ТОРАЙҒЫРОВ УНИВЕРСИТЕТІНІҢ
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
ТОРАЙГЫРОВ УНИВЕРСИТЕТА

ҚАЗАҚСТАН ҒЫЛЫМЫ МЕН ТЕХНИКАСЫ

2001 ЖЫЛДАН БАСТАП ШЫҒАДЫ

TORAIGHYROV UNIVERSITY

НАУКА И ТЕХНИКА КАЗАХСТАНА

ИЗДАЕТСЯ С 2001 ГОДА

ISSN 2788-8770

№ 3 (2023)

ПАВЛОДАР

НАУЧНЫЙ ЖУРНАЛ
ТОРАЙГЫРОВ УНИВЕРСИТЕТ
выходит 1 раз в квартал

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания,
информационного агенства и сетевого издания
№ KZ51VPY00036165

выдано
Министерством информации и общественного развития
Республики Казахстан

Тематическая направленность
Публикация научных исследований по широкому спектру проблем
в области металлургии, машиностроения, транспорта, строительства,
химической и нефтегазовой инженерии, производства продуктов питания

Подписной индекс – 76129

https://doi.org/10.48081/GZVJ4547

Импакт-фактор РИНЦ – 0,189

SRSTI 55.33.41

https://doi.org/10.48081/GOJT6832

Baigereyev S. R[1], Guryanov G. A[1], Suleimenov A. D[2]
[1]D. Serikbayev East Kazakhstan Technical University,
Republic of Kazakhstan, Ust-Kamenogorsk;
[2]Toraighyrov University, Republic of Kazakhstan, Pavlodar
*e-mail: samat.baigereyev@mail.ru

METHOD OF DECREASE IN ENERGY INTENSITY OF THE GRINDING PROCESS IN STIRRED MILLS

One of the most important and difficult problems related to the grinding process in a stirred mill is the high energy intensity. This article proposes a method for reducing the energy intensity of the grinding process in a stirred mill. The essence of this method bases on the organization of the radial and axial impact on the particles of the grounded material. This is achieved by the use of a new stirred mill design. While the radial action is conducted by the rotation of the ellipsoidal stirrer, the axial one is conducted by the vibrational oscillations of the chamber. The dependence of the theoretical power on the functioning parameters of the new grinder was established, and a computational experiment was carried out on the basis of this. As the investigation results showed it is possible to reduce energy consumption in a stirred mill by 20 % as a result of the use of this method.

Keywords: energy intensity, stirred mill, grinding process, power, product fineness, grinding media.

Introduction

Stirred mills are considered to be as one of the perspective alternative for traditional ball and vibrational mill. This is explained by the fact that stirring milling process can be implemeneted under high-speed mode and, consequently, under high value of grinding energy providing the fine and ultrafine product [1].

However, the fine and ultrafine process in stirred mills is characterized by high energy consumption. For example, the well-known stirred mill «IsaMill» realizes high-speed gridning process under 8000 kWt of power (stirrer speed is 1200 rpm, product fineness is 7 µm) or the stirred mill «Vertimill» consumes 3000 kWt to achieve 15 µm of product fineness.

In order to decide the problem related to considered problem the previous investigations of the energy consumption in stirred mills have been analyzed. For example, author of the work [2] presented the shear based stirred mill power model. According to the shear based stirred mill power model the mathematical dependance between power and parameters of the stirred mill has been defined. The dependance allows to determine the operational parameters of the stirred mill to achieve energy efficiency of the grinding process. In the work [3, 4, 5] the effect of the stirrer design on the power of the stirred mill has been investigated. As the results of investigations showed, while disk stirrer is characterized by low energy consumption, cross stirrer is characterized by high energy intensity. This is explained by the significant energy losses on the agitation of the grinding media by cross stirrer. However, comparing the product fineness, the use of cross stirrer allows to achieve the product with higher product fineness in comparison with the case of disk stirrer use.

As a method of decrease in the energy consumption in the stirred mills, the organization of the grinding process by action on the particles in radial and axial directions is proposed [6].

