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MODEL SYSTEM FOR SELECTING AND CORRECTING CHARGING PROGRAMS FOR BLAST FURNACES EQUIPPED WITH A BELL-LESS CHARGING APPARATUS

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This article describes a model system that has been developed to provide supporting information for decisions made in selecting and correcting the charging programs of BCA-equipped blast furnaces. The system was introduced on blast furnace No. 3 at the Enakievo Metallurgical Plant. The system can also be used to train furnace operators on the use of new charging equipment.

Keywords: *blast furnace, charging materials, charging, bell-less charging apparatus, charging program, model of charge distribution in the top of a blast furnace, model system, information system.*

In recent years, new blast furnaces (BFs) and blast furnaces that have undergone reconstruction have been equipped with bell-less charging apparatuses (BCAs). In contrast to bell-and-hopper charging apparatuses, the new pieces of equipment provide broad possibilities for control of both the radial and the peripheral distribution of the charge materials [1].

Modern 1719-m^3 blast-furnace No. 3 at the Enakievo Metallurgical Plant (EMZ) came back on line in October 2011 after a class-I overhaul. The furnace was equipped with a new chute-type single-channel Midi BCA made by the Paul Wurth Company. There is no other Ukrainian blast furnace that is equivalent to this unit with respect to its main parameters and design features [2]. Stationary heat-sensing beams were installed over the stockline of BF-3 ton to evaluate the efficiency with which the charge materials are distributed over its radius.

The efficiency of the charging programs that are used on blast furnaces is assessed mainly based on the distribution of gas composition over the furnace radius. This distribution is usually evaluated by equipping blast furnaces with modern systems that automatically take samples of the furnace gases. The heat-sensing beams that are used to monitor the distribution of the charge have several shortcomings, particularly the fact that their readings are appreciably affected by the temperature of the incoming charge materials (hot sinter) and the location of the stockline. The elevation of the stockline determines the degree of mixing of the gas flow, which leads to distortion of the temperature at measurement points above the stockline.

Information on the distribution of the charge materials in the top of a blast furnace is needed to evaluate changes in the structure of the stock when there are changes in the furnace operating regime. Such information is also needed to determine the indices that characterize the charge's distribution: the distribution of the ore burden; the distribution of the volume of charge materials over the radius of the top [1, 3, 4].

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To optimize (or narrow) the choice of charging regime for blast furnaces, the Institute of Ferrous Metallurgy (IChM) has developed and introduced a model system that provides information to support the decisions that are made in selecting and correcting the charging programs of BCA-equipped blast furnaces. These systems are computer information systems that help blast-furnace operators and engineers to make decisions in poorly structured problems by engaging in a direct dialog with the computer while using data in mathematical models [5].

The model system that was constructed and installed on BF-3 is designed so as to allow the user to work independently at the control post. The system serves as an instructional aid for process engineers in the blast-furnace shop, which is important for personnel that are engaged in the introduction of a new charging apparatus. The specific model system in question was developed with allowance for the charging technology used on BF-3, the design parameters of the furnace and the BCA, and the equipment of the charging system. The system makes it possible to calculate the ore burdens and volumes of charge materials in ten annular zones of the top that are equal in area. These items of information are important for correcting the charging programs currently used on BF-3 and choosing more efficient programs for eventual use.

The following initial data are used to design the charging programs:

1) the charging-cycle matrix (the distribution of the weight of the charge materials by skip car and stockhouse hopper);

2) the initial charging program (the distribution of the charge materials for different angular positions of the chute);

3) the level of the stockline; and

4) the indices that characterize the listed charge materials, this list being based on the contents of the hoppers in the stockhouse.

The output data:

1) the distribution of the layers of rounds charged into the top of the furnace;

2) the values calculated for the ore burden in the ten equiareal annular zones in the top of the furnace;

3) the weight distribution of the charge components in the ten annular zones;

4) the overall distribution of the weights and volumes of coke and the iron-bearing charge components in the ten annular zones; and

5) the geometric profile of the stockline after a charging cycle.

To approximate the actual operating conditions of BF-3 at the EMZ as closely as possible, all the charging parameters used in the model were refined based on the results of pre-startup studies of the distribution of the first volume of charge materials introduced into the furnace before it was blown in [2].

