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COEFFICIENT OF LOCAL LOSS OF MECHANICAL ENERGY OF THE FLOW FOR A MIXTURE OF CHARGE MATERIALS

Purpose. To determine the dependence of the coefficient of local losses of mechanical energy of flow of a two-component mixture of charge material on its depth, content of components, and average equivalent diameter of particles in the case of their free-dispersed motion.

Methodology. The value of the coefficient of local losses of mechanical energy was determined by the value of the hydraulic resistance of the fluid during its movement in open channels and pipes. In this paper, methods were used of comparative analysis, mathematical modeling and forecasting of dynamic processes in the flow of granular material.

Findings. Based on the results of theoretical studies, a mathematical model was obtained, the use of which allows calculating the coefficient of local losses of mechanical energy for the flow of a two-component mixture of charge materials with agglomerate particle sizes from 15 to 50 mm, pellets from 6 to 12 mm, coke from 10 to 60 mm. The developed model with satisfactory accuracy makes it possible to evaluate the movement of the charge from the indicated materials along the paths of the charging devices of blast furnaces at a speed in the range from 1.5 to 20 m/s and to determine the trajectories of the mixture of charge materials on the top with an accuracy of 0.2 m. It is noted that the calculation of the above coefficient by the known techniques is not accurate enough, which is associated with the uncertainty in the choice of a single average equivalent diameter of the particles of the two-component charge. Comparative analysis of the developed model with the known models and experimental data indicates that the accuracy of calculating the dynamic parameters of a two-component flow of charge materials using the developed model increases by 5–10 % in comparison with calculations using the previously known models.

Originality. For the first time, regularities of changes in the coefficient of internal mechanical losses of a two-component flow of charge materials from its depth, content of components, average equivalent particle diameters when moving along the paths of charging devices of blast furnaces have been established.

Practical value. Mathematical dependencies have been developed and can be used to determine the technological parameters of the charge of a modern blast furnace with different characteristics of the granulometry of the charge and the ratios of its components. This will increase the accuracy of predicting the course of the process under consideration, the degree of automation of the control systems for the technological process of the charge supply of blast furnaces, will make it possible to use expensive charge materials more efficiently, reduce energy consumption and reduce the harmful impact on the environment.

Keywords: *charge, blast furnace, charging device, energy, mixture*

Introduction. Most of the charge materials used in metallurgy are granular. In this regard, in order to ensure stable and efficient operation of the equipment, it becomes necessary to calculate the dynamic parameters of such flows. For the efficient carrying out of technological operations for transporting the charge, it is necessary to calculate the flow rate (mass or volumetric) of the material in the guiding elements of the equipment, which provides a given direction of flow. One of the directions for solving such a problem is the construction of a corresponding adequate mathematical model, an element of which, as a rule, is the Bernoulli equation for the flow. In this case, it is necessary to take into account the restrictions associated with the internal interaction of the particles of the material for various types of its movement.

The magnitude of losses during the movement of the flow of granular material is characterized by the magnitude of the coefficient of local losses (CLL). For a homogeneous charge material, the methods for determining the CLL are known [1]. However, when conducting blast-furnace melting, a two-component mixture of charge materials is often used. For example, a mixture of sinter and pellets can be used as an iron ore part, or a mixture of iron ore and fuel parts of a blast furnace charge can be fed to the top of the top. The average equivalent diameters of such materials can differ from each other by three times. For this type of mixtures, the use of the existing method for determining the CLL leads to unacceptably high significant calculation errors. At the same time, the method of analytical calculation of the CLL, which takes into account the concentrations of the components of the charge with different equivalent diameters, will make it possible to more accurately calculate the flow rate of the charge moving along the guide elements of the transportation system. In turn, this will allow saving energy resources of blast-furnace smelting by 1–3 %, as well as improving the environmental performance of the technology for producing blast-furnace pig iron.