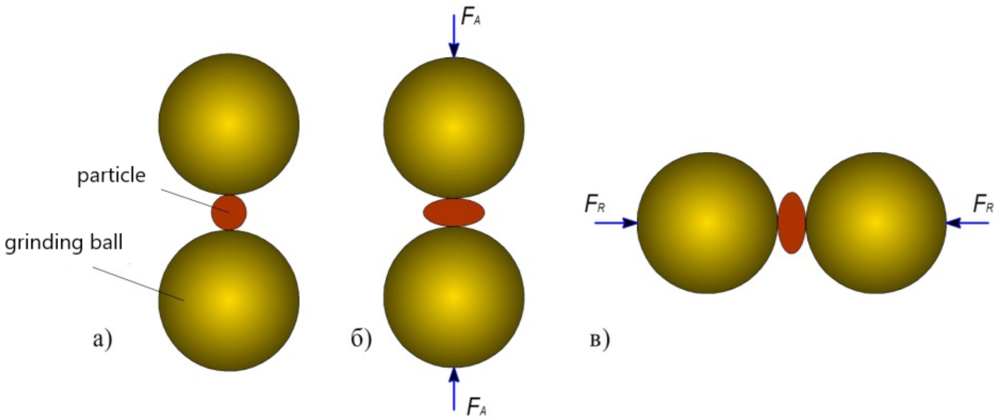

Figure 1 - The scheme of the proposed method

In order to realize this method a new design of the stirred mill has been used [7]. The radial effect on the particles of the material is conducted by an ellipsoidal stirrer, and the axial effect is conducted by vibration drive.

While the radial action is the action of the stirrer, the axial action is the action of the vibrational drive (Figure 2).

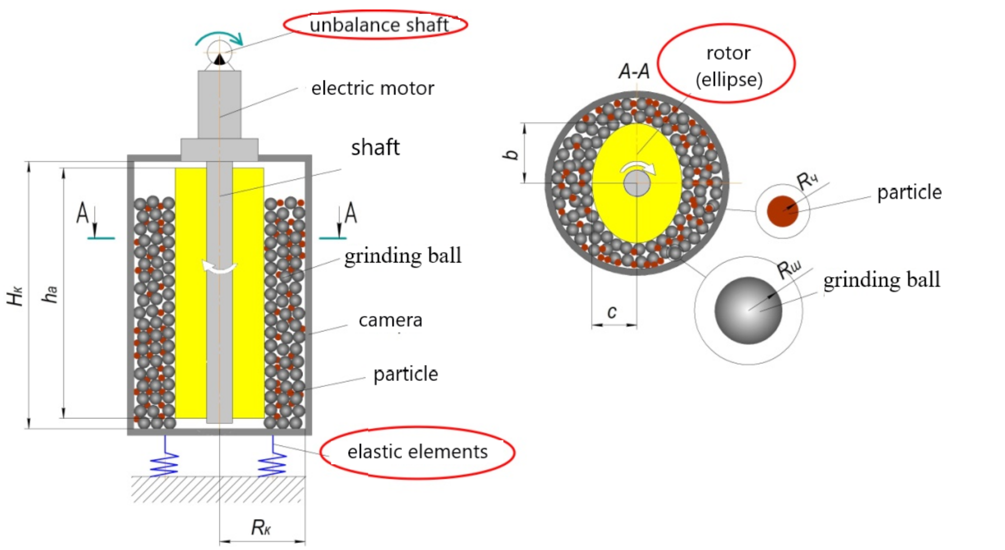

Figure 2 – The design of the stirred mill for imlementation of the proposed method

In this case, the power spending on the stirrer action is decreased due to action of the vibrational drive.

Materials and methods.

Power consumption PR in the stirred mill is carried out for the circulation of the PbR grinding balls by means of the rotation of the ellipsoidal stirrer and the process of grinding particles of the PgR material. Accordingly, the power balance equation for determining the power PR can be written as follows:

$$P_R = P_{\mathrm{bR}} + P_{gR} \tag{1}$$

The power required for circulation the grinding balls can be quantified by the following relationship:

$$P_{\mathrm{bR}} = m_{\mathrm{b}} \cdot g \cdot N_{\mathrm{b}} \cdot \frac{(b-c)\cdot n_R}{7{,}5}, \tag{2}$$

In Eq. (2), m_{b} is the mass of one grinding ball (kg), N_{b} is the number of grinding balls, b is the major semi-axis of the ellipse (mm), c is minor semi-axis of the ellipse (mm), n_R is the rotation speed of the stirrer, g is the acceleration of gravity (mm/s2).

