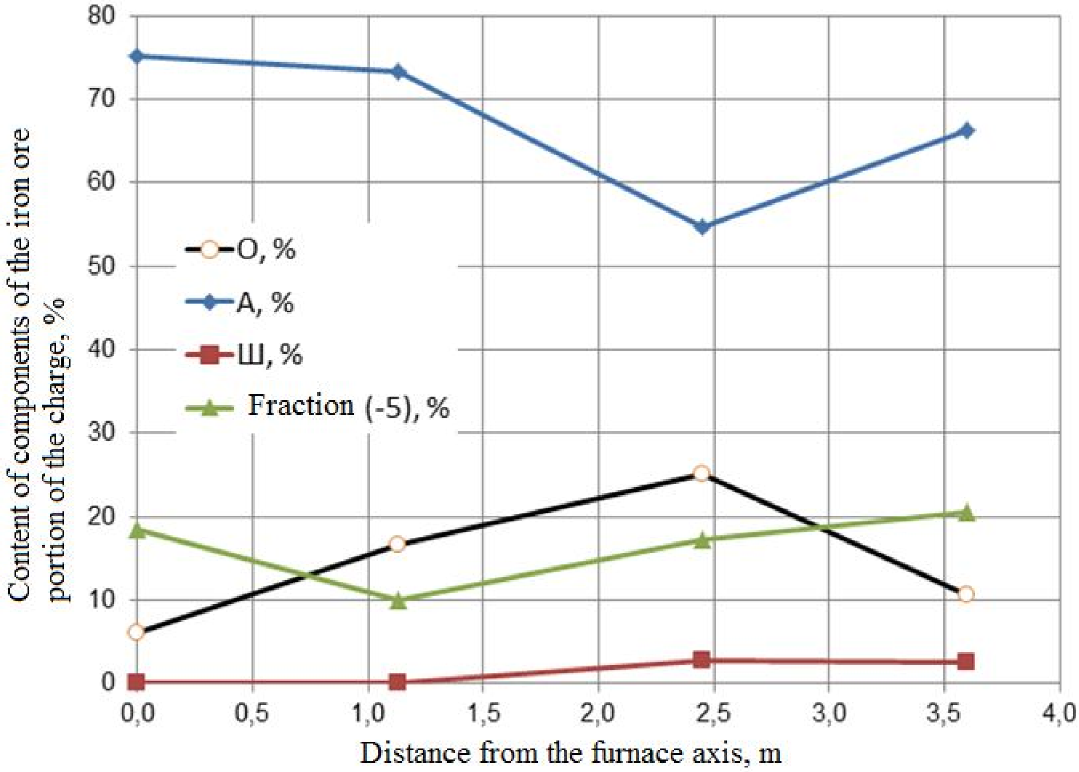

Figure 7. Distribution of components of research iron ore portion АОШ 9-4 along the radius of the furnace top

The results of the experimental studies show that the mass of the head part of the sinter portion (sinter mass loaded in the first skip without pellets) at 18.0-20.0 t distributes iron components along the radius of the furnace top is sufficiently close to the technological requirements: the content of pellets by periphery of the furnace does not exceed 11.0%, with a maximum in the intermediate zone and the fade-out of this material to the furnace axis [6].

Conclusions

Research on flow parameters of charge materials loaded into the blast furnace using BLT, mass distribution of portions and components on the furnace top, made before the start of blast furnace № 3 PJSC "Yenakiieve Iron and Steel Works", the definition of feedstock flow rate characteristics of the shutter of the hopper BLT, the study of formation of the surface profile of the charge stockline, particle size and component composition of layer of ferrous materials on radius of the furnace top after blowing furnace allowed to define and implement modes of BLT mechanisms necessary for the effective application of programs used for blast furnace charging.

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Исследования параметров потока шихтовых материалов и их распределения на колошнике современной доменной печи

Большаков В.И., Семенов Ю.С., Иванча Н.Г., Вишняков В.И., Шумельчик Е.И.,Подкорытов А.Л., Семион И.Ю., Кузнецов А.М., Зубенко А.В.

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