Literature review. At present, the characteristics of a moving stream of a charge are considered using the finite element method for a plane or spatial model of interaction [2–6]. In this case, for the calculations, the authors introduce a number of assumptions and restrictions, which not only complicates the calculation process, but also casts doubt on the adequacy of the results obtained.

In particular, in such studies the authors of [2] used a spatial model of clusters in the thickness of a moving granular material. With this approach, the granular material was considered as a collection of individual particles, and their interactions were calculated with updating at each calculation step using Newton's second law. That is, in combination, a linear contact model is used together with the Coulomb friction law. The authors take into account the internal interaction by the clustering coefficient, for which graphical dependences on stresses are known for various ratios of the diameters of the multicomponent granular material.

This approach has satisfactory accuracy for cases of relatively low (up to 2.5–3 m/s) velocities of particle flows. At the same time, this technique assumes to assign new initial conditions for using the numerical DEM method in each case when the position of the guiding element changes, which is associated with a large amount of preparatory work for calculations. In addition, the clustering coefficient cannot be used in the Bernoulli equation to determine the internal mechanical losses of a moving stream. The authors of [3] consider the motion of a flow of spherical particles in a resisting medium. On the basis of this model, the authors calculated the change in the particle velocity, the conditions for the formation of so-called clusters, determined the factors at which the fastest advance of the material is possible, the ratio of the particle sizes of the flow of the moving and resisting material. Nevertheless, this approach is inapplicable for determining the dynamic parameters of the flow of charge materials during its movement in the charging systems of blast furnaces due to the sufficiently high speeds at which the formation of cluster blocks is unlikely.

In [4], the process of elastic interaction between particles of granular material in a flow is considered, taking into account losses due to internal friction. The authors of the work assessed the internal resistance between the particles of the flow in terms of their "stiffness", which was calculated based on the choice of the damping stiffness coefficients. The stress state of the system is given taking into account the gradient of the flow velocity, the mass of the particles and the coefficient of their rigidity. At the same time, taking into account the effect of gravity in this work is limited by the coefficient of macroscopic friction, which leads to a low level of accuracy in predicting the motion of multicomponent mixtures.

In [5], the authors give a calculation of the stress state in a bulk cargo flow, where tangential and normal stresses depend only on the friction coefficient and the magnitude of the relative shear, which significantly reduces the accuracy of the calculated parameters of real flows of granular materials.

The authors of [6] consider the stress state of two-component mixtures of granular material, depending on the composition and moisture content of the materials in the mixture. However, this approach is applicable only for a static state or for the case of low velocities of the flow of a two-component mixture.

From the above, it follows that today there are no methods that allow determining the dynamic characteristics of flows of granular materials with high accuracy, and are suitable for describing the movement of the charge in the transportation systems of blast furnace production, which reduces the efficiency of the furnace loading systems.

Proceeding from this, the creation of an integrated analytical method for calculating the parameters that takes into account the loss of mechanical energy of the flow of a two-component mixture of bulk material is an urgent scientific and technical problem.

Purpose. Development of theoretical foundations for analytical calculation of the coefficient of local losses of mechanical energy of the flow of granular material, the introduction of which will increase the efficiency of blast furnaces due to productivity factors and energy savings.

Methods. On the basis of modern methods for determining the CLL, based on calculating the resistance to fluid movement in open channels and pipes, the CLL was calculated for a two-component blast furnace charge. Using the data obtained, the Shezy coefficient was calculated for the corresponding contents of the components of the granular mixture, as well as the theoretical values of the volumetric flow rates of the charge from the storage hopper with a slide gate. We checked the adequacy of the obtained mathematical model by comparing theoretical results with experimental data.