The determination of the number of grinding balls N_{b} is performed from the condition of the degree of filling the chamber with grinding balls, taken equal to $\varphi_{\mathrm{b}} = 0{,}8$ [8]. To do this, the location of the grinding balls is simulated (Figure 3).

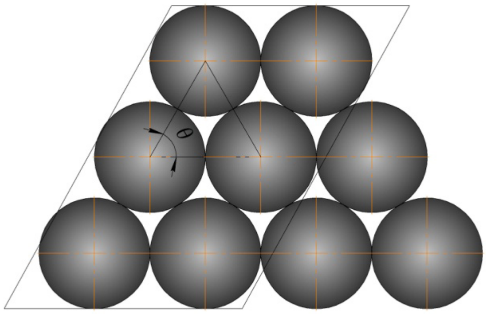

Figure 3 – Layout of the grinding balls (rhombic configuration)

As follows from Figure 3, a space (porosity) is formed between the grinding balls, the total volume of which is determined by the following formula [9]:

$$\sum V_{\mathrm{por}} = k_{\mathrm{por}} \cdot \sum V_{\mathrm{b}}, \tag{3}$$

In Eq. (3), k_{por} is the porosity coefficient (k_{por} = 0.259) corresponding to the rhombic configuration of the grinding balls (Figure 3), $\sum V_{\mathrm{b}}$ is the total volume of grinding balls (m^3).

The determination of the porosity coefficient k_{por} was made according to the Slichter formula:

$$k_{\text{por}} = 1 - \frac{\pi}{6 \cdot (1 - \cos\theta)\sqrt{1 + \cos\theta}}, \tag{4}$$

In Eq. (4), θ is the the angle of intersection of the lines connecting the centers of the grinding balls.

With a rhombic configuration of the balls,which most closely corresponds to the real layout of the grinding bodies,the angle $\theta = 60^0$because lines connecting the centers of the balls form an equilateral triangle. According to formula (4), the porosity coefficient at the value is $k_{\text{por}} = 0.259$.

The total volume of the balls is determined by the following formula:

$$\sum V_{\text{b}} = N_{\text{b}} \cdot V_{\text{b}} = 4{,}1888 \cdot N_{\text{b}} R_{\text{b}}^3, \tag{5}$$

In Eq. (5), N_b is number of grinding balls, V_b is volume of one grinding ball (mm^3) ($V_{\text{b}} = \frac{4}{3}\pi R_{\text{b}}^3$).

Taking into account Eq. (5), Eq. (3) can be written as follows:

$$\sum V_{\text{por}} = 1{,}0849 \cdot N_{\text{b}} R_{\text{b}}^3 \tag{6}$$

Taking into account Eqs. (5) and (6) the volume of filling the chamber with grinding balls $\sum V_{\text{bo}}$ with the formation of «interspherical voids» can be determined by the following formula:

$$\sum V_{\text{b}} = \sum V_{\text{b}} + \sum V_{\text{por}} = 5{,}2737 \cdot N_{\text{b}} R_{\text{b}}^3 \tag{7}$$

Taking into account the formula for determining the degree of chamber filling with grinding balls:

$$\varphi_{\text{b}} = \frac{\sum V_{\text{bo}}}{V_{\text{U}}} = \frac{5{,}2737 \cdot N_{\text{b}} R_{\text{b}}^3}{V_{\text{U}}} \tag{8}$$

In Eq. (8), V_{U} is the «useful volume» of the chamber, i.e. the space of the mill chamber with the exception of the volume occupied by the stirrer. The «useful volume» of the stirred mill chamber can be determined by the following formula:

$$V_{\text{U}} = V_{ch} - V_{\text{st}}, \tag{9}$$

In Eq. (9), V_{ch} is cylindrical chamber volume (mm^3), V_{st} is the stirrer volume (mm^3).

