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INTEGRATED STUDY OF THE EFFICIENCY OF GRINDING MATERIAL IN AN IMPACT-CENTRIFUGAL MILL

Abstract. Grinding processes, which are very common and occurring in almost any industry and agriculture, require large energy costs and are associated with irretrievable losses due to wear of working units of grinders. It is generally recognized that reduction in specific energy costs is possible when using mills in which grinding will be carried out mainly due to the impact loading of a material. The results of studies of a single impact grinding of materials with various physical and mechanical properties, depending on the impact velocity and design features of a grinder in an impact-centrifugal mill, are presented. Experimental dependences of impact-centrifugal grinding are presented. Graphic dependences of the median particle mass distribution of a ground material depending on the number of blades are obtained. The number of blades for a given rotor diameter (0.4 m) was 4, 6, 8, 12 pcs. The graph shows that when grinding chalk, the number of blades does not significantly affect the quality of grinding. When grinding sylvinite and in particular gypsum stone with an increase in the number of blades to 8, the grinding fineness improves, i.e., the median particle size decreases, however, with a further increase in the number of blades, the dispersed composition of the products remains almost constant. The analysis of known data on the theory of impact grinding is given, on the basis of which the principles of creating new energy-efficient machines for grinding materials, in particular to reduce energy costs, were formed.

Key words: impact loading of a material, impact-centrifugal mill, critical fracture initiation velocity, fractional composition, particle mass distribution median.

Introduction. Grinding processes are widespread in all industries, including agriculture. The grinding process requires high energy costs and is associated with an irretrievable loss due to wear of working units of grinders. The drive power of mills in cement production is measured in thousands of kilowatts. In a number of works [1], it is noted that about 10% of the world's electricity and several million tons of high-grade steel are consumed for grinding, and even more [2-5] according to statistics from the US mining and processing industry. The high energy costs are explained not only by the large volumes of processed materials, but also by the fact that the machines used for grinding, especially for grinding, are characterized by extremely low efficiency [6].

It is generally recognized that reduction in specific energy costs [7,8] is possible when using mills in which grinding will be carried out mainly due to the impact loading of a material. It was established by experiments that the average work of grinding by impact is approximately 42% of the work of grinding by crushing. Upon impact, the compressive force arises in a certain section so quickly that a crack is formed before the equilibrium energy distribution necessary for breaking is established in the particle [9].

To reduce energy costs, optimal impact loading of the material to be ground should be ensured with minimal effort and a high degree of fracture in one working cycle, avoiding excessive overgrinding. Therefore, a very important characteristic of the impact grinding process is the critical fracture velocity ($V_{кр}$), i.e. the velocity of impact loading of the material particle at which its ensured fracture begins. This indicator ($V_{кр}$) will determine the minimum rotor velocity with hammers or blades in almost all designs of impact-centrifugal grinders. Practically all researchers working in the field of impact grinding were involved in theoretical and experimental studies to determine the critical fracture initiation velocity ($V_{кр}$). Today, a large number of mathematical dependences are known to determine $V_{кр}$, for example, the formula of Academician V.P. Goryachkin [10] and Professor G.I. Pokrovskiy [11]:

$$V_{kp} = \sqrt{\frac{E}{\rho}} \cdot \frac{\sigma_p}{E} \tag{1}$$

A different theoretical approach showed a similar dependence in collaboration with Academician of the Ukrainian Academy of Sciences V.N. Poturaev [12]; dependences proposed by V.P. Romandin [13], P.M. Sidenko [14], E. Reiners [15] do not differ significantly.

Since the critical velocity ($V_{кр}$) at which the fracturing impact begins depends, first of all, on the mechanical properties and density of a piece of material, all of the above dependences can be represented in general form:

$$V_{кр} = f(\sigma_р, E, \rho_м) \tag{2}$$

However, the experimental results for determination of $V_{кр}$ given in [10] show that the actual critical velocity is several times higher than that obtained from the theoretical dependences given in the above works.

In the works of V.A. Bauman [16], B.V. Klushantsev [17], in the formulas for determination of $V_{кр}$, the size of the initial material fed to grinding is additionally taken into account. All researchers agree that the determining factors are the mechanical properties and density of the material, however the design parameters of the grinder, which should be taken into account on the basis of experimental studies, also have a significant effect [18-22].