Results. Currently [7] for calculating the CLL, the formula is used

$$\zeta = K_1 K_2 \frac{k^2 d^2}{a^2}; \qquad (1)$$

$$K_1 = \frac{1}{2}\left(f + \sqrt{1 + f^2}\right),$$

where k is a dimensionless coefficient depending on the shape of the particles ($k = 10$–13); f is the coefficient of internal friction of bulk cargo; a is height of the bunker outlet, m; K_2 is a dimensionless coefficient depending on the conditions of the outflow of bulk cargo from the bunker (direct or lateral outflow of bulk cargo from the bunker), determined from the experiment; d is the average equivalent diameter of the bulk cargo particles, m.

At present, to determine the coefficient, along with (1), the method for determining the hydraulic resistance during fluid movement in open channels and pipes is also used [8]. In this case, the movement of charge materials along an inclined plane is considered as a flat model. The design diagram of the movement of bulk cargo along an inclined plane in the case of its free-dispersed state is shown in Fig. 1.

Fig. 1 indicates: h – flow depth; G – the weight of the element in question; y – coordinate of the height of the moving layer; τ – shear stresses; V – the speed of the flow particles.

Due to the uniformity of movement, the height of the bulk cargo flow remains constant along its length. The origin of the coordinate system $0xy$ by virtue of the foregoing is assigned on the surface of the inclined sliding plane, and the $0x$ axis and $0y$ axis are oriented, respectively, parallel and perpendicular to

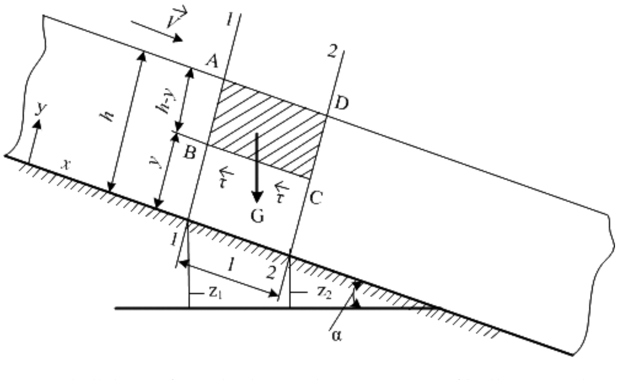

Fig. 1. Scheme for calculating the movement of bulk cargo along an inclined plane

the inclined sliding plane. Using the scheme in Fig. 1, in the bulk cargo flow, we select the ABCD element of length l, formed by two cutting planes *1–1* and *2–2*, perpendicular to the direction of the flow, and by the flow plane parallel to the inclined sliding plane and spaced from it at a distance y. Then from the equation of equilibrium of the projections of the force of gravity and the force of resistance on the axis $0x$, applied to the selected element of the bulk cargo, we have

$$t = \rho_c g(h - y)\sin\alpha, \tag{2}$$

where τ is shear stresses in the bulk cargo flow at a distance y from the inclined plane, H/m$^{2.}$

On the other hand, the tangential stresses in the flow of charge materials can be calculated using the formula

$$\tau = \frac{1}{3}\rho\cdot k^2 d^2\left(\frac{\partial V}{\partial y}\right)^2, \tag{3}$$

where ρ is the density of a piece of material; k is the coefficient depending on the shape and concentration of particles of bulk material; d is the average equivalent diameter of a piece of material of charge materials; V is the average velocity of the particles of the charge material in the flow.

The use of formulas (2, 3) is permissible subject to two main hypotheses. This is a hypothesis about the homogeneity of the material and a hypothesis about the proportionality of the physical and mechanical characteristics of the considered bulk cargo. In this case, the homogeneity of the material is understood as the uniformity of the distribution of the size and physical and mechanical properties of the particles of the material throughout the volume of the charge flow. The portioning of the flow is understood as the equality of the general dynamic characteristics of the bulk cargo to the sum of the characteristics of individual types of materials included in the mixture. Based on this, you can write

$$\tau = \tau_1 + \tau_2 = \frac{1}{3}\rho_1\cdot P_1\cdot k^2 d_1^{\,2}\left(\frac{\partial V}{\partial y}\right)^2 + \frac{1}{3}\rho_2\cdot P_2\cdot k^2 d_2^{\,2}\left(\frac{\partial V}{\partial y}\right)^2, \tag{4}$$

where P_1 is the probability of collision of the first type of material with the second; P_2 is the probability of collision of the second type of material with the first.