Taking into account the geometric shape of the mill chamber designed as a rectangular cylinder with radius R_{ch} and height H_{ch} the volume of the cylindrical chamber is determined by the following formula:

$$V_{ch} = \pi R_{ch}^2 \cdot H_{ch} \tag{10}$$

The volume of the ellipsoidal stirrer is determined by the following formula:

$$V_{st} = \pi \cdot b \cdot c \cdot h_{st}, \quad (11)$$

In Eq. (11), h_{st} is the stirrer height (mm).
Then, taking into account Eqs. (10) and (11), Eq. (9) takes the form:

$$V_U = \pi\left(R_{ch}^2 \cdot H_{ch} - b \cdot c \cdot h_{st}\right). \quad (12)$$

The dependance for calculation the number of grinding balls follows from Eq. (8) with taking into account Eq. (12):

$$N_b = \frac{\varphi_b \cdot \pi\left(R_{ch}^2 \cdot H_{ch} - b \cdot c \cdot h_{st}\right)}{5{,}2737 \cdot R_b^3}. \quad (13)$$

The total drive power of the ellipsoidal stirrer:

$$P_R = \left(\frac{3}{1-2\mu}\right)^3 \cdot (b-c) \cdot n_R \left[\frac{\beta^2 \cdot \sigma^3}{1{,}4512 \cdot \left(\frac{1}{R_b} + \frac{1}{R_p}\right)^2} + \frac{m_b \cdot N_b \cdot g}{7{,}5}\right]. \quad (14)$$

Similarly to Eq. (1), the required power of the vibration drive is determined by the formula:

$$P_A = P_{bA} + P_{grA}. \quad (15)$$

The power expended on the movement of grinding balls in the vertical direction due to the vibrational movement of the chamber is determined by the following formula:

$$P_{bA} = m_b \cdot N_b \cdot g \cdot A \cdot \varphi_A \quad (16)$$

The power expended for the operation of the mill in the axial direction:

$$P_A = \left(\frac{3}{1-2\mu}\right) \cdot \frac{m_b \cdot N_b \cdot g \cdot \beta^2 \cdot \sigma \cdot A^2 \cdot \varphi_A^2}{0.1935 \cdot \left(\frac{1}{R_b} + \frac{1}{R_p}\right)} \quad (17)$$

Therefore, the total power of the mill can be determined by summing the Eqs. (14) and (17), i.e.:

$$P = P_R + P_A. \quad (18)$$

Thus, a calculation formula for determining the theoretical power of a new design of mill has been obtained.

Results and discussion.

To evaluate the effectiveness of the proposed method for reducing energy consumption in a stirred mill, the computational experiment using a mill with the following parameters (Table 1) has been conducted.

Table 1 – The parameters of the stirred mill

Parameter	Symbol	Value
Chamber radius	R_{ch}	120 mm
Camera height	h_{ch}	100 mm
The major semi-axis of the ellipsoidal rotor	b	40 mm
The minor semi-axis of the ellipsoidal rotor	c	30 mm
Rotation speed of the unbalance	n_A	

The kinematic parameters of the stirred mill are represented by the following operating parameters which are the speed of rotation of the ellipsoidal stirrer n_R, the amplitude of the chamber oscillations A and the speed of rotation of the unbalance shaft n_A.

For a joint study of these factors on the energy consumption a multifactorial computational experiment has been conducted. The experiment consists in a theoretical calculation of the product fineness at various levels of numerical values of the speed of rotation of the ellipsoidal rotor n_R.

As a simulated material in a computational experiment, the river sand with the following physical and mechanical characteristics has been choosed (Table 2).

Table 2 – Physical and mechanical parameters of the particle material

Parameter	Symbol	Value
Ultimate tensile stress	$\sigma_{вр}$	$0{,}9\ \text{MPa}\left(\frac{\text{N}}{\text{m}^2}\right)$
Elastic modulus	E	$18000\ \text{MPa}\left(\frac{\text{N}}{\text{m}^2}\right)$
Poisson's ratio	μ	0,32

The values of ultimate tensile stress, modulus of elasticity and Poisson's ratio for a particle of river sand are selected based on reference information [10,11].

The levels of factor variation correspond to the smallest (min), average (med), and largest (max) parameter values within the selected ranges, i.e. $1000 \le n_R \le 2000$ rpm ($n_R = 1000$ rpm - min, $n_R = 1500$ rpm - med, $n_R = 2000$ rpm - max).

After the calculations, the values of the product fineness and, accordingly, the power costs were determined. The results are shown in the Table 3.

Table 3 – Results of a multifactorial computational experiment

n_R, rpm	1000	1500	2000
$d_{чRA}^{(\min)}$, µm	**4,71**	**3,1**	**2,1**
P, Wt	**950**	**1383**	**1816**

Graphical interpretation of the results of the study of the influence of the speed of rotation of the ellipsoidal stirrer on the product fineness and power is shown in Figure 4.

