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Rational design of low-tonnage technological complexes for fine and ultrafine grinding of materials

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Abstract. To solve the problem of obtaining superfine materials, a mathematical model of materials dispersion is proposed. The model uses the Focke-Planck equation to determine the probability density. The physical density of the probability density is interpreted as a differential characteristic of the composition of the ground material. The closure is performed using the equations of material balance and limitations that ensure the performance of low-tonnage technological complexes. Criteria for the controllability of the grinding process are proposed. These criteria take into account the random nature of the processes and the existing disturbances in the chamber of the vortex-acoustic disperser. In this case, the vortex -acoustic disperser in the working range of changing its parameters is considered as a complex physico-mechanical system. The developed mathematical model makes it possible to study the laws of the grinding process in a vortex-acoustic disperser. The model also makes it possible to find the optimal design and operational parameters of the disperser.

1. Introduction

Currently, the actual problem of obtaining high dispersion and ecologically clean materials for various industries is the creation of a new generation of energy and resource saving technologies based on controlled processes and devices. At the same time, it is necessary to create conditions for the operational reconfiguration of the technological structure and operating modes of the units in connection with the required change in load, raw materials and final product. To solve this complex problem, it is necessary to develop a fundamentally new methodology based on the use of methods of mathematical and simulation modeling, optimization, theory of guaranteed decision making under conditions of uncertainty of the initial information. Uncertainty may be due to incomplete information about the physicochemical, physicomachanical properties of substances and the physical characteristics of materials of mechanical equipment, the kinetic characteristics of technological processes at the design stage, as well as the unpredictability of changes in these parameters during production. This must be taken into account for designing low-tonnage technological complexes (LTC) to produce fine and ultrafine materials [1-2]. In addition it is necessary to ensure the high quality of the manufactured products with the highest possible level of resource saving, ecological purity and safety of production when designing new processes and devices.

2. Technological complex for producing superfine materials



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There is a traditional formulation of the problem of rational design of the physical and technological process.

A significant number of works by Russian and foreign scientists are devoted to solving problems of this type of design. The most important are iteration algorithms for two-stage design under uncertainty conditions developed by G.M. Ostrovsky and his colleagues [3].

However, it is often necessary to take into account random factors that are not identified during the operation of the complex often having a decisive influence on ensuring the optimal modes of its operation when solving problems of design of a technological complex.

As an example of designing energy- and resource-saving processes, we consider the problem of designing LTTC with a vortex-acoustic disperser (VAD) to obtain superfine materials [4-6].

The technologic scheme of the developed LTTC is shown in Figure 1.

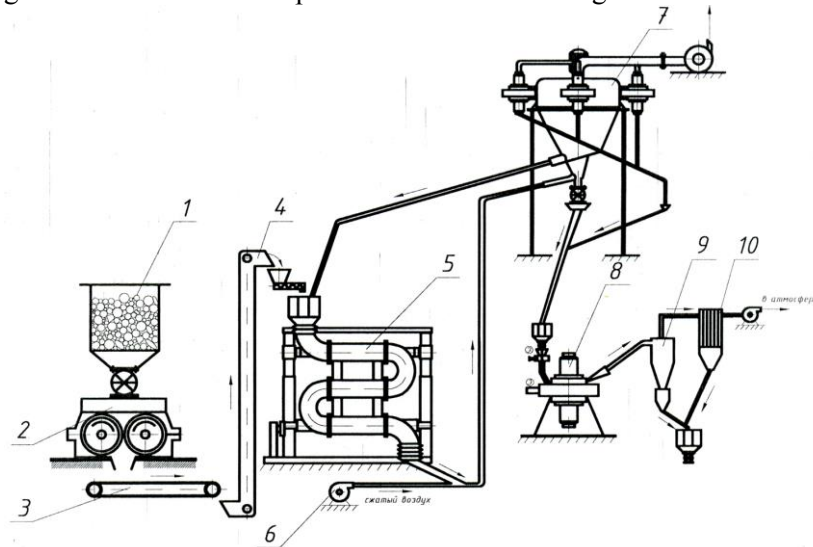


Figure 1. Operation line for production superfine materials: 1 – receiving hopper; 2 – press-roller grinder (PRG); 3 – belt feeder; 4 – elevator; 5 – centrifugal grinding and mixing unit (CGMU); 6 – fan; 7 – separator; 8 – vortex-acoustic disperser; 9 – cyclone; 10 – bag filter.