Index 1 is used for the first type of material from the mixture, respectively, index 2 – for the second type of charge material. Equating the shear stresses in expressions (2) and (4), as well as carrying out transformations, we obtain

$$\left(\frac{\partial V}{\partial y}\right)^2 = \frac{3\rho\cdot g(h-y)\sin\alpha}{\rho_1\cdot P_1\cdot k^2 d_1^{\,2} + \rho_2\cdot P_2\cdot k^2 d_2^{\,2}}. \tag{5}$$

Denoting the denominator of the right-hand side of (5) through, we get

$$\frac{\partial V}{\partial y} = \sqrt{\frac{3g\sin\alpha}{A}(h-y)}. \tag{6}$$

Integrating equation (6) over y from 0 to h, taking into account the boundary condition on the surface of the inclined plane (at $y = 0$, $V = 0$,) we arrive at the equation

$$V(y) = \frac{2}{3}\sqrt{\frac{3g\sin\alpha}{A}}\left[h^{3/2} - \left(h-y\right)^{3/2}\right]. \tag{7}$$

Assuming that $y = h$, we find the maximum flow rate

$$V_m = \frac{2}{3}\sqrt{\frac{3gh^3\sin\alpha}{A}}. \tag{8}$$

From a comparison of the obtained formulas (7) and (8) with the dependence in (Kiriya R.V., 1999), it is easy to see that for a homogeneous material that does not consist of a mixture of two types, the value A is equal to

$$A = k^2 d^2. \tag{9}$$

It is known that [9]

$$\xi = \frac{4.17k^2d^2l}{h^3}. \tag{10}$$

Considering (4, 5, 9) and (10), you can get

$$\xi = \frac{4.17\left(\rho_1\cdot P_1\cdot k^2 d_1^2 + \rho_2\cdot P_2\cdot k^2 d_2^2\right)\cdot l}{h^3}. \tag{11}$$

To use dependence (11), it is necessary to obtain equations that would make it possible to determine the collision probabilities for P_1 and P_2. For this purpose, let us designate through V the entire volume occupied by the charge material, through V_1 and V_2 – the volumes occupied by material 1 and material 2, respectively. The following quantities are called the volumetric concentrations of materials

$$\begin{cases} C_1 = \dfrac{V_1}{V} \\ C_2 = \dfrac{V_2}{V} \end{cases}. \tag{12}$$

That is, the ratio of the volume of material 1 to the total volume of material will be called the concentration of material 1 in a two-component mixture of granular material (12).

Let N_1 be the number of particles of material 1, while N_2 is the number of material 2, accordingly. If we represent pieces of material as balls, then the total volume of material particles is equal to

$$V = V_1 + V_2 = N_1\frac{4}{3}\pi R_1^3 + N_2\frac{4}{3}\pi R_2^3 = \frac{\pi}{6}N_1 d_1^3 + \frac{\pi}{6}N_2 d_2^3. \tag{13}$$

Taking into account (13), expression (12) takes the form

$$C_1 = \frac{N_1\frac{\pi}{6}d_1^3}{V} = \frac{N_1\frac{\pi}{6}d_1^3}{N_1\frac{\pi}{6}d_1^3 + N_2\frac{\pi}{6}d_2^3} = \frac{N_1 d_1^3}{N_1 d_1^3 + N_2 d_2^3}. \tag{14}$$

Similarly with (14) for C_2

$$C_2 = \frac{N_2\frac{\pi}{6}d_2^3}{V} = \frac{N_2 d_2^3}{N_1 d_1^3 + N_2 d_2^3}. \tag{15}$$