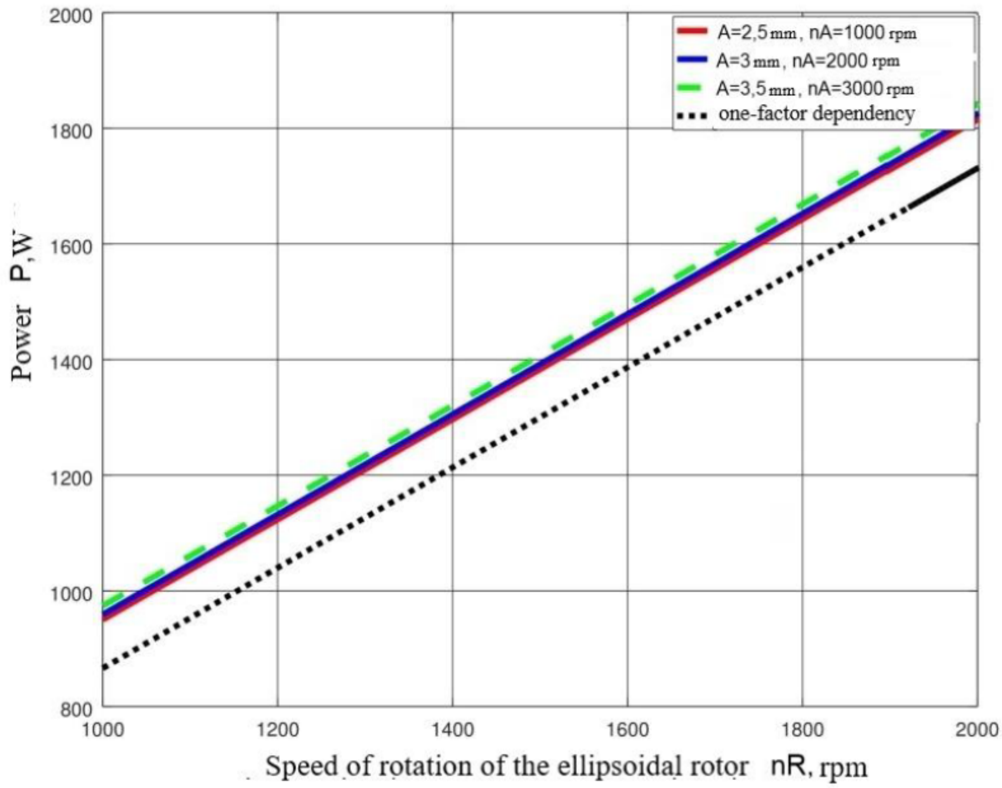

Figure 4 – The graph of dependence of mill power on the speed of rotation of the ellipsoidal stirrer

For comparison, within the specified range of ellipsoidal rotor speeds, we the one-factor dependence of the theoretical fineness of grinding and power on the speed value n_R has been determined. The calculation results are shown in Table 4.

Table 4 – The results of calculating the theoretical product fineness and power depending on the speed of rotation of the ellipsoidal rotor

n_R	1000	1500	2000
$2R_{\div R}^{(\min)}$, мкм	**11,32**	**5,03**	**2,83**
P_R, Вт	**866**	**1300**	**1732**

Thus, analyzing the values in Tables 3 and 4, it can be seen that in order to obtain a specific value of the product fineness, it is required to spent less power applying the proposed method.

Conclusion.

The grinding process in stirred mills is one of the most energy-intensive processes. As a rule, a significant power for the grinding process is expended in the process of stirring the load.

To solve this problem, a method is proposed to reduce energy consumption by acting on the particles of the material simultaneously in the radial and axial directions. To implement this method, a new design of the mill was used. The radial effect on the particles of the material is carried out by an ellipsoidal stirrer, and the axial effect is carried out by means of a vibration drive.

To evaluate the effectiveness of this method, a theoretical dependence of the power on the parameters of the mill is derived. Using this dependence a computational experiment was conducted.

Under a computational experiment a comparative analysis of the calculation of powers for radial-axial and only radial action has been conducted. The results of a comparative analysis showed the effectiveness of reducing the energy intensity of the grinding process by 20 % while achieving the same product fineness.