The dispersed composition of the material crushed by impact loading will also depend on its mechanical and physical properties, to a large extent on the velocity of impact loading and the design features of the grinder [19,20]. Therefore, specific dependences for determining the critical velocity ($V_{кр}$), as well as the dispersed composition of the grinding products should be found experimentally.

To study the process of single impact grinding, an experimental plant of the impact-centrifugal mill was used. The analysis of the fractional composition of grinding products was carried out using the method of mechanical classification (sieving) on sieves. At the first stage of experimental studies, the process of single impact grinding was studied. The studies were carried out on the experimental plant shown in figure 1.

The main unit of the plant is the impact-centrifugal mill, consisting of the cylindrical body 1 coated inside by the rods 2. The cover 3 with the bearing unit 4 and the shaft 5 in the center for rotation of the disk 6 with the blades 7 is attached to the upper part of the body. The shaft 5 is driven with V-belt transmission from the electric motor 8. The disk rotation velocity was varied over a wide range by changing the motor velocity using a high-frequency controller (inverter). The initial material for grinding in the mill was fed from the hopper 9 by the screw feeder 10. The screw was driven from the electric motor 11 through the reductor-regulator 12, which made it easy to control the amount of material fed to the mill. In addition to the material, air entered the mill through the holes 13 in the cover 3. The conical collector 14 is attached to the lower part of the mill, where the ground material is poured and periodically removed through the shutter 15 from the mill. Air from the mill was removed through the tube section 16 ending with the filter sleeve 17. The studies were carried out using the reflective rods 2 of square cross section with a side of 14 mm “option a” and a round “option b” with a diameter of 14 mm. The diameter of the working disk at the ends of the blades was 0.4 m.

As the material for the experimental studies there were used: lime granules after the furnace, with the size of $(2 - 8) \cdot 10^{-3}$ m; gypsum stone with the particle size of $(2 - 10) \cdot 10^{-3}$ m; chalk with the particle size of $(2 - 10) \cdot 10^{-3}$ m; sylvinite with the particle size of $(2 - 15) \cdot 10^{-3}$ m; ammonium sulfate crystals with the particle size of $(2 - 8) \cdot 10^{-3}$ m; grains of wheat and barley; ammophos granules with the particle size of $(2 - 5) \cdot 10^{-3}$ m; pyrolysis products of rubber products $(2 - 5) \cdot 10^{-3}$ m; oil coke $(2 - 5) \cdot 10^{-3}$ m.

After each of the experiments, the analysis was carried out according to the fractional composition of grinding products. Currently, a large number of methods and their modifications are known for determining the dispersed composition of both dusts and ground materials [22].

The simplest and sufficiently accurate method is the method of mechanical classification (sieving) on sieves. For the experimental studies of the fractional composition of grinding products, the authors used a set of standard sieves with a minimum hole size of 0.063 mm and a maximum of 4 mm.

For a graphic representation of the material's fractional composition, a distribution function $D_{(\delta)}$ is taken expressed as a percentage of the mass of all particles which diameter is less than the holes of this sieve to the total mass of the analyzed material.

The results of experimental studies of the fractional composition of products of grinding lime, chalk, gypsum stone, sylvinite, ammonium sulfate, ammophos, solid pyrolysis products of rubber products, oil coke and barley grain are shown in the graph (figure 2).

The fractional distribution curves shown in the graph were obtained at the rotor velocity of 2900 rpm, which corresponds to a tangential velocity at the ends of the blades of 60.7 m/s and an optimal loading on the initial material of 460-520 kg/h with the particle size of 3-8 mm. It can be seen from the graph that under the impact-centrifugal loading, lime granules and chalk particles are most finely ground. The high grinding degree of these materials is explained by the fact that they consist of tiny crystals, the bond between which is much weaker than the bond between crystals of other substances, for example, gypsum stone. Between the crystals of gypsum stone, the bond is stronger, as evidenced by the grinding results. The barley grains are ground much worse than all, this is due primarily to the fact that the grain is enveloped outside with several layers of a strong and elastic shell. It should be noted that of all the grain crops ground in the experimental plant (barley, rye, wheat, peas), barley was the most durable.

The graph (Fig. 3.) shows the fractional composition curves of products of grinding gypsum stone and pyrolysis products. The graph shows that with an increase in the loading, the dispersed composition of the grinding products worsens and with an increase in the loading on the mill more than 760 kg/h, the decrease in the quality of grinding is more noticeable. However, the fractional composition of the pyrolysis products varies slightly with increasing productivity. This is due to the high fragility of the material.