For the sum of volumetric concentrations, the following expression is valid

$$C_1 + C_2 = 1. \tag{16}$$

Let us divide equation (13) into equation (14)

$$\frac{C_1}{C_2} = \frac{N_1 d_1^3}{N_2 d_2^3}, \tag{17}$$

or

$$C_1 = C_2\frac{N_1 d_1^3}{N_2 d_2^3}. \tag{18}$$

In this case, taking into account (15–17) and (18), the ratio of the number of particles of material 1 to the number of particles of material 2 is

$$\frac{N_1}{N_2} = \frac{C_1}{C_2}\frac{d_2^3}{d_1^3}. \tag{19}$$

Total number of particles is

$$N = N_1 + N_2. \tag{20}$$

According to expression (20),

$$\frac{N_1}{N} + \frac{N_2}{N} = 1. \tag{21}$$

Transforming (19) taking into account (20) and (21), we obtain

$$N_1 = \frac{C_1}{C_2}\frac{d_2^3}{d_1^3}N_2. \tag{22}$$

In this case, formula (20), taking into account (22), will have the form

$$N = \left(\frac{C_1}{C_2}\frac{d_2^3}{d_1^3}+1\right)N_2. \tag{23}$$

The collision probabilities are numerically presented as the ratio of the number of particles of the considered type of material to the total number of particles of the mixture of materials

$$\begin{cases} P_1 = \dfrac{N_1}{N} \\ P_2 = \dfrac{N_2}{N} \end{cases}. \tag{24}$$

In this case, taking into account (21–23), expression (24) will have the form

$$P_1 = \frac{\dfrac{C_1}{C_2}\dfrac{d_2^3}{d_1^3}}{\dfrac{C_1}{C_2}\dfrac{d_2^3}{d_1^3}+1}; \tag{25}$$

$$P_2 = \frac{1}{\dfrac{C_1}{C_2}\dfrac{d_2^3}{d_1^3}+1}. \tag{26}$$

After converting, we get

$$P_1 = \frac{C_1}{C_1 + C_2\left(\dfrac{d_1}{d_2}\right)^3}; \tag{27}$$

$$P_2 = \frac{C_2}{C_2 + C_1\left(\dfrac{d_2}{d_1}\right)^3}. \tag{28}$$

Thus, taking into account (25–28), the loss factor can be calculated by the formula

$$\xi = \frac{4.17\left(\rho_1\cdot\dfrac{C_1}{C_1+C_2\left(\dfrac{d_1}{d_2}\right)^3}\cdot k^2{d_1}^2+\right)\cdot l}{h^3} + \frac{+4.17\left(\rho_2\cdot\dfrac{C_2}{C_2+C_1\left(\dfrac{d_2}{d_1}\right)^3}\cdot k^2{d_2}^2\right)\cdot l}{h^3}. \tag{29}$$

Fig. 2 shows the dependence calculated by formula (29) for the following values of the variables: $C_1 = 0.85$; $C_2 = 0.15$; $\rho_1 = 5.8\ \mathrm{t/m^3}$; $\rho_2 = 3.3\ \mathrm{t/m^3}$; $k = 13$; $d_1 = 11$ mm; $d_2 = 8$ mm.