The technological process of production of fine materials includes 3 stages:

- 1st stage – stage of material pre-grinding in a press roller mill;
- 2nd stage – stage of fine grinding of the material in the vortex-acoustic disperser;
- 3rd stage – stage separation of ground polydisperse material.

The source material enters the receiving hopper 1 from where the cell feeder is fed to the press-roller grinder 2. In the PRG the material is pre-grounded to ensure its microdefect structure. Next, the material is fed with belt feeder 3 and the elevator 4 to centrifugal grinding and mixing unit 5, which is selectively grinding the pre-ground material. The ground material enters the pipeline, where it is picked up by the stream of compressed air created by the fan 6 and sent to the separator 7, where the gradual separation of the fine material into fractions takes place. After passing through the separator, the coarse fraction of the material is returned for regrinding at the CGMU, and the fine settling in the external elements is fed into the vortex-acoustic disperser 8 in which the final ultrafine regrinding of the material takes place. At the outlet of the vortex-acoustic disperser the gas flow is directed to precipitate into the cyclone 9 and the bag filter 10. The deposited material is the finished product.

Mathematical models of the dispersion process in VAD chambers are expressed by systems of nonlinear algebraic and rigid differential equations, respectively. The solid phase is considered as a polydisperse fraction of particles which is described by the density distribution of the number of particles by size in accordance with the logarithmic normal distribution law [7].

We write the generalized mathematical model of the process of dispersing materials. In the main grinding chamber Markov process is characterized by a probability density $f(d, t)$, which by its physical

meaning, can be identified with the differential characteristic of the grain composition of size d at a time point t . To determine the probability density we will use the Focker-Planck equation:

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial d} \left[-K(d) + \frac{B}{2} \frac{\partial}{\partial d} \right] f(d, t), \quad (1)$$

where the spatial coordinate is the particle size d .

B is the diffusion coefficient in the particle size space, and the transfer coefficient $K(d)$ is associated with the energy laws of grinding:

$$\partial E = -k_m d^{-m} \partial d, \quad k_m = \text{const} \quad (2)$$

($m=1.3/2.2$ for the laws of Quick, Bond and Rittinger, respectively) by the relation [3]:

$$\frac{\partial d}{\partial t} = K(d) = -\frac{1}{k_m} \frac{\partial E}{\partial t} d^m = -c_m d^m. \quad (3)$$

The material enters the main grinding chamber continuously and the outflow of the finished material occurs continuously. The degree of grinding of the finished product depends on the following variables: on the vortex, acoustic and aerodynamic characteristics of the energy carrier (air); from the mass of material in the grinding chamber; the density of the mixture of ground material; on its physical and mechanical characteristics; the initial density of the distribution, which is considered known; the duration of the grinding or the average residence time of the particles of the material in the vortex-acoustic disperser.

The above equations of mathematical models must be supplemented by equations of material balance.

Limitations that ensure the performance of low-tonnage technological complexes, the quality of the finished material, can be

$$M_{\xi}(Q) = 50 - 100, \text{ kg/hour} \\ M_{\xi}(K) \geq 95 - 98\%, \quad (4)$$

$$Bep_{\xi}(f^{ex} \in (d_{\min}, d_{\max})) \geq 0.85 - 0.95,$$

where Q – technological complex productivity, K – output of the finished product after separation,

f^{ex} – ground material distribution function, $Bep_{\xi}(\dots)$ – probability of fulfillment.

Uncertain parameters in mathematical models are the concentration, dispersion of the ground product (the parameters of the logarithmic normal distribution law), the total air flow, performance and kinetic constants of the material grinding process, vortex and acoustic characteristics of the movement of the gas-dispersed medium in the grinding chamber.

