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ISSN 0543-5846
METABK 63(3-4) 333-336 (2024)
UDC – UDK 669.162.2:338.972.002.3–531.1:532.57:62.001.57=111

LOAD CONTROL OPERATIONAL CORRECTION OF A BLAST FURNACE BASED ON THE CORRELATION MODELS

Received – Primljeno: 2024-02-08
Accepted – Prihvaćeno: 2024-04-03
Original Scientific Paper – Izvorni znanstveni rad

The paper uses regression analysis to research the movement dynamics of charge materials along the paths of a blast furnace coneless loader device. The research's main goal is to consider two main factors when optimizing the loading process of the blast furnace - the opening degree of the charge shutter of the loading device hopper and the inclination angle of the distribution tray. That approach allows the optimization of the loading impact, taking into account the current change in the granulometric parameters of the blast furnace charge. A model for determining the dynamic parameters of the charge flow in the case of its movement along the paths of the blast furnace coneless loading device has been developed.

Keywords: blast furnace, operational correction, charge flow, descent speed from the tray, mathematical model.

INTRODUCTION

For effective distribution forecasting of charge materials on the blast-furnace mouth, important information for basic computations is the speed dependence of charge descent from the distribution tray of the coneless loading device. Research [1-3] established that the rate of charge rise depends not only on the geometric parameters of the loading path elements and the inclination angle of the tray but also on the granulometric characteristics of the charge materials loaded on the furnace mouth. Therefore, the presented method in this study aims to obtain analytical dependencies of the descent rate of the charge from the tray with careful consideration of the specified factors.

RESULTS

According to [4], the equivalent diameter can be obtained depending on:

$$d = \sum d_i \psi_i \tag{1}$$

where d_i – fraction size; ψ_i – the fraction share in the entire volume of this charge material portion. The equivalent diameter is 0,011 meters.

In computations, the coefficient of friction was chosen to be 0,72 [5]. Applying the methodology [6], the following values of volume flow rates from the blast furnace CLD storage hopper and the corresponding flow velocities were computed (Table 1).

After leaving the storage hopper, the bulk materials enter the inclined discharged hopper.

Given the design features of this tract part, the initial peak speed was obtained by the formula:

$$V_{0m} = \sqrt{\mathrm{V}^2 + 2\mathrm{g} \cdot \theta} \tag{2}$$

Where $\mathrm{V}_{\text{б}}^2$ – initial speed; θ = 0,1 m is the vertical distance projection from the axis of the hopper outlet opening to inclined discharged hopper axis.

The cross section and height of the mound of charge materials at the beginning of the discharged hopper should be obtained by the formulas:

$$S_{0m} = \frac{\mathrm{Q}}{V_{0m}} \tag{3}$$

$$h_{0m} = \frac{\mathrm{S}_{0\text{т}} + 0,03}{0,8} \tag{4}$$

where $\mathrm{S}_{0\text{т}}$ – initial cross section. Applying the Padé approximation and choosing the appropriate Chézy coefficient, we obtain dynamic data of the material flow descent from an inclined discharged hopper (Table 2).

The initial velocity in a vertical pipe is computed as follows:

$$V_{0\,укт} = V \quad (\alpha) \cdot \mathrm{k_b} \sin 55^\circ \tag{5}$$

where $V_{кт}$ – speed at the end of the pipe.

The speed at the end of the charge flow in the vertical pipe equals:

$$V_{1y} = \sqrt{V_{0y}^2 + 63,77} \tag{6}$$

Table 3 presents the data computed by dependencies (5) and (6).

Thus, control of the final speed change in the vertical pipe can be done only by changing the charge shut-

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Table 1 **Computed parameters of material flow leakage from the hopper**

No	Opening angle of the shutter α degrees	Volume consumption of bulk materials from bunker m ^{3}/s	The flow rate of the charge materials flow from the bunker m/s
1	15	0,075	0,625
2	30	0,342	1,04
3	45	0,743	1,4
4	60	1,25	1,84

Table 2 **Dynamic data of the charge materials rise with an inclined discharged hopper**

No	Gate opening angle α degrees	The initial cross-sectional area of the charge flow at the discharged hopper	The initial height of the charge in heat h0t m	Coefficient Chézy C	The height of the materials rise from an inclined discharged hopper m	The rising rate of the charge from an inclined discharged hopper, m/s
1	15	0,049	0,09	2	0,1	0,88
2	30	0,196	0,28	6	0,086	5,92
3	45	0,375	0,52	8	0,11	10,54
4	60	0,541	0,79	10	0,184	19,83

ter opening angle of the storage hopper of the blast furnace loading device. To determine the initial parameters of the movement of the charge materials flow on the rotating tray-distributor, it is necessary to know the gate opening angle and the tray inclination angle to the vertical axis.