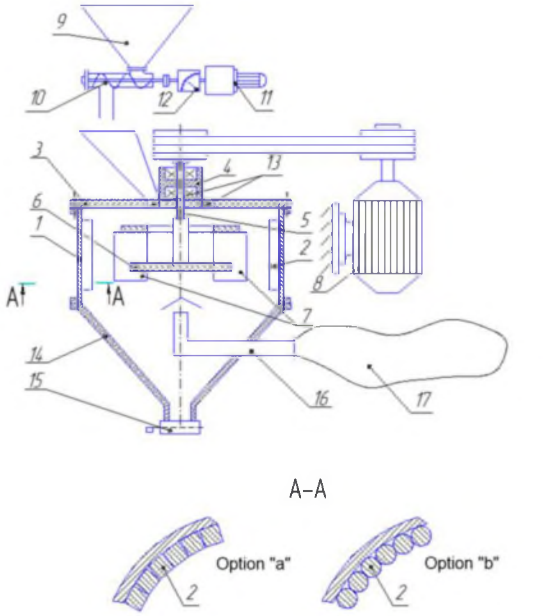

Figure 1 – Scheme of the plant for the study of impact-centrifugal mill. 1 – mill body; 2 – reflective rods; 3 – cover; 4 – bearing unit; 5 – shaft; 6 – disk; 7 – blades; 8, 11 – electric motor; 9 – hopper; 10 – feeder; 12 – reductor-regulator; 13 – holes; 14 – collector; 15 – shutter; 16 – tube section; 17 – filter sleeve

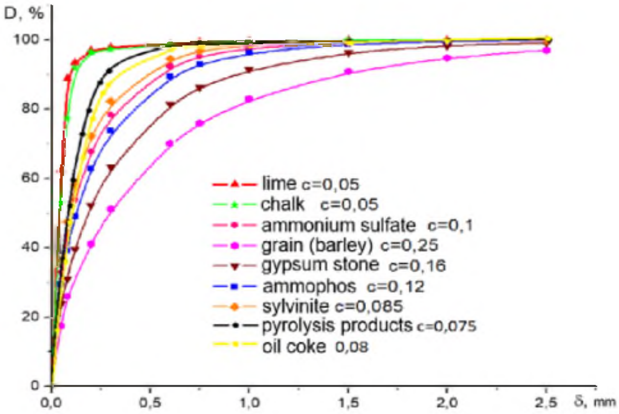

Figure 2 – Fractional composition of products of impact-centrifugal grinding of materials with various strength characteristics. G = 460-520 kg/h, n = 2900 rpm

The influence of the rotor velocity on the quality of grinding products was also carried out when grinding sylvinite, gypsum stone, grain and oil coke. The studies were carried out at the rotor velocity of 750, 940, 1450 and 2900 rpm with a loading of 480 kg/h for gypsum stone and 60 kg/h for oil coke. The results of studies presented in Figure 4 were obtained by grinding gypsum stone (curves 1-4) and oil coke (curves 5-8). The graph shows that the rotor velocity is one of the main factors determining the fineness of grinding material. In addition to the influence of the material's mechanical properties, rotor velocity and loading, geometrical parameters of impact-centrifugal grinders were studied on the quality of grinding materials.

In the course of further studies, the optimal number of rotor blades and their height were determined. Figure 5 shows graphic dependences of the median particle mass distribution of the ground material depending on the number of blades. The number of blades for a given rotor diameter (0.4 m) was 4, 6, 8, 12 pcs. The graph shows that when grinding chalk, the number of blades does not significantly affect the quality of grinding. When grinding sylvinite and in particular gypsum stone with an increase in the number of blades to 8, the grinding fineness improves, i.e., the median particle size decreases, however, with a further increase in the number of blades, the dispersed composition of the products remains almost constant. This is explained by the fact that the granules of lime and chalk have low mechanical strength, and they are ground to small particles immediately after the first impact, as for sylvinite and gypsum stone, then at the first impact the material breaks up into small and large particles. Larger particles bounce off the rods and are again thrown onto the rods. Naturally, the more blades, the more particles fall under the impact of the blades, and naturally their grinding will continue to a certain fineness.

