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AN ALGORITHM FOR INVESTIGATING THE CLOSED CYCLE ORE GRINDING TECHNOLOGICAL SCHEME

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ABSTRACT

The efficiency of the ore grinding technological process is mainly conditioned by implementation of separate operations ensuring it. The sequence of carrying out those operations is determined by the technological scheme topology used in that process. The topological scheme depending on the peculiarity of organizing the production process, characteristics of power consumption regimes can be modified. As a result, it becomes necessary to carry out the calculation of the technological scheme modified for this or that reason, the investigation and analysis of the technological situation for the new scheme. That is why, in the present work, an algorithm for investigating the scheme used in the ore grinding technological process ensuring the automated reproduction of the technological scheme topology and a successive calculation of operations included in it is proposed.

By analyzing the parameter states of the vector characterizing the properties of the input flow of the operations included in the technological scheme, the closed cycles and feedforward of the scheme have been revealed. To determine the parameter values of the circulating material, the total disagreement function has been reduced.

The proposed algorithm has been tested for a closed cycle one-phase and two-phase schemes of ore grinding. The results of the test have confirmed the truth of the developed algorithm. To implement the proposed algorithm, a program has been developed allowing to investigate and estimate the closed cycle grinding technological process for the selected technological scheme, mills of different types, classifiers, as well as in case of grinding ores of different qualities.

KEYWORDS: technological scheme, ore, grinding, algorithm, circulating parameter.

INTRODUCTION

Ore grinding is the basic process of the ore beneficiating enterprises, production of construction and chemical materials. It has an important role in increasing the labour efficiency of the mentioned production enterprises. The ore grinding technological process is characterized by interrelated successive operations, the transmission lines (topology) of the material flow obtained as a result of those operations, and the type of the technological operations carried out in the scheme units. A change in the output characteristics of each operation, as well as the transmission lines included in the grinding process leads to a change in the qualitative and quantitative properties of the ground material. Thus, it can be concluded that it is difficult to develop a generalized algorithm for investigating different schemes of the grinding process.

Few works [1-5] are devoted to the development of methods for a systematized investigation of the schemes used in the grinding technological process. These works are mainly aimed at revealing the relation between the separate technological parameters and the consumed electric power, and are expedient for separate partial investigations.

The method and algorithm (MELNIK algorithm) [6] for investigating the ore grinding process include the description of the situation, the development of the model for the situation recognition and the implementation of the management decisions. The optimization and control algorithm for the grinding process of one-phase grinding scheme is considered. The developed algorithm does not take into consideration the changes of the qualitative parameters of the circulating material. That is why, it is not expedient to use it for the complex investigation of the grinding process.

The program CL (Comminution laws) of the UniCruGr software package is for investigating the one-phase and multiphase grinding schemes. It takes into account the laws of the changes in the energetic parameters [7, 8], and calculates the power consumption of the mills by using the laws of Bond, Rittenger, and Kiki-Kirpichev for estimating the grinding power.

For the method introduced, input parameters include the topology of the grinding scheme; granulometric composition of the supplied and finished materials; the averaged value of electric power; the average productivity of the process. The calculated output data are: determination of the electric power consumed for grinding ores having different granulometric composition.

The mathematical models lying in the basis of the program CL do not take into account all the main factors influencing the amount of the consumed electric power. Besides, the power expenditures of water and pulp pumps and classifiers are neglected.

The Bond method used by O.N. Tikhonov has long been the ain method for calculating the power consumption of the ore mills in the American company Allis Chalmers [9] due to the following capacities:

- determines the power consumed at grinding in case of changing the initial data and the grinding conditions;
- determines the power expenditure under the set production conditions;
- selects the type of the mill for calculation and, based on the required productivity of the designed process, determines the power consumed by each mill;
- determines the number of the used mills according to the total consumption power.