In the course of the studies, we determined the discharge characteristics of the charging door of the hopper of the BCA (the dependence of the volumetric flow rate of the charge on the degree of opening of the door), determined the trajectories of the charge materials in the top of the furnace, measured the profiles of the stockline after charging, and studied the parameters of the flow of charge materials [2]. We also determined that a change in the angle of inclination of the chute and the volumetric flow rate of the material at the outlet end of the chute is accompanied by a change in the coordinate of the point corresponding to the flow's center of gravity relative to the chute's working surface in the longitudinal direction. To account for this in the model system, an algorithm was developed to calculate the width of the charge-materials flow in relation to the angle of inclination of the chute, the level of the stockline, and the volumetric rate of flow of the charge.

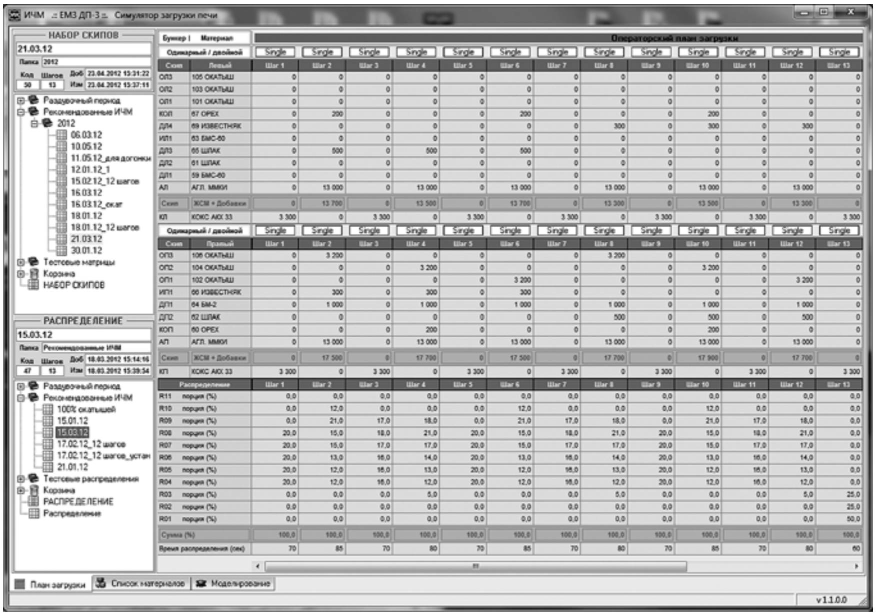
Using results obtained from the pre-startup tests on BF-3 and from calculation of the trajectories of the center of gravity of the charge-materials flow, we constructed the following relations and incorporated them into the model system:

1) the dependence of the angles of inclination of the chute of the BCA on the level of the stockline;

2) the dependence of the angles of repose of the charge materials on the type of material in each equiareal zone of the top of the furnace; and

3) the dependence of the width of the charge-materials flow on the time it takes to charge a round, the angle of inclination of the chute, and the level of the stockline.

For a user working with the model system, there are three forms in which the initial data is entered into the system and results are generated: Charging Plan, List of Materials, and Modeling. The initial data for modeling the charging of the furnace are located in the initial windows of the program: Charging Plan and List of Materials. The charging-cycle matrix and the initial charging program are entered into the Charging Plan box, the characteristics of the list of charge materials are



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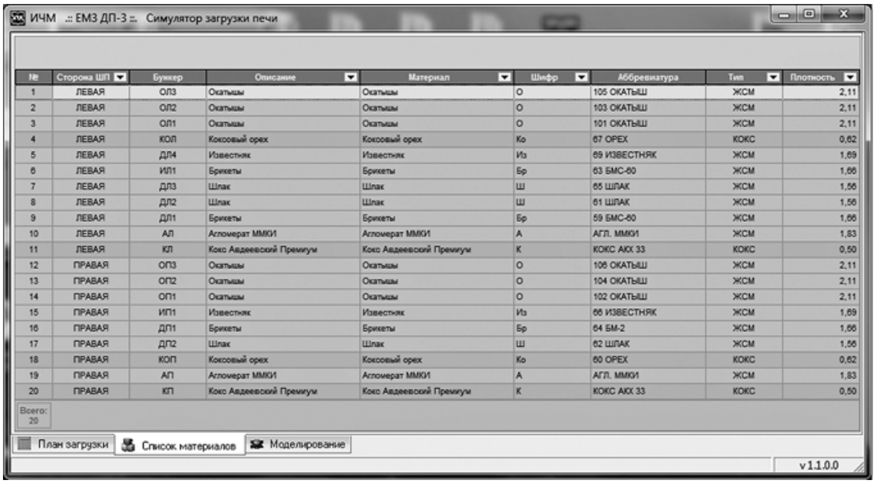
Бункер | Материал — Операторский план загрузки