In addition to laboratory studies on the influence of the number of blades, surveys of industrial mills with a diameter of 0.6 and 0.8 meters were carried out. Based on the results of all these studies, the recommended number of rotor blades with acceptable accuracy can be found from the known dependence recommended for determining the number of impeller blades of centrifugal fans:

$$z = 4{,}3\,\frac{j+1}{j-1} \tag{3}$$

where $j = \frac{D_2}{D_1}$; D_1 – rotor diameter along the inner edge of the blades; D_2 – rotor diameter at the ends of the blades. The value of j should be taken within j = 1.4-3.

The influence of the blades' height on the quality of grinding the material was carried out when it changed from 0.04 to 0.12 m. Sylvinite and gypsum stone were used as the ground material, the material loading was 480 kg/h, and the rotor velocity was 1450 rpm. For both materials, increasing the height of the blades from 0.04 to 0.08 meters significantly improves the grinding quality, which is shown in figure 6. However, a further increase in the height does not significantly affect the grinding quality.

It should be borne in mind that increasing the height of the blades leads to an increase in air flow through the mill, which leads to additional energy consumption for the idle mill drive. However, many researchers note [14,16] that the optimal air flow through the mill allows to cool its working elements, quickly remove ground material from the grinding zone and thereby increase the efficiency of grinding material [7].

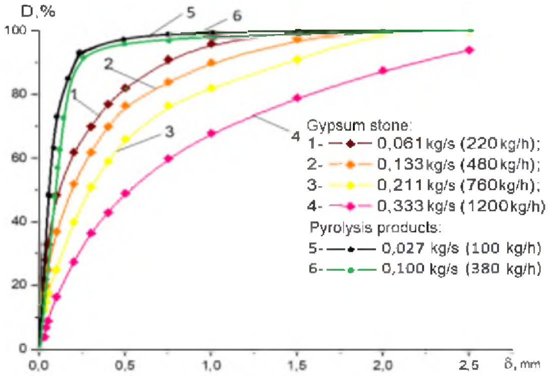

Figure 3 – Fractional composition of products of impact-centrifugal grinding of gypsum stone at various productivity n=2900 rpm

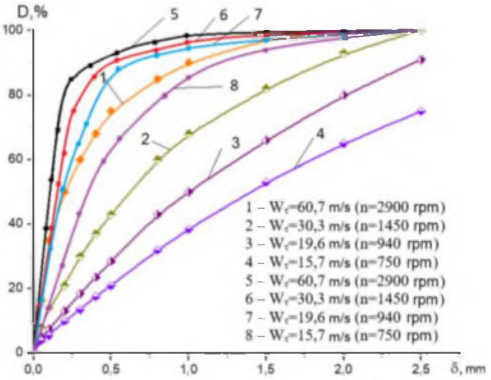

Figure 4 – Fractional composition of products of impact-centrifugal grinding of gypsum stone and oil coke at various rotor velocities

Based on laboratory studies and industrial tests, the height of the blades should be taken as:

$$h_2 = 0{,}2D_2 \tag{4}$$

The influence of the gap between the reflective rods and the ends of the rotor blades is presented in the form of a graph in figure 7 obtained when grinding grain (curve 1) and gypsum stone (curve 2). The graph shows that with an increase in the gap, the grinding quality worsens. This is explained by the fact that both materials with the rotor velocity of n=1450 rpm are difficult to grind, and numerous impacts are required to obtain a thin product. However, with an increase in the gap, the possibility of repeated contact with the blades decreases. At the same time, with a decrease in the gap, a number of negative phenomena are also observed, namely, the specific energy consumption increases and intense wear of the edges of the blades is observed. Based on laboratory tests and industrial implementation, the gap between the reflective rods and blades should be taken for small mills with a diameter of up to 0.5 meters in the range of 5-8 mm for larger mills up to 15 mm.

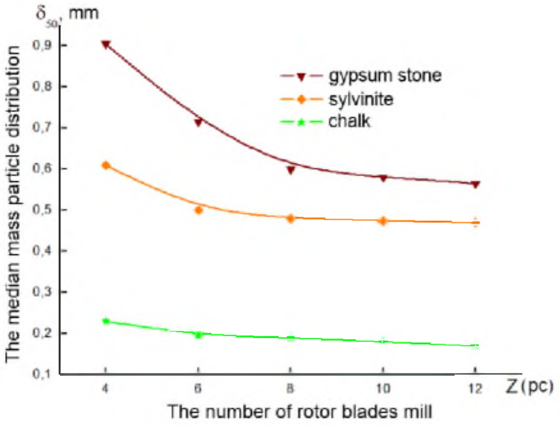

Figure 5 – Dependence of the median particle mass distribution during impact-centrifugal grinding on the number of rotor blades. G=480 kg/h, n=1450 rpm