The Bond method is expedient for mills with a diameter of up to 3,8m, that is why, to extend the possibilities of applying the latter, the company Allis Chalmers, cooperating with dozens of enterprises engaged in ore grinding, has carried out numerous activities to correct Bond's formula by comparing the laboratory and practical maintenance values of Bond's coefficient for that purpose.

The analysis of the above-mentioned works concerning the ways of investigating the ore grinding process shows that unique methods and algorithms have been developed by different scientific teams and authors. Particularly, significant experience has been gained in the spheres of studying the impacts of some parameters characterizing the operation regimes of the ore mills and the grinding technological schemes on the consumed electric power.

The known methods do not take into account the impact of the quantitative and qualitative indices of the circulating materials, the diversity of the technological process topologies, and the process randomness. Based on this, it can be stated that the development of an algorithm for a comprehensive investigation of the grinding scheme taking into consideration the quantitative and qualitative indices of the circulating materials is an urgent problem.

The main goal of the present work is to develop an algorithm for investigating the ore grinding process scheme allowing to comprehensively investigate and estimate the process for the ground material of different qualities in case of different topological schemes.

THE PROBLEM STATEMENT AND THE METHOD SUBSTANTIATION

It is known that in the ore grinding technological process, one-phase, two-phase and three-phase schemes [10] of different topological structures are used which are different by the sequence of the operations carried out. In Figure 1 grinding schemes of different topologies having gained wide application are introduced.

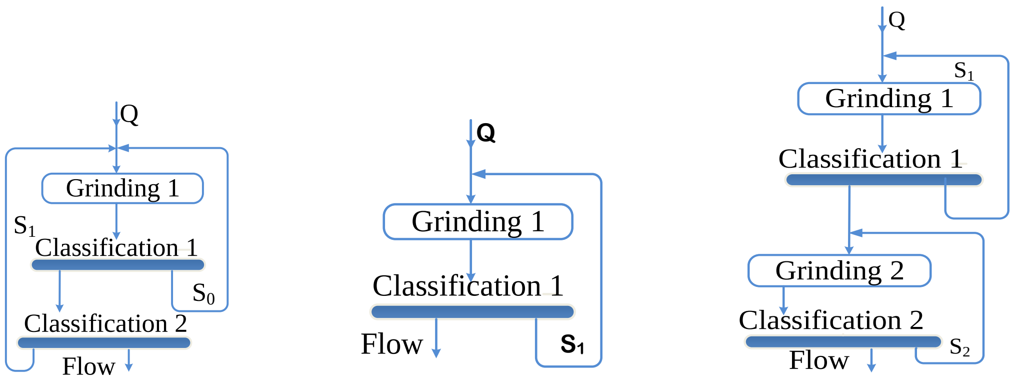

Figure 1. Grinding process schemes: a) one-phase; b) one-phase biclassifier; c) two-phase

Any scheme carrying out the grinding technological process includes a certain number of different technological devices carrying out grinding, classifying, and shipping operations characterized by peculiar operation modes.

The grinding process investigation procedure is characterized by the sequence of investigating the separate operations of the latter and the transmission of the obtained results to the next operation. The topology of the technological scheme is the main information determining the sequence of carrying out the operations. The technological scheme depending on the ore supply frequency, the peculiarity of organizing the production process, the peculiarities of power consumption regimes, the (maximum hours of consumption, limited regimes) can be modified. As a result, it is necessary to carry out a new calculation, an analysis, and technological parameter optimization of the technological scheme previously modified for some reason. That is why, in the present work, the following phases of the algorithm for investigating the scheme used in the ore grinding technological process are proposed:

- automated reproduction of the technological scheme topology;
- calculation of the operations included in the technological scheme.

