FEATURES OF GRINDING AND MIXING FEED COMPONENTS IN HAMMER MILL

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Abstract. The efficiency of the process of grinding and mixing feed in hammer mills depends on various controllable factors, including the speed of the hammers, the size of the sieve holes, the density of hammers on the drum, the mass fraction of the control component, and the shape of the hammer. With the same parameters of the hammer mill and grain moisture content of different crops, products with different indicators of grinding uniformity were obtained during processing. The average particle size of the grinding products differed by 10-17%, and the uniformity of their fractional composition by 5-13%, which can be explained by their different grinding ability. In the studied interval of hammer speed (V_m = 50-80 $m \cdot s^{-1}$), the uniformity of mixing the components practically does not change and is at a sufficiently high level: P = 92-95%. With an increase in the size of the sieve holes from 4 to 6 mm, the grinding modulus M increases by 33-56%, and the coefficient of variation ν decreases by 6-22%. An increase in the girth angle from 60 to 240 degrees increases the M index by 12-25%, and the ν coefficient decreases by 20%; an increase in the density of hammers (coefficient k from 0.66 to 1.1) reduces the grinding module to 5% without changing the ν coefficient. The experimental hexagonal hammers provided an increase in the plant productivity from 6 to 24% and a decrease in specific energy consumption by 4 to 23% due to improved conditions for sifting through the sieve openings and a reduction in the time spent in the working chamber.

Keywords: grinding; mixing; cast iron powder; hammer rotor; rotational speed; feed particle size; energy consumption.

Introduction

The feed manufacturing process includes a whole range of technological and auxiliary operations. However, any technological process includes grinding and mixing operations.

The qualitative indicators of the grinding process are characterized by a high content of uniform particle size distribution at the optimal particle size of the final product, and mixing is characterized by high homogeneity of the feed mixture [1-8]. High-quality feed components have a significant impact on live weight gain, feed consumption per unit of gain, product yield, operating and reduced costs. Therefore, we need to identify the factors that influence the formation of the fractional composition of grinding products and the preparation of a homogeneous mixture from them, to investigate the possibilities of controlling the efficiency of feed processing machines, primarily hammer mills.

An analysis of the work of researchers who used hammer choppers shows that the main focus was on productivity and compliance of the resulting product with the needs of animals. These indicators are achieved by increasing the feed rate of feed components into the grinding chamber [2; 9] and the speed of the hammers and their thickness. A number of researchers have devoted their work to improving the working bodies (hammers) [10; 11], because their working surfaces wear out during operation. Under the influence of impact and friction loads, the impact faces of hammers wear out, which leads to their rounding, which causes the angles of attack in the core of the processed layer to differ significantly from the direct impact. In turn, this leads to a decrease in productivity and efficiency of grinding, increase in energy consumption, imbalance of the hammer rotor, an increase in the vibroacoustic activity of the crusher, and other negative consequences. In [10], the authors proposed a solution that involves the use of ring-shaped multi-tooth hammers, the durability of which increases by 4...5 times when using traditional materials and conventional heat treatment, eliminates the need for periodic rearrangement of hammers, and stabilizes the operation of the crusher. Thus, in [1], the main goal is to improve the technology of manufacturing hammers by casting for an impact crusher with a modified shape from an alloy containing cast iron. Both the original and the proposed hammers were tested and showed that the proposed hammers had higher crushing uniformity compared to the original ones.

To make the hammer crusher more versatile, researchers [12; 13] proposed a schematic diagram of a vibratory disc crusher that implements the idea of combined interaction of the vibratory and rotational motion of the actuator, a combination of impact and cutting effects of the working elements on the material, which will allow processing raw materials with a high moisture content.

A multipurpose hammer-type unit was proposed by scientists in [14]. The work is devoted to the study of the grinding process with simultaneous mixing. The rational rotor speed was 2880 min-1, while the grinding uniformity was in the range of 89-99% without a significant reduction in equipment throughput, ensuring timely removal of the product from the grinding zone. Rational operating modes of the crusher were also determined. Regarding the process of feed grinding, the speed of hammers is the most characteristic factor of hammer crushers [15]. However, scientific and technical information practically lacks materials on the effect of the same parameter on the quality of mixing components in the process of their simultaneous grinding.