Одинарный / двойной		Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single
Скип	Левый	Шаг 1	Шаг 2	Шаг 3	Шаг 4	Шаг 5	Шаг 6	Шаг 7	Шаг 8	Шаг 9	Шаг 10	Шаг 11	Шаг 12	Шаг 13
ОЛ3	105 ОКАТЫШ	0	0	0	0	0	0	0	0	0	0	0	0	0
ОЛ2	103 ОКАТЫШ	0	0	0	0	0	0	0	0	0	0	0	0	0
ОЛ1	101 ОКАТЫШ	0	0	0	0	0	0	0	0	0	0	0	0	0
КОЛ	67 ОРЕХ	0	200	0	0	0	200	0	0	0	200	0	0	0
ДЛ4	69 ИЗВЕСТНЯК	0	0	0	0	0	0	0	300	0	300	0	300	0
ИЛ1	63 БМС-60	0	0	0	0	0	0	0	0	0	0	0	0	0
ДЛ3	65 ШЛАК	0	500	0	500	0	500	0	0	0	0	0	0	0
ДЛ2	61 ШЛАК	0	0	0	0	0	0	0	0	0	0	0	0	0
ДЛ1	59 БМС-60	0	0	0	0	0	0	0	0	0	0	0	0	0
АЛ	АГЛ. ММКИ	0	13 000	0	13 000	0	13 000	0	13 000	0	13 000	0	13 000	0
Скип	ЖСМ + Добавки	0	13 700	0	13 500	0	13 700	0	13 300	0	13 500	0	13 300	0
КЛ	КОКС АКХ 33	3 300	0	3 300	0	3 300	0	3 300	0	3 300	0	3 300	0	3 300

Одинарный / двойной		Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single	Single
Скип	Правый	Шаг 1	Шаг 2	Шаг 3	Шаг 4	Шаг 5	Шаг 6	Шаг 7	Шаг 8	Шаг 9	Шаг 10	Шаг 11	Шаг 12	Шаг 13
ОП3	106 ОКАТЫШ	0	3 200	0	0	0	0	0	3 200	0	0	0	0	0
ОП2	104 ОКАТЫШ	0	0	0	3 200	0	0	0	0	0	3 200	0	0	0
ОП1	102 ОКАТЫШ	0	0	0	0	0	3 200	0	0	0	0	0	3 200	0
ИП1	66 ИЗВЕСТНЯК	0	300	0	300	0	300	0	0	0	0	0	0	0
ДП1	64 БМ-2	0	1 000	0	1 000	0	1 000	0	1 000	0	1 000	0	1 000	0
ДП2	62 ШЛАК	0	0	0	0	0	0	0	500	0	500	0	500	0
КОП	60 ОРЕХ	0	0	0	200	0	0	0	0	0	200	0	0	0
АП	АГЛ. ММКИ	0	13 000	0	13 000	0	13 000	0	13 000	0	13 000	0	13 000	0
Скип	ЖСМ + Добавки	0	17 500	0	17 700	0	17 500	0	17 700	0	17 900	0	17 700	0
КП	КОКС АКХ 33	3 300	0	3 300	0	3 300	0	3 300	0	3 300	0	3 300	0	3 300