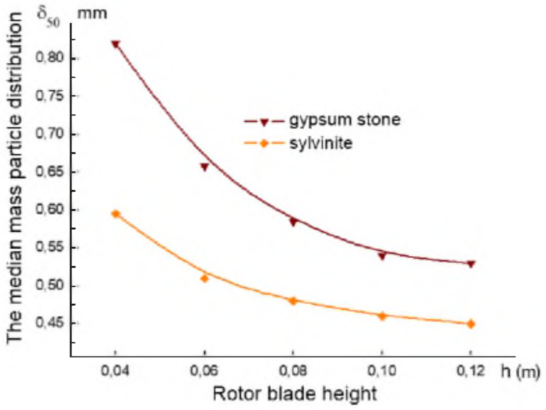

Figure 6 – Dependence of the median particle mass distribution during impact-centrifugal grinding on the blades' height. G=480 kg/h, n=1450 rpm

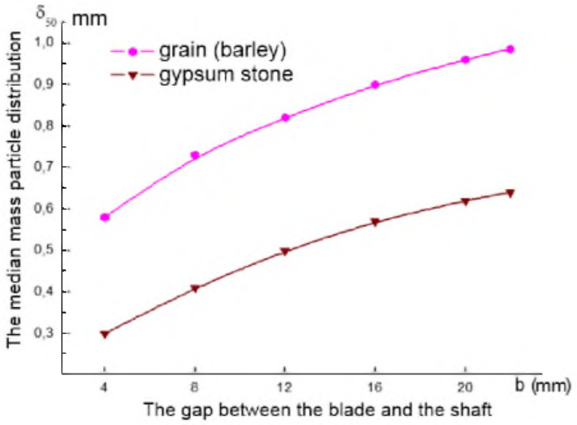

Figure 7 – Dependence of the median particle mass distribution during impact-centrifugal grinding on the size of the gap between the ends of the rotor blades and reflective rods. G=480 kg/h, n=1450 rpm

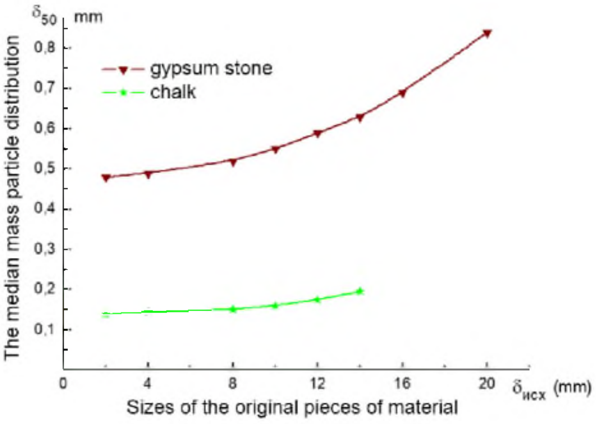

Figure 8 – Dependence of the median particle mass distribution during impact-centrifugal grinding on the size of the initial pieces of material. G=480 kg/h, n=1450 rpm

The influence of the size of the initial material pieces on the grinding quality was carried out by grinding chalk, gypsum stone and sylvinite. The results of studies are presented in the graph in figure 8. The particle size in the study varied from 2 to 20 mm.

The graph shows that when grinding chalk, which strength is not large, the particle size of the initial material has practically no effect on the grinding fineness. At the same time, sylvinite and gypsum stone, with an increase in size, are ground somewhat worse, this is due to the fact that their strength is much higher and for fine grinding of such materials it is necessary to increase the velocity of impact loading and provide conditions for multiple impact.

Most researchers [22] believe that the Rosin – Rammler equation gives the best fit of the mathematical description to the experimental data of the grinding products.

The Rosin-Rammler formula has the following form

$$R_{(\delta)} = 100 \cdot e^{-b\delta^n} \quad \text{or} \quad D_{(\delta)} = 100\,(1 - e^{-b\delta^n}) \tag{5}$$

where b and n – empirical constants.