Therefore, based on the above, our research will focus on the performance of the crusher, the optimal speed, number, shape of hammers, and the efficiency of the grinding process.

The aim of the work is to reduce energy consumption and improve the quality of feed preparation by improving the process and means of its implementation.

Materials and methods

For a particular crusher and its specific operating conditions, there is a limit to effective increase in the speed of the drum working bodies. At the optimum hammer speed, the crusher productivity is determined by the dimensions (diameter D and width L) of the crushing chamber. Given that an increase in the diameter of the chamber reduces the efficiency of the crushing process, it is more expedient to increase the productivity of the plant by increasing the width of the working chamber. In this case, the nature of the distribution of the processed material (load) over the width of the working chamber is very important. In crushers with peripheral feed, the feed material enters the working chamber relatively evenly across its entire width. It is obvious that in crushers with a central feed of raw materials, its specific value Q will decrease as it moves away from the front (along the material loading) wall of the grinding chamber.

The active working body that performs direct grinding is a hammer. The speed and direction of movement of the processed material in the working chamber largely determine the crushing (efficiency of the destructive action of the working bodies) and throughput (intensity and timeliness of sifting the product through the holes of the separation surface) capabilities of the hammer crusher, and therefore the efficiency of its technological process as a whole. Under the condition of elastic impact, the particles of the processed material do not move along the working faces of the hammers, but bounce off them. The direction of the absolute velocity of particles υ_a is determined by the ratio of its radial υ_r and normal υ_τ components and depends on the shape of the hammer (the position of its frontal face to the radius of the drum) (Fig. 1).

$$\upsilon_r = \upsilon_f \cos\psi \,, \tag{1}$$

$$\upsilon_\tau = \upsilon_a \sin\psi \,, \tag{2}$$

where ψ – angle between the direction υ_a and the radius vector ρ.

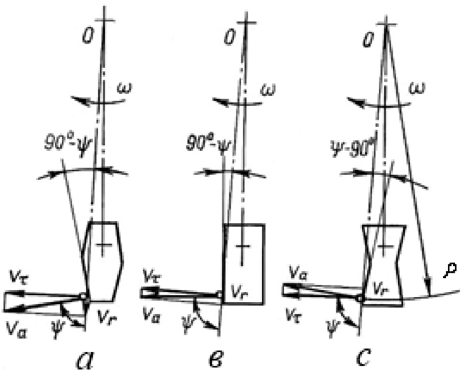


Fig. 1. **Analysis of the effect of the hammer shape on the direction of flight of a bouncing particle**

Thus, as the processed feed layer moves along the sieve surface, its particles that are in direct contact with this surface and seem to slide along it have a low probability of sifting into the off-sieve space, they are more likely to be ground or reflected into the middle of the layer. Particles that fall into the sieve holes from the middle of the layer or after bouncing off the hammers have a much higher probability of falling into the off-sieve space. In this regard, the reflection of grinding products from hammers can be ensured by choosing a rational shape and placement of the working faces of hammers to influence the value of the angle ψ, and through it, the value of the radial velocity υ_r, on which the intensity of sifting of grinding products into the off-sieve space depends. Two shapes of hammers were used for the study: rectangular and hexagonal.

One of the most important parameters of a hammer is its weight, which is consistent with the speed of its movement. The crushing effect of the hammer is determined by its kinetic energy reserve E_m:

$$E_м = \frac{M_м \upsilon_м^2}{2} \; . \qquad (3)$$

Thus, the speed of the hammers υ_m is more significant than the mass M_m, therefore, the drum speed during grinding and thus the speed of the hammers cannot be reduced.

In turn, the intensity of sifting the product by the sieve surface increases with an increase in the size of its holes d_o, their number i_o per unit area of the sieve, and the radial υ_r component of the velocity of the particles of the processed layer, and decreases with an increase in the resistance of the separation surface to sifting the product. The above parameters have a similar effect on the specific load of the crusher working chamber.

We have experimentally confirmed that for the timely removal of crushing products from the working chamber of a hammer crusher, the throughput of its separating surface should be 1.5-2 times higher than the crushing capacity of the crusher. This condition makes it possible to increase the productivity of the crusher at the outlet of the working chamber (throughput of the separating surface) and ensures timely removal of crushing products from it, contributes to improving the quality (uniformity of fractional composition, reduction of dust particles) of processed feed, and reducing energy consumption.