AN ALGORITHM FOR REPRODUCING THE GRINDING TECHNOLOGICAL SCHEME TOPOLOGY

The present algorithm allows to automate the recognition of operations including the v technological scheme. The sequence of its implementation is as follows:

- introduction of the technological scheme connections in the form of matrix lines;
- formation of i-th group line by (i-1) group, searching by the (i-1) group for all those connections for the ℓ line whose beginning coincides with the end of the mentioned line ℓ;
- separation of the lines ending with output points and derivation as direct connections;
- derivation of the lines having similar beginnings and ends as closed circuits;
- disregard of the lines having peaks with more than two similar numbers which do not provide the initial feed;
- determination of the operation type.

By means of the obtained results, it is possible to carry out the recognition of the technological scheme topology, particularly the determination of the code corresponding to the unit, closed circuits (sections included in the cycle). After recognizing the closed cycles and operations constituting the scheme, it becomes possible to pass onto the next stage of investigation.

AN ALGORITHM FOR CALCULATING THE OPERATIONS INCLUDED IN THE TECHNOLOGICAL SCHEME

The algorithm for calculating the investigated technological scheme is introduced below. First, it is checked if the vector parameters characterizing the input flow properties of the technological operations are known.

The existence of the unknown input parameters shows that the calculated operation is in a closed cycle, and that it is applied for the first time. In that case, the table of initial estimates is used, and using the obtained output data of the given operation as input data for the next operation, the calculation for the latter is carried out. The parameter values of the circulating material obtained as a result of the calculation of all the successive operations included in the closed cycle are compared with the initial estimate values.

On the whole, the ore grinding process, regardless of the qualitative peculiarities of the ground ore, mainly includes the mixing, grinding, and classifying operations. The calculation of those operations becomes possible in the case when the whole complex of technological operations is introduced as modifications of the input flows (parameters) into the output flows.

In the general case, the dependence of the input and output flows of separate operations can be introduced by the following expression [6]:

$$Y = P(X, Z), \tag{1}$$

where Y is the vector of variables characterizing the output material; X – the vector of variables characterizing the input material; Z – the vector of the controlled and uncontrolled factors characterizing the operation studied.
The input and output flows of those operations are introduced below.

The input flow vector of the mixing operation constitutes the values of the amounts of the supplied ore and the material (sand) returning to the mill in a unit of time, the content of the hard material in them, and the content of the ore of the calculated sizes. The vector of the output constitutes the values of the amount of material obtained in the result of mixing, the content of the hard material in it, the content of the ore group of the calculated sizes.

The parameters of the vector characterizing the input flow of the ore grinding operation are: the values of the material obtained in the result of mixing in a unit of time, the content of the hard material in it, and the content of the ore of the calculated sizes. The parameters of the vector characterizing the output flow are: the values of the material obtained in the result of grinding, the content of the hard material in the mill, and the content of the ore group of different sizes obtained after grinding.

The parameters of the vector characterizing the input flow properties of the classifying operation are: the values of the amount of the classified material, the content of the hard material in it, and the content of the ore group of the calculated sizes. The parameters of the vector characterizing the output flow properties are the values of the material amounts obtained in the result of classification, the content of the hard material in them, and the content of the ore group of different sizes in the flow and sand.

AN ALGORITHM FOR DETERMINING THE PARAMETER VALUES OF THE CIRCULATING MATERIAL

To determine the parameter values of the circulating material, the total disagreement function is minimized [11]:

$$F = \left(\frac{Q_{Sji} - Q_{Sji-1}}{Q_{Sji}}\right)^2 + \left(\frac{T_{Sji} - T_{Sji-1}}{T_{Sji}}\right)^2 + \left(\frac{R_{Sji} - R_{Sji-1}}{R_{Sji}}\right)^2 \rightarrow \min_{Q_{Sj}, T_{Sj}. R_{Sj}},$$

where *i* is the number of gradual approach, j - the number of the considered closed cycle, Q_{sji} – the amount of the i-th gradual approach circulating material, T_{sji} and R_{sji} are the hardness of the circulating material of the i-th gradual approach and the content of the unfinished material respectively.