Since the physical and mechanical properties of the material, the rotor velocity, and the mill productivity will affect the dispersed composition of the materials being ground, the Rosin-Rammler formula is somewhat modified by introducing an additional parameter δ_{50} to take these parameters into account, after which it takes the following form:

$$R_{(\delta)} = 100 \cdot e^{-b\left(\frac{\delta}{\delta_{50}}\right)^n} \quad \text{or} \quad D_{(\delta)} = 100 \cdot \left[1 - e^{-b\left(\frac{\delta}{\delta_{50}}\right)^n}\right] \tag{6}$$

where δ_{50} – particle mass distribution median, i.e., the particle size at which the mass of all particles is smaller or larger than 50%.

The influence of the material's physical and mechanical properties both on the grinding quality and on the material's critical fracture initiation velocity according to theoretical concepts should be sought in the form of the relationship:

$$\delta_{50} = k\frac{\sigma_p}{\sqrt{E \cdot \rho_м}} \tag{7}$$

The influence of the rotor velocity is most conveniently expressed through the tangential rotor velocity at the ends of the blades. Then the empirical equation for determining the median particle mass distribution will have the following form:

$$\delta_{50} = k\frac{\sigma_p}{\sqrt{E\rho_м}}V_\tau^l G^m \tag{8}$$

where k, l, m – constants determined on the basis of the experimental data shown in figures 2-4; V_τ – tangential rotor velocity at the ends of the blades, (m/s); G – productivity of the mill, (kg/s).

However, for many materials that were ground, data on the tensile strength σ_p and elastic modulus E are absent in the reference literature. P.M. Sidenko [14] explains this by the fact that there are a lot of factors influencing the mechanical strength of materials and, in the first place, on σ_p and E, and besides, they are variable. Therefore, to calculate the grinding efficiency, it is necessary to use "grinding coefficient". It is determined experimentally and its value is available in the relevant literature. Considering the above, in the formula (8), the expression taking into account the physical and mechanical properties of the material was replaced by the coefficient c, which takes into account primarily the strength properties of the material and was found on the basis of experimental data for each ground material. When processing the experimental data, the values of the exponents l and m and the coefficient k in the equation 8 were determined. Ultimately, the equation for determining the particle mass distribution median has the following form

$$\delta_{50} = 2{,}71 C V_\tau^{-1{,}42} G \tag{9}$$

The value c for the ground materials has the following value: grain (barley) C=0.25, lime and chalk C=0.05, crystals of ammonium sulfate C=0.1, ammophos C=0.12, gypsum stone C=0.16, sylvinite C=0.08, oil coke C=0.08, solid pyrolysis products of rubber products C=0.075.

When processing the experimental data, the values of the empirical constants b=0.68 and n=0.75 were determined in the Rosin-Rammler formula and then it has the final form:

$$D_{(\delta)} = 100\left[1 - e^{-0{,}68\left(\frac{\delta}{\delta_{50}}\right)^{0{,}75}}\right] \tag{10}$$

In determining the critical velocity, the fracture initiation, taking into account the data of various authors, for example [15], was taken to be the velocity when the initial material was split into pieces, the largest of which is equal to the half of the initial.

The studies were carried out on the experimental plant (figure 1). The change in the rotor velocity was controlled using a high-frequency controller. The experiments were carried out on gypsum stone, sylvinite, granules of lime and grain. The size of the initial particles was close to 6 mm. When the plant was operating with the certain rotor velocity, ten pieces of the initial material were fed to the grinding. After the grinding, the mill turned off, the shutter opened, and visual observation, as well as sieving on the laboratory sieves, determined the size of the ground material. When the maximum size of the ground particles was very close to the half of the initial, the experiments on this material were terminated.

The full material velocity was calculated by solving numerically the differential equations of particle motion in the mill rotor [22]. The processing of the experimental data showed that there is a clear relationship between the coefficient *c* and the critical velocity, which is understandable since it takes into account the strength properties of the material and then:

$$V_{кр} = 224 \cdot C \tag{11}$$

Thus, the critical velocity for the materials will be as follows: grain (barley) $V_{кр}$ = 56 m/s, ammophos $V_{кр}$ = 29 m/s, lime $V_{кр}$ = 11,2 m/s, crystals of ammonium sulfate $V_{кр}$ = 22,4 m/s, gypsum stone $V_{кр}$ = 39 m/s, sylvinite $V_{кр}$ = 19 m/s, solid pyrolysis products of rubber products $V_{кр}$ = 16.8 m/s, oil coke $V_{кр}$ = 17.92 m/s.