Распределение		Шаг 1	Шаг 2	Шаг 3	Шаг 4	Шаг 5	Шаг 6	Шаг 7	Шаг 8	Шаг 9	Шаг 10	Шаг 11	Шаг 12	Шаг 13
R11	порция (%)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
R10	порция (%)	0,0	12,0	0,0	0,0	0,0	12,0	0,0	0,0	0,0	12,0	0,0	0,0	0,0
R09	порция (%)	0,0	21,0	17,0	18,0	0,0	21,0	17,0	18,0	0,0	21,0	17,0	18,0	0,0
R08	порция (%)	20,0	15,0	18,0	21,0	20,0	15,0	18,0	21,0	20,0	15,0	18,0	21,0	0,0
R07	порция (%)	20,0	15,0	17,0	17,0	20,0	15,0	17,0	17,0	20,0	15,0	17,0	17,0	0,0
R06	порция (%)	20,0	13,0	16,0	14,0	20,0	13,0	16,0	14,0	20,0	13,0	16,0	14,0	0,0
R05	порция (%)	20,0	12,0	16,0	13,0	20,0	12,0	16,0	13,0	20,0	12,0	16,0	13,0	0,0
R04	порция (%)	20,0	12,0	16,0	12,0	20,0	12,0	16,0	12,0	20,0	12,0	16,0	12,0	0,0
R03	порция (%)	0,0	0,0	0,0	5,0	0,0	0,0	0,0	5,0	0,0	0,0	0,0	5,0	25,0
R02	порция (%)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	25,0
R01	порция (%)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	50,0
Сумма (%)		100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Время распределения (сек)		70	85	70	80	70	85	70	80	70	85	70	80	60

Fig. 1. Charging Plan window.



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1	ЛЕВАЯ	ОЛ3	Окатыши	Окатыши	О	105 ОКАТЫШ	ЖСМ	2,11
2	ЛЕВАЯ	ОЛ2	Окатыши	Окатыши	О	103 ОКАТЫШ	ЖСМ	2,11
3	ЛЕВАЯ	ОЛ1	Окатыши	Окатыши	О	101 ОКАТЫШ	ЖСМ	2,11
4	ЛЕВАЯ	КОЛ	Коксовый орех	Коксовый орех	Ко	67 ОРЕХ	КОКС	0,62
5	ЛЕВАЯ	ДЛ4	Известняк	Известняк	Из	69 ИЗВЕСТНЯК	ЖСМ	1,69
6	ЛЕВАЯ	ИЛ1	Брикеты	Брикеты	Бр	63 БМС-60	ЖСМ	1,66
7	ЛЕВАЯ	ДЛ3	Шлак	Шлак	Ш	65 ШЛАК	ЖСМ	1,56
8	ЛЕВАЯ	ДЛ2	Шлак	Шлак	Ш	61 ШЛАК	ЖСМ	1,56
9	ЛЕВАЯ	ДЛ1	Брикеты	Брикеты	Бр	59 БМС-60	ЖСМ	1,66
10	ЛЕВАЯ	АЛ	Агломерат ММКИ	Агломерат ММКИ	А	АГЛ. ММКИ	ЖСМ	1,83
11	ЛЕВАЯ	КЛ	Кокс Авдеевский Премиум	Кокс Авдеевский Премиум	К	КОКС АКХ 33	КОКС	0,50
12	ПРАВАЯ	ОП3	Окатыши	Окатыши	О	106 ОКАТЫШ	ЖСМ	2,11
13	ПРАВАЯ	ОП2	Окатыши	Окатыши	О	104 ОКАТЫШ	ЖСМ	2,11
14	ПРАВАЯ	ОП1	Окатыши	Окатыши	О	102 ОКАТЫШ	ЖСМ	2,11
15	ПРАВАЯ	ИП1	Известняк	Известняк	Из	66 ИЗВЕСТНЯК	ЖСМ	1,69
16	ПРАВАЯ	ДП1	Брикеты	Брикеты	Бр	64 БМ-2	ЖСМ	1,66
17	ПРАВАЯ	ДП2	Шлак	Шлак	Ш	62 ШЛАК	ЖСМ	1,56
18	ПРАВАЯ	КОП	Коксовый орех	Коксовый орех	Ко	60 ОРЕХ	КОКС	0,62
19	ПРАВАЯ	АП	Агломерат ММКИ	Агломерат ММКИ	А	АГЛ. ММКИ	ЖСМ	1,83
20	ПРАВАЯ	КП	Кокс Авдеевский Премиум	Кокс Авдеевский Премиум	К	КОКС АКХ 33	КОКС	0,50

Всего: 20

Fig. 2. List of Materials window.

entered into the List of Materials box, and the level of the stockline is entered into the Modeling box immediately prior to beginning the modeling process.