Table 3 **Dynamic data of the charge materials movement in the vertical pipe of the blast furnace coneless loading device**

No	Shutter opening angle, degres]	Speed at the beginning of the pipe, m/s	Speed at the end of the pipe, m/s
1	15	1,21	8,08
2	30	7,27	10,8
3	45	10,54	12,23
4	60	13,18	15,66

The dependence for determining the initial speed on the tray is as follows:

$$V_{02} = V_{1y}(\alpha)\cdot k_b \cdot \cos\beta \tag{7}$$

Next, data were compiled on determining the descent speed from the distribution tray for the opening angles of the slide gate of 15, 30, 45, and 60 degrees at different angles of the tray inclination.

Using the specified data for the specified type of material and granulometric composition, we will simplify the analytical expressions for the final determination of the descent rate of the charge flow from the distributor tray. The specified speed is the main parameter. Thereby, we can determine the flow trajectory of charge materials in the blast furnace mouth space.

In this way, the volumetric consumption analytical dependence of charge materials from the loading device storage hopper on the degree of gate shutter opening is derived:

$$Q(\alpha) = -0{,}166 + 0{,}015\alpha + 2{,}34\cdot10^{-6}\cdot\alpha^3 \tag{8}$$

where α – gate opening angle.

Considering that the outflow rate of batch materials from the loading device storage hopper can be computed as the volume flow rate ratio to the outlet opening area and taking into account the (2) dependence, after the transformation, we get:

$$V_{0m} = \sqrt{\frac{\mathrm{Q}^2(\alpha)}{S_б^2} + 1{,}96} \tag{9}$$

where $S_б$ is the hopper outlet area, m $^{2.}$

The cross-sectional area of the charge materials flow located at the beginning of an inclined discharged hopper is equal to the ratio of the charge volume flow rate to the flow rate at the beginning of the discharged hopper. The area of the charge materials flow at the beginning of the inclined discharged hopper equals:

$$S_{0m} = \frac{\mathrm{Q}(\alpha)}{\sqrt{\frac{\mathrm{Q}^2(\alpha)}{S_б^2} + 1{,}96}} \tag{10}$$

After the transformation, the height of the charge materials flow at the beginning of the inclined discharged hopper equals:

$$h_{0m} = \frac{\mathrm{Q}(\alpha)}{0{,}8\sqrt{\frac{\mathrm{Q}^2(\alpha)}{S_б^2} + 1{,}96}} + 0{,}0375 \tag{11}$$

The source [7] provides data on the change in the outlet opening area of the loading device storage hopper when the gate opening angle changes, which is presented as a graph. The graph data approximation leads to the expression:

$$S_б(\alpha) = 0{,}35 + 0{,}052\alpha - \\ -2{,}34\cdot10^{-4}\cdot\alpha^2 - 0{,}247\sqrt{\alpha} \tag{12}$$

then we have

$$h_{0m} = \frac{-0{,}166 + 0{,}015\alpha + 2{,}34\cdot10^{-6}\cdot\alpha^3}{0{,}8\sqrt{\frac{\left(-0{,}166 + 0{,}015\alpha + 2{,}34\cdot10^{-6}\cdot\alpha^3\right)^2}{\left(0{,}35 + 0{,}052\alpha - 2{,}34\cdot10^{-4}\cdot\alpha^2 - 0{,}247\sqrt{\alpha}\right)^2} + 1{,}96}} + 0{,}0375 \tag{13}$$

Simplification of formula (13) leads to the expression:

$$h_{0m} = -0{,}0653 + 0{,}00971\alpha + \\ +3\cdot10^{-5}\alpha^2 + 10^{-6}\alpha^3 \tag{14}$$

Applying the Padé approximation, we can get the expression:

$$V_{км} = 6{,}91 + 6{,}64\cdot10^{-5}\cdot\alpha^3 - \frac{92{,}9}{\alpha} \tag{15}$$

Given the (5) dependence, the expression for determining the initial speed in a vertical pipe has the form:

$$V_{0y} = 3{,}11 + 3\cdot 10^{-5}\alpha^{3} - \frac{41{,}81}{\alpha} \tag{16}$$

Considering the (6) formula, we obtain an expression for determining the charge materials speed at the vertical pipe end:

$$V_{1y} = \sqrt{\left(3{,}11 + 3\cdot 10^{-5}\alpha^{3} - \frac{41{,}81}{\alpha}\right)^{2} + 63{,}77} \tag{17}$$