As indicators of the controllability of the grinding process, we take the criteria that take into account the random nature of the processes and the existing disturbances in the VAD chamber. One indicator is the ratio of the weighted average particle diameter (expectation) of the finished product M_2 and the source material M_1

$$K_1 = \frac{M_2}{M_1}.$$

The second indicator is the ratio of the dispersion of the ground material at the outlet of the VAD without a control system (without resonators) σ_1^2 to the dispersion of the finished product at the output at different natural frequencies of the grinding chamber resonators σ_2^2 :

$$K_2 = \frac{\sigma_1^2}{\sigma_2^2}.$$

By the value of these indicators the effectiveness of the grinding process in the selected technological scheme for obtaining superfine materials can be judged [8,9].

Figure 2 shows the implementation scheme of the above-described method of designing energy and resource-saving processes and technological systems for fine and ultrafine grinding of materials.

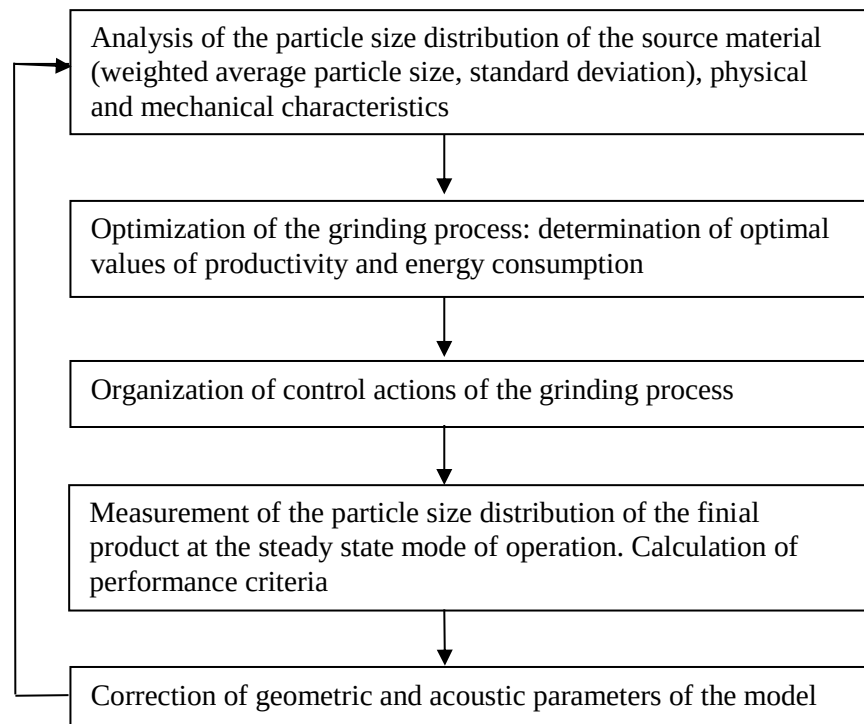


Figure 2. The scheme of implementation of the method of optimal design of energy - and resource-saving processes and complexes of fine and ultrafine grinding of materials.

Mathematical processing of experimental data on the finished product allows to obtain the parameters of the logarithmic normal distribution law, which characterize the efficiency of the grinding process in the VAD.

Graphically, this can be represented as follows (Figure 3).

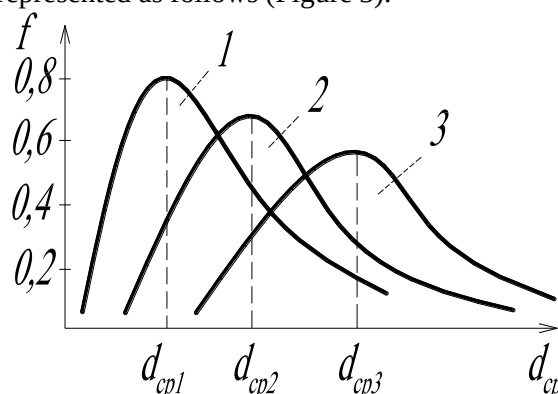


Figure 3. The distribution function of particles of ground material by size.

Analyzing the distribution function, we can conclude that the grinding process proceeds more efficiently in case 1, since there d_{cp} are fewer particles than in cases 2, 3. Granular composition of the finished product characterized by dispersion is more homogeneous.

3. Conclusion

With the help of the developed mathematical model, it is possible to study the laws of the grinding process under consideration in a vortex-acoustic disperser as a complex physicomachanical system in

the working range of changing its parameters (process modeling) and finding the optimal design-technological parameters of the VAD.

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