The Charging Plan window consists of two main parts separated by a horizontal line (Fig. 1). The top part shows the charging-cycle matrix along with the weight distribution of the charge materials among the different skip cars and stockhouse hoppers. The weight of the charge materials (in kilograms) for rounds (steps) of the charging program are entered into the matrix by the operator for each stockhouse hopper. The maximum number of rounds of the charging program is 18. The number of stockhouse hopper is always 20, this parameter being determined by configuration of the charging system of BF-3. Based on this, in the charging-cycle matrix one round consists of 20 values (matrix columns) for the weight of the batch of charge materials from each stockhouse hopper. The matrix is separated horizontally into two submatrices corresponding to

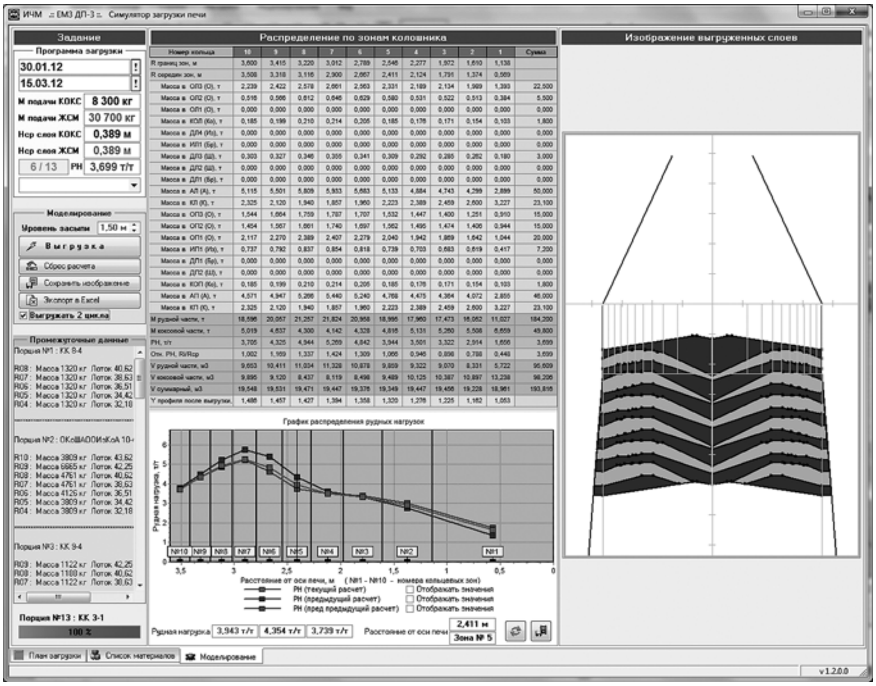

Fig. 3. Modeling window.

the left and right sides of the charging system (left and right skip cars), and each of these submatrices is in turn divided into sections for coke and iron-bearing materials.

The bottom part of the window shows the matrix that depicts the distribution of the charge materials with respect to the angular position of the chute. In this matrix, the operator enters the charge-materials distribution (in percents) with respect to the angular position of the chute and charging time (distribution time) for different rounds of the charging program. The maximum number of rounds of the program is 18. The number of angular positions of the chute is always 11, in accordance with the design of the BCA of BF-3. Based on this, each step (column) of the matrix of the charge-materials distribution consists of 11 values for the relative (in percents) weight of a given round and the time that it is charged by the charging apparatus.

The database of the model system can hold an unlimited number of matrices for the charging cycle and the distribution of the charging materials with respect to the angular position of the chute.

The List of Materials window consists of a table showing a list of the materials being charged into furnace with an indication of the stockhouse hopper from which the materials are obtained (Fig. 2). The number of possible charging materials corresponds to the number of stockhouse hoppers and is equal to 20. This information is duplicated for each hopper when the same given charging material is being taken from several different hoppers.

The operation of charging the furnace is modeled in the Modeling window (Fig. 3) after the initial data (the matrices for the set of skip cars and the distribution of the charge materials with respect to the angular position of the BCA chute) has been specified. This window consists of three main parts: the set points; the distribution of the charge materials in the different zones of the top of the furnace; an image of the structure of the charged layers of materials.

When the matrices are entered, it is assumed that each set of skip cars in a round of the charging cycle corresponds to a certain distribution of the charge materials (in percents) based on the angular position of the BCA chute. The volumes of charge materials calculated for a given round based on weight and density are placed in the hoppers and the skip cars, respectively (the volume of each car is 11.5 m^3 and the volume of each hopper is 24 m^3). The user is shown a list of errors when the values of the parameters just mentioned are incompatible with one another.