By minimizing the F efficiency function, the optimal quantities of the initial data at which the minimum difference of the circulating quantities received in the result of the initial estimate and calculation is obtained. To minimize the total disagreement function, the Nilder Mid method [12] is chosen. It gives an opportunity to ensure a high speed for reaching the optimal point by an automatic change in the optimization steps. In Figure 2. the block diagram for determining the values of the circulating material parameters is introduced.

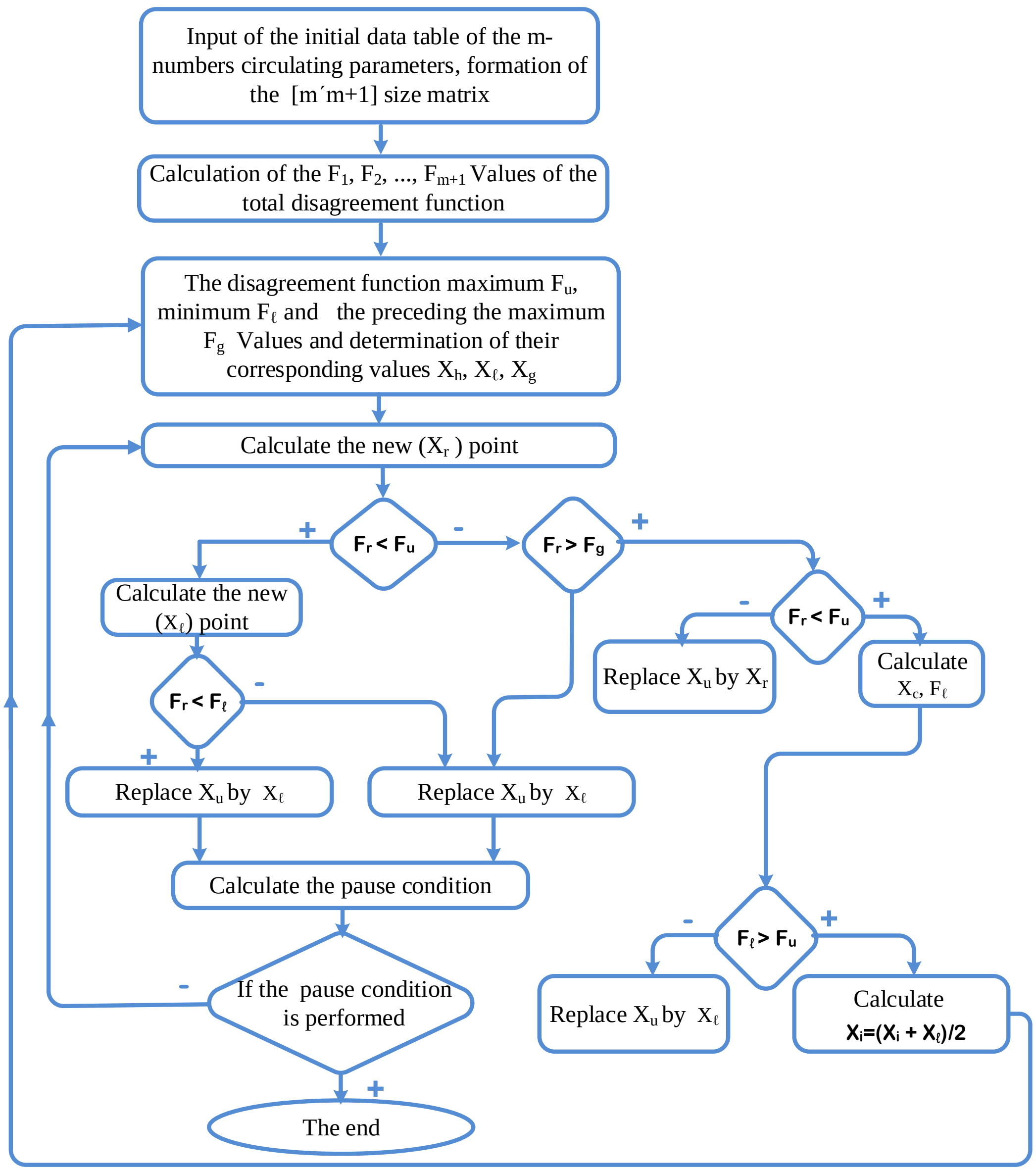

Figure 2 . Tthe block diagram for determining the values of the circulating material parameters