From the analysis of the course of the dependence in Fig. 2 it follows that an increase in the flow depth within 0.4–0.5 meters leads to a decrease in the loss factor from 0.45 to 0.2. This pattern is explained by great influence of the interaction of particles of the flow of granular material along the depth of the flow. In this regard, in the case of applying the Bernoulli equation to the description of the movement of the flow of bulk cargo in the paths of the loading devices, the degree of filling the guide elements with the charge is of paramount importance. That is, at the same instantaneous material consumption, the ratio of the average flow velocity and its geometry can have values that vary over a wide range. Among other things, the ratio of the concentrations of the components of the charge will largely affect the coefficient of internal losses of mechanical energy. Therefore, when the content of the components of the mixture of charge materials changes, all other things being equal, the dynamics of the flow and, consequently, the consumption will be different. With allowance for this, in order to ensure the specified gas dynamics of the blast furnace top zone, which depends on the flow paths, the loading system must necessarily introduce corrective actions on the control mechanisms when the content of one or another metallurgical charge component changes for a two-component mixture of charge materials at any size and concentration of its components. On frequent occasions, when considering the movement of charge materials along the elements of the loading system, it is necessary to determine the Shezy coefficient C (speed factor), which characterizes the loss of mechanical energy when the charge moves along troughs and chutes for a mixture of charge materials during their free-dispersed movement. Analyzing the known expressions for determining the Chezy coefficient [8] for a mixture with regard to (29), we can obtain the following dependence (30). To determine the specific values of the Shezy coefficient for a mixture of charge materials (for example, agglomerate and pellets), we use the expression

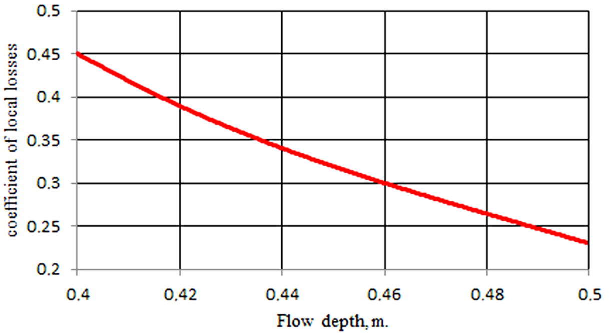

Fig. 2. Dependence of the coefficient of local losses of mechanical energy of the flow for a mixture of charge materials on the depth of the flow

$$C = \frac{2b\sqrt{\dfrac{6g\cdot h^5}{R}}}{5\sqrt{\left(\rho_1 P_1 k^2 d_1^2 + \rho_2 P_2 k^2 d_2^2\right)\left(0.8h-0.03\right)}}. \tag{30}$$

Dependence (30) is shown in Fig. 3. It should be noted that a change in the concentration of one or another compo-

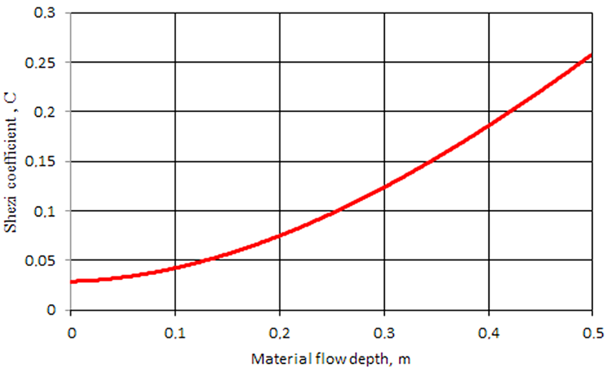

Fig. 3. Dependence of the Shezy coefficient on the flow depth during free-dispersed movement of the mixture of charge materials along the elements of the charging devices of blast furnaces

nent of the mixture of the granular flow significantly affects the behavior of the material when moving along the paths of the charging devices of blast furnaces. In this regard, when changing the charge conditions of smelting in a blast furnace, it is imperative to carry out corrective measures to ensure the required parameters of gas dynamics of the blast furnace top zone [9–12]. The synergy of innovative computational methods in combination with classical approaches [13, 14] allows obtaining reliable computational schemes that are suitable for production.

To determine the influence of the refined calculation of the CLL of the mechanical energy of the flow of charge materials on the forecast for determining the instantaneous volumetric consumption of charge materials when they are discharged from the storage hopper of the bell-less charging device of the blast furnace, the dependences shown in Fig. 4 are plotted. The dotted line shows the dependence of the instantaneous consumption of the mixture of charge materials on the value (in percent) of opening the gate gate of the storage hopper in the case of using the generally accepted method for calculating the CLL. The solid line shows the dependence of the instantaneous consumption of charge materials on the value of the slide gate opening in the case of using the above method for determining the CLL for the flow of a two-component mixture of charge materials when loading into a blast furnace.