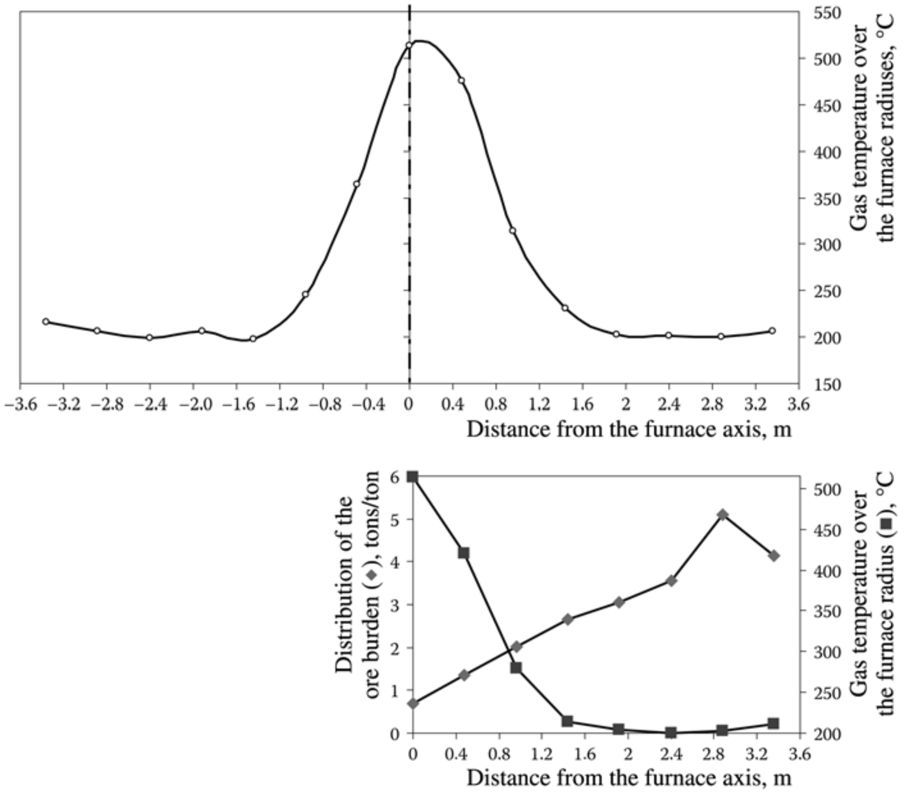

Fig. 4. Relationship between ore burden and top-gas temperature over the radius of the furnace.

After all the initial data have been correctly assigned and the Loading button is pushed, the configuration of the layers of charge materials in the top of the furnace is calculated and visualized and calculations are also performed to determine the distributions of these materials and the ore burden over the radius of the top.

The distribution of the layers of charged materials in the top of the furnace is visualized on the right side of the window (see Fig. 3) in the form of a geometric schematic diagram showing the distributions of volumes of charge materials over the radius of the top and in the upper part of the shaft. The resulting table in the central part of the window (Fig. 3) shows the distribution of the weights of the different components of the charge by hopper and the overall distributions of the weight and volume of the coke and iron-bearing components in the ten equiareal annular zones of the top. Calculated values of the ore burden in these ten zones are shown in the graph (Fig. 3).

Since BF-3 at the Enakievo plant does not have equipment to automatically sample the furnace gases in the radial direction, the temperature of the top gas that is determined based on the readings of the heat-sensing beams serves as a qualitative index of the charge materials' distribution. To substantiate the adequacy of the model system, we checked the agreement between the values it calculated for the ore burden and top-gas temperature in the radial direction during a period when the furnace was charged in accordance with the system's charging program. The correlation coefficient characterizing the agreement between the ore burden and top-gas temperature was –0.84 (Fig. 4). This level of agreement and the indices that were calculated for the distribution of the charge materials in the top of BF-3 at the Enakievo plant show that the model system which was developed is adequate for its intended application.

Conclusion. A model system was constructed and introduced on blast furnace No. 3 at the Enakievo Metallurgical Plant to help make decisions on selecting and correcting the furnace's charging programs. Use of the system allows furnace operators to determine and implement the measures that are appropriate for changing the charging regime. In addition to performing its main function, the system can also be used to train furnace personnel in mastering the operation of new charging equipment.

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