The cross-sectional area of the charge materials flow at the beginning of the distributor rotating tray can be determined, on the one hand, as the ratio of the volume flow rate to the material speed, and on the other hand. Thus, we obtain the equality:

$$S_{0л} = \frac{\mathrm{Q}}{\mathrm{V}_{02}} = 0{,}8h_{0л} - 0{,}03 \tag{18}$$

Given (13) (14), after the transformation, we obtain:

$$h_{0л} = \frac{\mathrm{Q}}{0{,}8\mathrm{V}_{1\mathrm{y}}\cdot k_{b}\cdot\cos\beta} + 0{,}0375 \tag{19}$$

It is obvious that the descent rate of the charge materials from the rotating tray-distributor depends on the opening angle of the CLD storage hopper shutter and, simultaneously, on the tray inclination angle concerning the vertical axis of the furnace. In this regard, it was decided to present the descent rate of charge materials from the distribution tray as a statistical dependence, which coefficients depend on the charge gate opening degree:

$$V_{схл} = \mathrm{a}_{0} + a_{1}\beta + a_{2}\beta^{2} + a_{3}\beta^{3} \tag{20}$$

where β is the inclination angle of the CLD distribution tray.

Thus, in order to determine the descent rate of the charge materials of the loading device rotating tray-distributor of the blast furnace, it is necessary to select the appropriate coefficient of the equation (20), which characterizes the specific opening angle of the storage hopper sliding shutter, and depending on the tray inclination angle, determine by expression (20) the charge materials speed descent.

To determine the equation (20) coefficients at any values of the opening angle of the storage hopper sliding shutter, a regression equation was made for each coefficient according to the data given in Table 4.

Table 4 **The equation (20) coefficients value**

α, hail	15	30	45	60
a_0	3,71	9,21	8,55	5,23
a_1	-0,01	0,344	-0,157	0,25
a_2	$-1{,}17\mathrm{x}10^{-4}$	0,01	$6{,}31\mathrm{x}10^{-3}$	$6{,}53\mathrm{x}\ 10^{-3}$
a_3	$-4{,}04\mathrm{x}\ 10^{-7}$	$-8{,}81\mathrm{x}\ 10^{-5}$	$6{,}9\mathrm{x}\ 10^{-5}$	$-5{,}32\mathrm{x}\ 10^{-5}$

At a gate opening angle of 15 degrees, the descent speed dependence on the tray inclination angle clearly expresses linear character. Dependencies for other degrees of shutter opening are polynomial in nature. That is, first of all, because the distribution tray filling is affected not only by the force of gravity but also by the centrifugal force that occurs due to the tray rotation to the furnace axis. In this regard, there is a change in speed at a given shutter opening angle within limits that are not very wide. The free-dispersed movement of bulk materials largely depends on the Chézy coefficient, which in turn depends on the material coarseness and the material layer thickness on the guiding surface. At different tray sections, the prevailing force is either gravity or centrifugal force, so the speed dependence has a wavy character. The dependences in Figure show that the gate opening significantly affects the value of the descent rate of the charge materials from the tray. The specified speed, in turn, is a parameter that directly affects the charge movement trajectory in the blast furnace space and, therefore, the flow falling point on the backfill surface. Equation (20) can be used by the automatic backfill profile correction system to determine the fall radius of the charge flow, which directly affects the trajectory of the charge movement in the blast furnace space and, therefore, the flow falling point on the backfill surface.