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1 **Sterling D., Breitung-Faes S., Kwade A.** Experimental evaluation of the energy transfer within wet operated stirred media mills / Powder Technology. – Vol 425, 2023. [Электронный ресурс]. – https://doi.org/10.1016/j.powtec.2023.118579

2 **Radziszewski P.** Shear based stirred mill power model - An adimensional analysis / Minerals Engineering. – Vol. 73, 2015. – P. 16–20.

3 **Suleimenov A. D., Mukanov R. B., Sembaev N. S., Zaripov R. Yu., Imangazinova D. B.** Innovative ball mill in road construction / Science and technology of Kazakhstan – № 2, 2021. – P. 166–172.

4 **Altyn O., Benzer H., Enderle U.** Effects of operating parameters on the efficiency of dry stirred milling / Minerals Engineering. – Vol. 43–44, 2013, P. 58–66.

5 **Altyn O., Benzer H., Enderle U.** The effects of the chambe diameter and stirrer design on dry horizontal stirred mill performance / Minerals Engineering. – Vol. 69, 2014, P. 24–28.

6 **Baigereyev S., Guryanov G.** New method for increase in product fineness in stirred mills // Archives of Civil and Mechanical Engineering. – 2019. – P. 768–778.

7 **Гурьянов Г. А., Байгереев С. Р.** Устройство для тонкого измельчения материалов. // Патент на изобретение РК №33204. МПК B02C 17/16. Опубл. 26.10.2018, Бюл.№ 40.

8 **Jayasundara C. T., Yang R. Y., Yu, J. A. B.** Rubenstein Effects of disc rotation speed and media loading on particle flow and grinding performance in a horizontal stirred mill // International Journal of Mineral Processing. – 2010. – P. 27–35.

9 **Ромм Е. С.** Структурные модели порового пространства горных пород. – Ленинград: Недра, 1985. – 240 с.

10 **Кошкин, Н. И., Ширкевич, М. Г.** Справочник по элементарной физике. – М. : Наука, 1972. – 256 с.

11 **Романенко, В. Е.** Физико-химические основы гидратационного твердения порошковых сред / В. Е. Романенков, Е. Е. Петюшик. – Минск : Беларус. навука, 2012. – 197 с.

REFERENCES

1 **Sterling D., Breitung-Faes S., Kwade A.** Experimental evaluation of the energy transfer within wet operated stirred media mills / Powder Technology. – Vol 425, 2023. [Electronic resource]. – https://doi.org/10.1016/j.powtec.2023.118579

2 **Radziszewski P.** Shear based stirred mill power model - An adimensional analysis / Minerals Engineering. – Vol. 73. – 2015, P. 16–20.

3 **Suleimenov A. D., Mukanov R. B., Sembaev N. S., Zaripov R. Yu., Imangazinova D. B.** Innovative ball mill in road construction / Science and technology of Kazakhstan – № 2, 2021. – P. 166–172.

4 **Altyn O., Benzer H., Enderle U.** Effects of operating parameters on the efficiency of dry stirred milling / Minerals Engineering. – Vol. 43–44, 2013. – P. 58–66.

5 **Altyn O., Benzer H., Enderle U.** The effects of the chambe diameter and stirrer design on dry horizontal stirred mill performance / Minerals Engineering. – Vol. 69, 2014. – P. 24-28.

6 **Baigereyev S., Guryanov G.** New method for increase in product fineness in stirred mills // Archives of Civil and Mechanical Engineering. – 2019. – P. 768–778.

7 **Gur'yanov G. A., Bajgereev S. R.** Ustrojstvo dlya tonkogo izmel'cheniya materialov [Device for fine grinding of materials] // Patent na izobretenie RK №33204. MPK B02C 17/16. Opubl. 26.10.2018, Byul.№ 40.

8 **Jayasundara C. T., Yang R. Y., Rubenstein A. B. Yu, J.** Effects of disc rotation speed and media loading on particle flow and grinding performance in a horizontal stirred mill // International Journal of Mineral Processing. – 2010. – P. 27–35.

9 **Romm, E. S.** Strukturnye modeli porovogo prostranstva gornyh porod [Structural models of the pore space of rocks] – Leningrad : Nedra, 1985. – 240 p.

10 **Koshkin, N. I., SHirkevich, M. G.** Spravochnik po elementarnoj fizike [Handbook of elementary physics.] – M. : Nauka, 1972. – 256 p.