The correction of the parameters of the circulating material of the grinding process topological scheme is carried out by the following procedure:

1. In accordance with the initial data table, a matrix is formed the number of whose columns is equal to the number of the circulating material parameters - m, and the number of the lines - $m+1$.

$$x_{ij} = x_{0j} + h_j e_j \quad , \quad \text{where} \quad i = 1,2,\ldots,m+1 \ , \quad j = 1,2,\ldots,m$$

Here x_{oj} and h_j are respectively the quantities of the initial estimate and the change step of the j-th circulating parameter, e_j - the unit vector.

2. For each line of the formed matrix the values of the F function are calculated, the minimum and maximum values, as well as the functions with the values preceding the maximum ones and the vectors corresponding to them are separated.

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$$F_u = \max(F_i) \Rightarrow \mathbf{x_u},\ F_\ell = \min(F_i) \Rightarrow \mathbf{x}_\ell,\quad F_g \Rightarrow \mathbf{x_g}$$

To replace the line corresponding to the (Fu) function with the maximum value of the formed matrix by a new one, the following operations are performed.

3. By representing $\mathbf{x}_u$, the new $\mathbf{x}_r$ vector is obtained:

$$\mathbf{x}_r = 2\mathbf{x}_c - \mathbf{x_u}\ , \text{ where } \quad \mathbf{x}_c = \frac{1}{m}\sum_{i \neq u} \mathbf{x}_i$$

4. The incompatibility function $F(\mathbf{x}_r) = F_r$ is calculated, the F_r and F_u functions are compared:

a) if $F_r < F_\ell$, a maximally small value of the function is obtained showing that it is more convenient to move from point x_c to $\mathbf{x}_r$, and a stretch is performed in that direction changing the $\mathbf{x}_r$ vector into the $\mathbf{x}_e$ vector by the following expression:

$$\mathbf{x}_e = \gamma \mathbf{x}_r + (1-\gamma)\mathbf{x}_c\,,$$

where γ is the stretch coefficient ‡ (γ >1),

b) if $\mathrm{F_e} < \mathrm{F}_\ell$, the $\mathbf{x}_u$ vector is replaced by the $\mathbf{x}_e$ vector and the condition of the end of the parameter optimization is checked. Checking the condition of the optimization end:

$$\sqrt{\frac{\sum_{i-1}^{m}\left(F_i - \overline{F}\right)}{m}} \leq \varepsilon\,, \tag{2}$$

where ε is a selected small number, $\overline{F}$ is the mean value of F and is determined in the following way:

$$\overline{F} = \frac{1}{m+1}\sum_{i=1}^{m} F_i$$

In case the problem solution end condition is fulfilled, the process of the optimal point search is interrupted, otherwise a return to the 2nd step is performed.

c) If $F_e \geq F_\ell$, it means that the found x_e vector is not adequate and it is necessary to replace the x_u vector by the x_r vector.

d) If, in the result of comparison, it turns out that $F_r > F_\ell$ and $F_r \leq F_g$, it means that x_r is the best point and x_u is replaced by x_r.

e) If $\mathrm{F_r} > \mathrm{F}_\ell$ and $\mathrm{F_r} > \mathrm{F_g}$, a transition to the next step is performed.