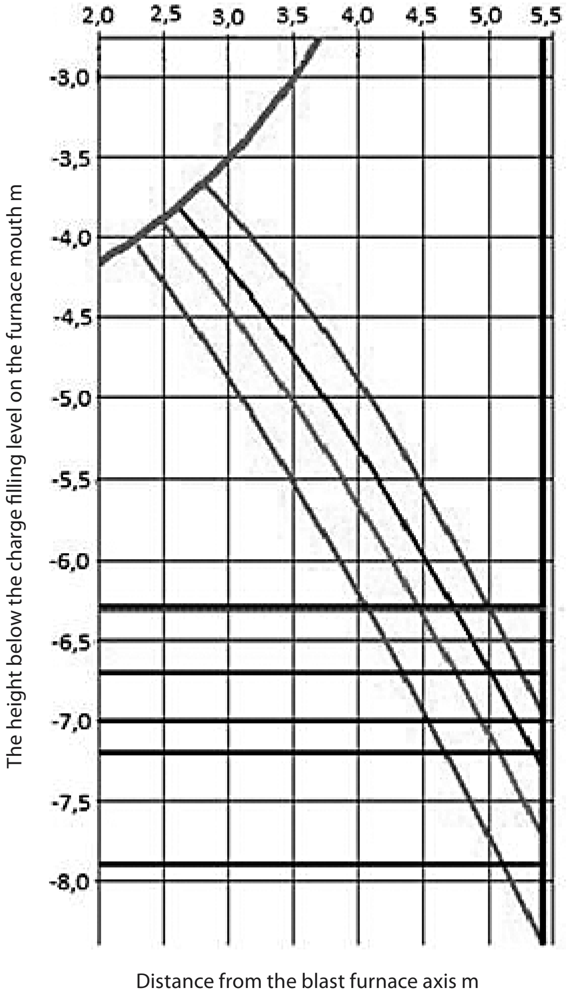

Figure 1 Charge materials pouring trajectories in the blast furnace mouth space for tray inclination angles of 50, 47, 45, and 42 degrees concerning the blast furnace vertical axis.

Figure 1 shows the specified trajectories built for the tray inclination angles of 50, 47, 45, and 42 degrees.

Figure 1 represents horizontal lines at the bottom of the Figure 1 showing the following levels from top to bottom: technological “0”, the upper section level of the furnace protective plates, the level 200 mm below the protective plates upper section, the level 500 mm below the protective plates, the level 700 and 1400 mm below of the protective plates upper section, respectively.

The right vertical bold line denotes the blast furnace mouth wall. The corresponding trajectories are located slightly below the experimental level lines. Because the charge materials flow has a certain width, a good convergence of experimental and theoretical data is observed.

Thus, the scientific approach to solving the problem of operationally ensuring the rational distribution of charge materials on the blast furnace mouth is justified by the given correction of the flow trajectories. By using the analytical dependencies obtained in the paper in combination with the requirements for the distribution of charge materials from the standpoint of rational gas dynamics, there is an opportunity to avoid conditions deterioration of recovery processes when the characteristics of the used charge materials are changed. For example, it is known that with the same inclination angles of the distribution tray and degrees of opening of the storage hoppers sliding gate, batch materials of different sizes will have different trajectories in the blast furnace space. Computations show that the displacement of trajectories can occur by a significant amount. If the loading mode remains the same, the redistribution of charge materials will inevitably change. That will lead to the recovery conditions deterioration of iron ore raw materials in the charge column upper layers in the so-called “dry” zone.

Provided that the furnace has monitoring systems for the charge backfill surface on the furnace mouth, the indicated change in the charge redistribution will be promptly recorded with specific changes in parameters. The question is how to change the influencing loading factors to achieve the best recovery conditions. For that purpose, the paper considers the approaches for correcting loading parameters in detail.

Simple mathematical dependencies have been obtained to determine the geometric and kinematic parameters of the charge flow coming from the distributor tray. The specified dependencies easily fit into any automated technological process management system. The automated system is designed to assist the blast furnace technologist in making the right decision, ensuring the efficient course of blast furnace melting as a whole.

The mathematical model created by the paper’s author reveals wide possibilities for varying the loading parameters of the blast furnace when using CLD. According to the obtained model, analytical computations allow us to calculate the correction of the inclination angle of the distributor tray and (or) the opening degree of the hopper charge shutter. The difference between the model and the existing ones is that considering the actual parameters of granulometry and gas dynamics by mathematical expressions allows one to obtain specific correction values to achieve the set goal - increasing productivity and reducing the consumption of the melting energy carrier. That allows a quick influence on the gas permeability of the furnace charge column, fulfilling the specified ore and gas loads. Those measures allow the use of the regenerative capacity of gases at a higher level to bring the real ore load as close as possible to the computed one, which allows significant savings in coke.

CONCLUSIONS

Analytical data for operational correction of blast furnace loading control, considering the actual parameters of granulometry and physical and mechanical characteristics of the charge materials loaded into the blast furnace, received further scientific development. Based on the mathematical models obtained, dependencies were obtained, which allowed a quick correction of the course of the blast furnace melting in the event of a change in the charge materials’ dispersion. That allows for an increase in the domain process efficiency in case of a change of charge conditions.

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Note: The responsible for English translation is V. V. Busygin, Ulsteinvik, Norway