In Fig. 4, dots show the average experimental values of the consumption of charge materials, obtained by analyzing the operation of blast furnace No. 9 ArcelorMittal Kryvyi Rih during the day. To analyze the adequacy of the curves, the method of least squares was applied in relation to graphical dependencies and point experimental values. The standard deviation with respect to the experimental data for the curve obtained on the basis of the presented materials was 0.001833, which is more than three and a half times higher than for the dashed curve obtained using known techniques.

Thus, when using the developed technique, the accuracy of predicting the instantaneous consumption of granular materials released from the storage hopper of the blast furnace bell-less charging device is significantly increased. The technique can be applied to any equipment designed for dosing and transporting granular materials.

Conclusions. It was found that the dependence of the local loss factor (LF) of mechanical energy for the flow of granular material on the depth of the material flow is quadratic, and an increase in the flow depth within the range from 0.4 to 0.5 meters leads to a change in the LF from 0.45 to 0.235. In this case, the Shezy coefficient nonlinearly increases from 0.025 to 0.25 when the depth of the material flow changes from 0.025 to 0.5 m. In this regard, the calculation of the volumetric consumption of charge materials in the regulating and guiding elements of the charging devices of blast furnaces is recommended to be carried out using the Bernoulli equation, and the Shezy coefficient to be calculated according to the method described in the work.

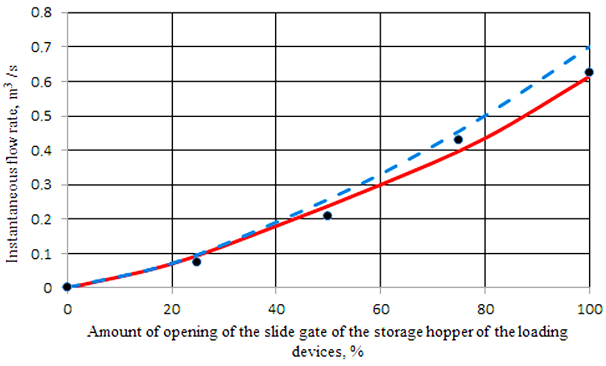

Fig. 4. Theoretical and experimental relationships:

solid line – dependence according to the developed method; dotted line – dependence according to the previously existing method; points – experimental data

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Коефіцієнт місцевих втрат механічної енергії потоку для суміші шихтових матеріалів

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Мета. Встановити залежність коефіцієнта місцевих втрат механічної енергії потоку двокомпонентної суміші шихтового матеріалу від його глибини, вмісту компонентів, середнього еквівалентного діаметра частинок у разі їх вільно-дисперсного руху.

Методика. Величину коефіцієнта місцевих втрат механічної енергії визначали за величиною гідравлічного опору рідини при її русі у відкритих каналах і трубах. У роботі використовували методи порівняльного аналізу, математичного моделювання та прогнозування динамічних процесів у потоці гранульованого матеріалу.

Результати. За результатами теоретичних досліджень отримана математична модель, використання якої дозволяє обчислювати коефіцієнт місцевих втрат механічної енергії для потоку двокомпонентної суміші шихтових матеріалів із розмірами частинок агломерату від 15 до 50 мм, окатишів від 6 до 12 мм, коксу від 10 до 60 мм. Розроблена модель із задовільною точністю дозволяє оцінити рух шихти із зазначених матеріалів по трактах завантажувальних пристроїв доменних печей зі швидкістю в межах від 1,5 до 20 м/с і визначати траєкторії потоку суміші шихтових матеріалів на колошнику з точністю до 0,2 м. Відзначено, що розрахунок зазначеного вище коефіцієнта за відомими методиками недостатньо точний, що пов'язано з невизначеністю вибору єдиного середнього еквівалентного діаметра частинок двокомпонентної шихти. Порівняльний аналіз розробленої моделі з відомими моделями та експериментальними даними свідчить про те, що точність обчислень динамічних параметрів двокомпонентного потоку шихтових матеріалів по розробленій моделі в порівнянні з розрахунками за раніше відомими моделями збільшується на 5–10 % .