5. The F_r and F_u functions are compared:

a) If $\mathrm{F_r} > \mathrm{F_u}$, the vector x_u is replaced by the x_v vector determined by the following expression:

$$\mathbf{x}_v = \beta \mathbf{x}_u + (1-\beta)\mathbf{x}_c\,,$$

where β is the compression coefficient $(0 < \beta < 1)$.

b) if the $F_r < F_u$, the x_u vector is replaced by the x_r vector, and the value of the F_u function – by F_r, compression is performed. In that case, the x_v vector is determined by the following expression:

$$\mathbf{x}_v = \beta\mathbf{x}_r + (1-\beta)\mathbf{x}_c:$$

6. The values of the F_v and F_u functions are compared:
   a) if $F_v < F_u$, the points of the vector x_u are replaced by the points of the vector x_v and the condition of optimization process pause (2) is checked.

In case the pause condition does not take place, a return to the 2nd step is carried out.

   b) if $F_v > F_u$, it means that all the attempts to find a smaller value than the value of the F_u function have failed, the vector x_i is replaced by the vector $x_i + (x_i - x_\ell)/2$. The optimization peak condition (2) is checked, and in case of the failure of the latter, a return to the initial step is performed.

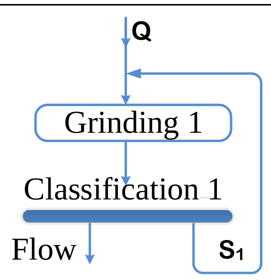
TESTING THE ALGORITHM

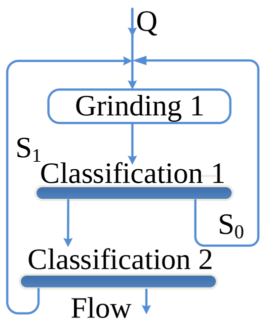
The proposed algorithm has been tested for the ore grinding one-phase and two-phase schemes.
To implement the proposed algorithm, a computer program allowing to investigate and estimate the closed cycle grinding technological process for the selected technological scheme, different types of mills and classifiers, as well as in case of grinding ore of different qualitative characteristics is developed. The program operates in the following way.

The operator selects the grinding scheme to be investigated, the type of the mills, the amount, the degree of the mill filling K, the relative velocity of rotation ψ, the bulk density of the grinding balls γ, the granulometric composition of the ground ore, and other characteristic parameters, the efficiency of the electric drives used in the process, as well as the table of the circulating parameter initial data including the amount of the circulating material, the hardness of the circulating material, and the content of the unfinished material.

After identifying the operations included in the technological scheme, the instruction "calculate" is given. During the calculation, in case of finding unknown data on the circulating material, the filled table of the initial estimate is displayed on the monitor whose data can be modified or left unchanged by the user. The user can also change the approach accuracy. After completing the correction of the circulating parameters, the question "The first cycle of the initial estimate correction is over. Should the correction be repeated?" can be read on the screen. In the case of a positive reply, the process of the circulating parameters is repeated showing the table of the regulated parameters on the screen. The regulated parameter values are used at carrying out calculations characterizing the grinding and classifying operations. In Table 1, the calculation results obtained for one-phase and two-phase grinding scheme are introduced.

Table 1. The calculation results of circulating parameters

The type of the technological scheme	Calculated parameters	Calculation data
	The amount of the circulated material	0,7858048
	The hardness of the circulated material	0,321506
	The content of the unfinished material of the circulated material	98,632024%
	The amount of the circulated material of the first phase	0,9403625

	The amount of the circulated material of the second phase	1,951382
	The content of the unfinished material of the circulated material of the first phase	86,6815024%
	The content of the unfinished material of the circulated material of the second phase	32,256145%
	The hardness of the circulated material of the first phase	0,658063
	The hardness of the circulated material of the second phase	0,678823

To check the truth of the developed algorithm, the calculation and experimental data of the closed cycle one-phase and two-phase schemes are compared.

In Figure 3 and 4, the dependences of the circulating material amount of the one-phase grinding scheme on the degree of the mill filling, the relative velocity of rotation and the bulk density of the grinding balls are introduced.