In addition to the mill design developed and studied by the authors, other industrial impact grinders, for example, hammer and ball industrial, have found wide application in industry. In particular, it is known that in a hammer mill no more than 17% of energy is spent on grain grinding by impact, and the rest is spent on grinding by abrasion. Therefore, when developing new mill designs, it is necessary to strive for the grinding process to be carried out mainly due to the impact, and for this purpose it is necessary to study the impact phenomenon itself.

Conclusions. 1. The experimental studies on the impact-centrifugal grinding of the materials were carried out taking into account their physical and mechanical properties, impact loading velocity, productivity and geometrical parameters of the grinder.

2. The processing of the experimental studies allowed to determine the optimal geometrical parameters of impact centrifugal grinders and, based on the Rosin-Rammler formula, obtain the mathematical dependence describing the dispersed composition of the grinding products depending on the physical and mechanical properties of the material, the impact loading velocity, and the grinder performance.

3. Based on the experimental studies and the processing of the experimental data, the mathematical dependences were obtained for calculating the productivity and the dispersed composition of the grinding products in impact-centrifugal mills.

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ЕКПІНДІ ОРТАДАН ТЕПКІШ ДИІРМЕНДЕ МАТЕРИАЛДЫ ҰСАҚТАУ ТИІМДІЛІГІН КЕШЕНДІ ЗЕРТТЕУ

Аннотация. Өнеркәсіп пен ауыл шаруашылығының кез келген саласында кең таралған ұсақтау үдерісі ірі энергетикалық шығынды талап етеді және ұсатқыш жұмыс тораптарының тозуына байланысты қайтарымсыз шығынға ұшыратады. Жалпы энергия шығыны диірменді пайдалану барысында азаюы мүмкін, онда ұсақтау негізінен материалды соққымен жүктеу есебінен жүзеге асырылады. Жұмыста екпінді ортадан тепкіш диірменді зерттеу бойынша қондырғы сұлбасы берілген. Тәжірибелік зерттеу үшін келесі материалдар пайдаланылды: пештен кейінгі әк түйіршігі, өлшемі (2-8)$\cdot 10^{-3}$ м; бөлшек өлшемі (2-10)$\cdot 10^{-3}$ м гипс тасы; бөлшек өлшемі (2-10)$\cdot 10^{-3}$ м бор; бөлшек өлшемі (2-15)$\cdot 10^{-3}$ м сильвинит; бөлшек өлшемі (2-8)$\cdot 10^{-3}$ м аммоний сульфатының кристалдары; бидай мен арпа дәні; бөлшек өлшемі (2-5)$\cdot 10^{-3}$ м аммофос түйіршіктері; бөлшек өлшемі (2-5) •10^{-3} м резеңке техникалық бұйымдардың пиролиз өнімдері (2–5) $\cdot 10^{-3}$ м; мұнай коксы соққылы жүктеу жылдамдығына және екпінді ортадан тепкіш диірменде ұсақтағыштың конструктивтік ерекшеліктеріне байланысты түрлі физикалық және механикалық қасиеттері бар материалдарды бір рет соққылы ұсақтау үдерісін зерттеу нәтижелері келтірілген. Екпінді ортадан тепкіш ұнтақтаудың тәжірибелік тәуелділігі ұсынылған. Қалақ санына байланысты ұсақталған материал бөлшектер массасының медиандық таралуының графикалық тәуелділігі алынды. Ротордың осы диаметріне арналған күрек саны (0,4 м) 4, 6, 8, 12 дананы құрады. Кестеде көрсетілгендей, бұл сәтте майдалау бор саны жауырын аса әсер етпейтін сапасы тартылған. Сильвинитті ұсақтауда және әсіресе гипс тасын қалақ санының 8 тоннаға дейін ұлғаю арқылы жақсартылады, яғни бөлшектердің мыс мөлшері азаяды, алайда қалақ санының одан әрі ұлғаюында өнімнің дисперсиялық құрамы іс жүзінде тұрақты болып қалады. Ұрмалы ұсақтау теориясы бойынша белгілі деректерге талдау жасалды, соның негізінде материалдарды ұсақтау үшін, атап айтқанда, энергия шығынын азайту үшін жаңа энерготиімді машиналарды құру принциптері қалыптасты. Жүргізілген талдау негізінде екпінді ортадан тепкіш диірменнің құрылымы әзірленді. Ұсақталатын материал ретінде сильвинит және гипс тасы пайдаланылды, материал бойынша жүктеме 480 кг/с, ротордың айналу жылдамдығы 1450 айн/мин болды. Ұсақталатын материал ретінде сильвинит және гипс тасы пайдаланылды, материал бойынша жүктеме 480 кг/с, ротордың айналу жылдамдығы 1450 айн/мин болды. Алайда ұнтақтау сапасына биіктікті одан әрі ұлғайту аса әсер етпейді.