Наукова новизна. Уперше встановлені закономірності зміни коефіцієнта внутрішніх механічних втрат двокомпонентного потоку шихтових матеріалів від його глибини, змісту компонентів, середніх еквівалентних діаметрів частинок при русі по трактах завантажувальних пристроїв доменних печей.

Практична значимість. Розроблені математичні залежності, що можуть бути використані для визначення технологічних параметрів завантаження сучасної доменної печі за різних характеристик гранулометрії шихти та співвідношеннях її компонентів. Це дозволить збільшити точність прогнозування ходу розглянутого процесу, ступінь автоматизації систем управління технологічним процесом шихтоподачі доменних печей, надасть можливість більш ефективно використовувати дорогі шихтові матеріали, знизити споживання енергоресурсів і шкідливий вплив на навколишнє середовище.

Ключові слова: *шихта, доменна піч, завантажувальний пристрій, енергія, суміш*

Коэффициент местных потерь механической энергии потока для смеси шихтовых материалов

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Цель. Установить зависимость коэффициента местных потерь механической энергии потока двухкомпонентной смеси шихтового материала от его глубины, содержания компонентов, среднего эквивалентного диаметра частиц в случае их свободно-дисперсного движения.

Методика. Величину коэффициента местных потерь механической энергии определяли по величине гидравлического сопротивления жидкости при ее движении в открытых каналах и трубах. В работе использовали методы сравнительного анализа, математического моделирования и прогнозирования динамических процессов в потоке гранулированного материала.

Результаты. По результатам теоретических исследований получена математическая модель, использование которой позволяет вычислять коэффициент местных потерь механической энергии для потока двухкомпонентной смеси шихтовых материалов с размерами частиц агломерата от 15 до 50 мм, окатышей от 6 до 12 мм, кокса от 10 до 60 мм. Разработанная модель с удовлетворительной точностью позволяет оценить движение шихты из указанных материалов по трактам загрузочных устройств доменных печей со скоростью в пределах от 1,5 до 20 м/с и определять траектории потока смеси шихтовых материалов на колошнике с точностью до 0,2 м. Отмечено, что расчёт указанного выше коэффициента по известным методикам недостаточно точен, что связано с неопределенностью выбора единого среднего эквивалентного диаметра частиц двухкомпонентной шихты. Сравнительный анализ разработанной модели с известными моделями и экспериментальными данными свидетельствует о том, что точность вычислений динамических параметров двухкомпонентного потока шихтовых материалов по разработанной модели по сравнению с расчетами по ранее известным моделям увеличивается на 5–10 %.

Научная новизна. Впервые установлены закономерности изменения коэффициента внутренних механических потерь двухкомпонентного потока шихтовых материалов от его глубины, содержания компонентов, средних эквивалентных диаметров частиц при движении по трактам загрузочных устройств доменных печей.

Практическая значимость. Разработаны математические зависимости, которые могут быть использованы для определения технологических параметров загрузки современной доменной печи при различных характеристиках гранулометрии шихты и соотношениях ее компонентов. Это позволит увеличить точность прогнозирования хода рассматриваемого процесса, степень автоматизации систем управления технологическим процессом шихтоподачи доменных печей, даст возможность более эффективно использовать дорогостоящие шихтовые материалы, снизить потребление энергоресурсов и вредное воздействия на окружающую среду.

Ключевые слова: *шихта, доменная печь, загрузочное устройство, энергия, смесь*

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