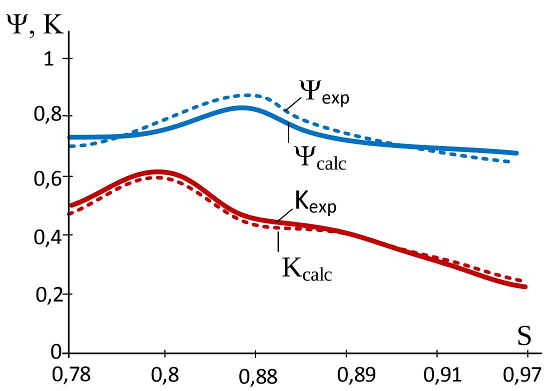


Figure 3. The dependence of the circulating material amount on the degree of the mill filling (K) and the relative velocity of rotation (ψ)

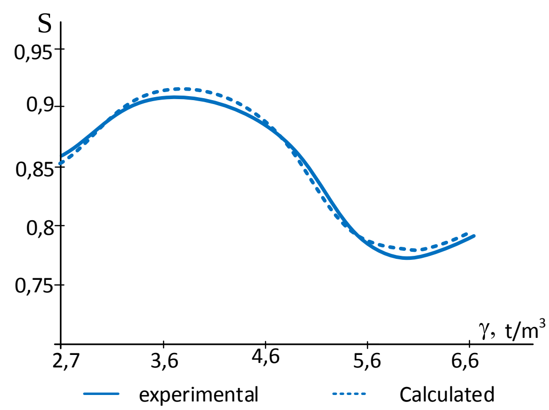


Figure 4. The dependence of the circulating material amount on the bulk density of the grinding balls (γ)

In Figure 5. The dependences of the circulating material amount of the one-phase grinding scheme and the content of the hard material in it on the density of the ground ore.

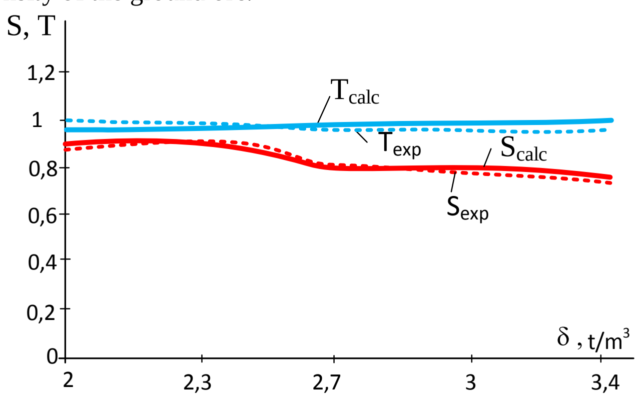


Figure 5. The dependences of the circulating material amount (S), the content of the hard material in it (T) on the specific density of the ground ore (δ).

As a parameter characterizing the circulating material amount, the part of the whole supplied ore is used which then returns to the mill in the form of sand and is determined by the following ratio:

$$S = {}^{Q_S}\!/_{Q},$$

where Q_S is the productivity of the sand-like material returning to the mill, Q - the productivity of the ore supply. In Figure 6 and 7, the dependences of the circulating material amounts of the first and second phases of the two-phase grinding scheme on the degree of the mill filling and the relative velocity of rotation are introduced respectively:

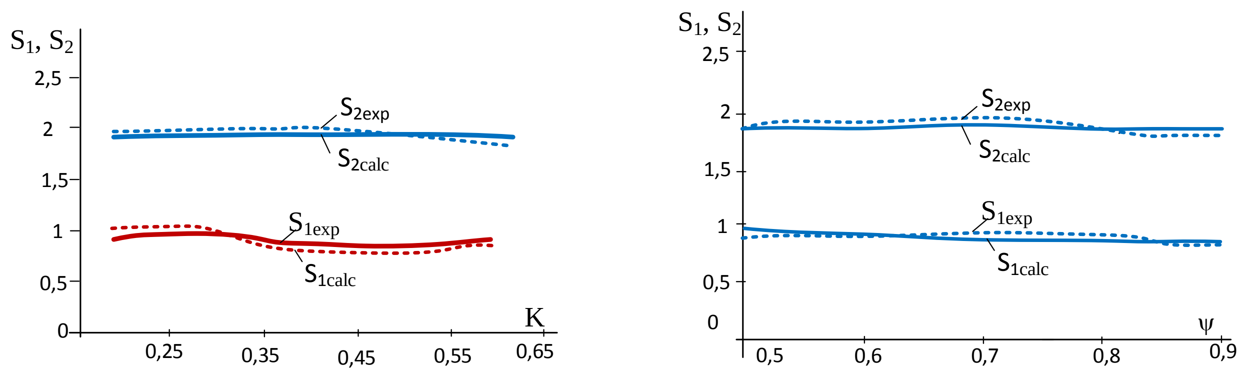


Figure 6. The dependences of the circulating material amounts (S1, S2) of the first and second phases on: the degree of the mill filling (K), b) the relative velocity of the mill rotation (ψ).

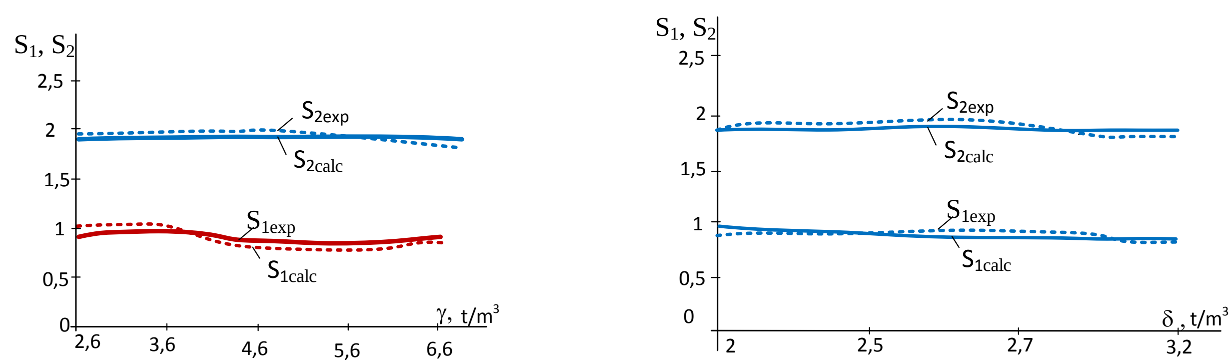


Figure 7. The dependences of the circulating material amounts (S_1, S_2) of the first and second phases on: a) the bulk density of the grinding balls γ, b) the specific density of the ground ore.

The comparative analyses of the experimental and calculation data prove that the deviation of the experimental and calculation results from each other does nor exceed 2,3%. This confirms the expedience of using the developed algorithm for the purpose of investigating different grinding technological schemes.

CONCLUSIONS

1. An algorithm for investigating the ore grinding technological process ensuring the automated reproduction of the grinding technological scheme topology, the calculation of the operations (mixing, grinding, classifying) included in the scheme and the determination of the circulating material parameter values by minimizing the disagreement efficiency function.
2. The truth of the developed algorithm has been confirmed by comparing the grinding scheme calculation data with the experimental ones. The algorithm has been tested and introduced in different enterprises for

investigating the technological state in case of situational changes in the technological process and making further decisions.

3. The developed algorithm and the program package allow to estimate the power consumption of the grinding technological process and the output material technological parameters according to the operations for the ores of different qualitative characteristics, different types of mills and classifiers, different states of their operation modes. The developed algorithm and program package have been tested and introduced in a number of enterprises and are verified by adequate statements on introduction.

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