11 **Romanenko, V. E.** Fiziko-himicheskie osnovy gidratacionnogo tverdeniya poroshkovyh sred [Physical and chemical bases of hydration hardening of powder media] / V. E. Romanenkov, E. E. Petyushik. – Minsk : Belarus. navuka, 2012. – 197 p.

Material received on 31.07.23

С. Р. Байгереев[1], Г. А. Гурьянов[2], А. Д. Сулейменов[3]
[1,2]Д. Серікбаев атындағы Шығыс Қазақстан техникалық университеті,
Қазақстан Республикасы, Өскемен қ.;
[3]Торайғыров Университеті, Қазақстан Республикасы, Павлодар қ,
Материал баспаға түсті 31.07.23

БИСЕРЛІК ҰСАҚТАҒЫШТАРДА ҰНТАҚТАУ ПРОЦЕСІНІҢ ЭНЕРГИЯ СЫЙЫМДЫЛЫҒЫН ТӨМЕНДЕТУ ӘДІСІ

Бисер ұсақтағыштың ұнтақтау процесіне байланысты ең маңызды және күрделі мәселелердің бірі – жоғары энергия сыйымдылығы. Бұл мақалада бисерлік ұсақтағыштағы ұнтақтау процесінің энергия сыйымдылығын төмендету әдісі ұсынылады. Бұл әдістің мәні ұсақталған материалдың бөлшектеріне радиалды және аксиалды әсер етуді ұйымдастыруда жатыр. Бұған жаңа бисерлік ұсақтағыштың конструкциясын пайдалану арқылы қол жеткізіледі. Радиалды әрекет эллипсоидты ротордың айналуы есебінен, ал аксиалды – камераның тербеліс қозғалысы арқылы жүзеге асырылады. Жаңа ұсақтағыштың жұмыс істеу параметрлеріне теориялық қуаттың тәуелділігі орнатылып, соның негізінде есептеу эксперименті жүргізілді. Зерттеу нәтижелері көрсеткендей, бұл әдісті қолданудың арқасында бисерлік ұсақтағыш энергия шығынын 20 %-ға азайтуға болады.

Кілтті сөздер: энергия сыйымдылығы, бисерлік ұсақтағыш, ұнтақтау үрдісі, қуат, ұнтақтау жіңішкелігі, ұнтақтау денелері.

С. Р. Байгереев[1], Г. А. Гурьянов[2], А. Д. Сулейменов[3]
[1,2]Восточно-Казахстанский технический университет
имени Д. Серикбаева, Республика Казахстан, г. Усть-Каменогорск
[3]Торайгыров Университет, Республика Казахстан, г. Павлодар
Материал поступил в редакцию 31.07.23

СПОСОБ СНИЖЕНИЯ ЭНЕРГОЕМКОСТИ ПРОЦЕССА ИЗМЕЛЬЧЕНИЯ В БИСЕРНЫХ МЕЛЬНИЦАХ

Одной из наиболее важных и сложных проблем, связанных с процессом измельчения в бисерной мельнице, является высокая энергоемкость. В данной *статье предложен метод снижения энергоемкости процесса измельчения в бисерной мельнице. Сущность данного метода заключается в организации радиального и аксиального воздействия на частицы измельчаемого материала. Это достигается за счет применения новой конструкции бисерной мельницы. Радиальное воздействие осуществляется за счет вращения эллипсоидного ротора, а аксиальное - посредством вибрационных колебаний камеры. Установлено зависимость теоретической мощности от параметров функционирования нового измельчителя и на основе этого проведен вычислительный эксперимент. Как показали результаты исследований, вследствие применения данного метода, возможно снизить энергозатраты в бисерной мельнице на 20 %.*

Ключевые слова: энергоемкость, бисерная мельница, процесс измельчения, мощность, тонкость помола, мелющие тела.

Теруге 08.09.23 ж. жіберілді. Басуға 29.09.23 ж. қол қойылды.
Электрондық баспа
5,07 Mb RAM
Шартты баспа табағы 17,61 Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген: Е. Е. Калихан
Корректор: А. Р. Омарова, Д. А. Кожас

Тапсырыс № 4133

«Toraighyrov University» баспасынан басылып шығарылған
Торайғыров университеті
140008, Павлодар қ., Ломов көш., 64, 137 каб.

«Toraighyrov University» баспасы
Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.
67-36-69

e-mail: kereku@tou.edu.kz
nitk.tou.edu.kz