Түйін сөздер: материалды соққымен жүктеу, екпінді ортадан тепкіш диірмен, жойылу басының күрделі жылдамдығы, фракциялық құрамындағы бөлшектер массасының таралу медианы.

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КОМПЛЕКСНОЕ ИССЛЕДОВАНИЕ ЭФФЕКТИВНОСТИ ИЗМЕЛЬЧЕНИЯ МАТЕРИАЛА В УДАРНО-ЦЕНТРОБЕЖНОЙ МЕЛЬНИЦЕ

Аннотация. Процессы измельчения, являющиеся весьма распространенными и встречающимися практически в любой отросли промышленности и сельском хозяйстве, требуют больших энергетических затрат и сопряжены с безвозвратными потерями в связи с износом рабочих узлов измельчителей. Обще- признано, что снижение удельных затрат энергии возможно при использовании мельниц, в которых измельчение будет осуществляться в основном за счет ударного нагружения материала. В работе представлена схема установки по исследованию ударно-центробежной мельницы. В качестве материала для экспериментальных исследований использовались: гранулы извести после печи, размером (2 – 8)$\cdot 10^{-3}$ м; гипсовый камень с размером частиц (2 – 10)$\cdot 10^{-3}$ м; мел с размером частиц (2 – 10)$\cdot 10^{-3}$ м; сильвинит с размером частиц (2 – 15)$\cdot 10^{-3}$ м; кристаллы сульфата аммония с размером частиц (2 – 8)$\cdot 10^{-3}$ м;зерно пшеницы и ячменя; гранулы аммофоса с размером частиц (2 – 5)$\cdot 10^{-3}$ м; продукты пиролиза резинотехнических изделий (2 – 5)$\cdot 10^{-3}$ м; нефтяной кокс Приведены результаты исследований процесса однократного ударного измельчения материалов различных физических и механических свойств в зависимости от скорости ударного нагружения и конструктивных особенностей измельчителя в ударно-центробежной мельнице. Представлены экспериментальные зависимости ударно-центробежного измельчения. Получены графические зависимости медианного распределения массы частиц измельченного материала в зависимости от числа лопаток. Число лопаток для данного диаметра ротора (0,4 м) составляло 4, 6, 8, 12 шт. Из графика видно, что при измельчении мела число лопаток не оказывает существенного влияния на качество помола. При измельчении сильвинита и в особенности гипсового камня с увеличением числа лопаток до 8 тонина помола улучшается, то есть медианный размер частиц уменьшается, однако при дальнейшем увеличении числа лопастей дисперсный состав продуктов остается практически постоянным. Дан анализ известным данным по теории ударного измельчения, на основании которых были сформированы принципы создания новых энергоэффективных машин для измельчения материалов, в частности для снижения энергозатрат. Исходя из проведенного анализа, была разработана конструкция ударно-центробежной мельницы. Влияние высоты лопаток на качество измельчения материала проводилось при ее изменении от 0,04 до 0,12 м. В качестве измельчаемого материала использовались сильвинит и гипсовый камень, нагрузка по материалу составляла 480 кг/ч, скорость вращения ротора – 1450 об/мин. Для обоих материалов увеличение высоты лопаток от 0,04 до 0,08 метра значительно улучшает качество помола, что изображено на рисунке 6. Однако дальнейшее увеличение высоты на качество помола существенного влияния не оказывает. Влияние высоты лопаток на качество измельчения материала проводилось при ее изменении от 0,04 до 0,12 м. В качестве измельчаемого материала использовались сильвинит и гипсовый камень, нагрузка по материалу составляла 480 кг/ч, скорость вращения ротора 1450 об/мин. Для обоих материалов увеличение высоты лопаток от 0,04 до 0,08 метра значительно улучшает качество помола. Однако дальнейшее увеличение высоты на качество помола существенного влияния не оказывает.

Ключевые слова: ударное нагружение материала, ударно-центробежная мельница, критическая скорость начала разрушения, фракционный состав медиана, распределение массы частиц.

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