To implement the program of experimental research, a structural and functional diagram was developed (Fig. 2) and a unit for simultaneous grinding and mixing of grain components was manufactured.

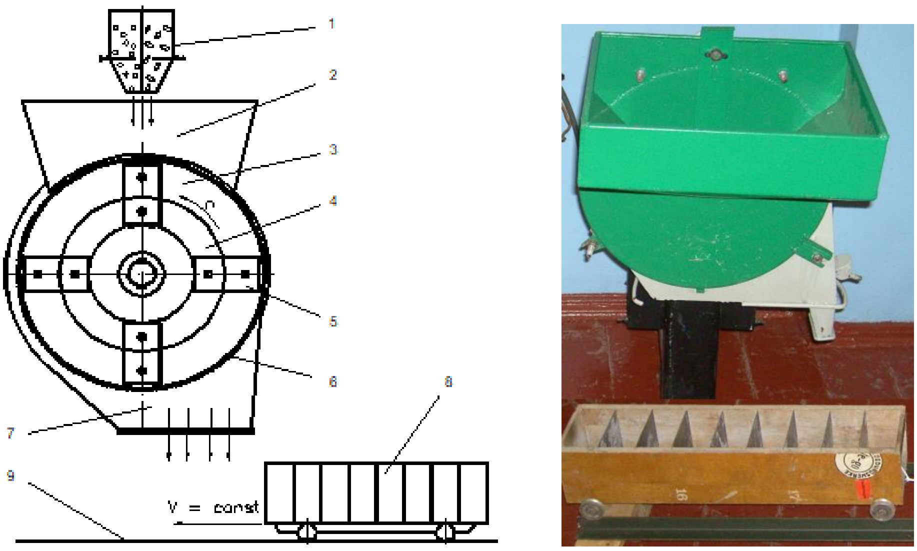


Fig. 2. **Scheme of the experimental unit:** 1 – block of gate feeders–feeders; 2 – receiving neck; 3 – grinding chamber; 4 – rotor; 5 – hammers; 6 – sieve; 7 – unloading chamber; 8 – trolley with partitions

The experimental setup (Fig. 2) allows: installing sieves with different hole diameters and changing the angle of the girth of the working chamber; changing the number of hammers on the drum with different shapes of their working faces (Fig. 3); adjusting the ratio of the main and control components;

adjusting the drum rotation frequency by using a frequency converter; taking samples of prepared feed at regular intervals. In the course of the research, electronic and parallel mechanical tachometers DT-2234C + were used to determine the drum rotation frequency, energy indicators were determined using a wattmeter AD16-22KW, rulers, squares, and tape measure was used to determine linear dimensions. The uniformity of grinding was determined using a sieve analyser.

The feedstock is fed into the crusher's intake mouth by a volume metering unit. Each of its sections has a volume proportional to the share of the corresponding component in the finished mixture and is equipped with a device for uniform dosing of the feed through an adjustable window. The component feed from each section can be adjusted independently.

To take samples of the feed at the outlet of the crusher-mixer, an electrically driven sectional trolley was used, which moves evenly on rail guides. The trolley has 8 sections separated by thin partitions. All sections are the same width (77 mm). An electric drive was used to ensure a uniform speed of movement of the trolley under the crusher discharge mouth.

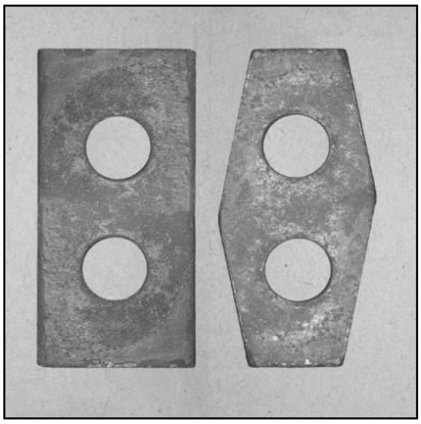
a)  b) 

Fig. 3. **Variants of the studied working bodies of the crusher-mixer:**
a – sieve; – b hammers, serial (left) and experimental (right)

The results of the experimental studies were processed by the methods of mathematical statistics and probability theory using software that allows determining the average values of the corresponding optimization criterion, standard deviations, coefficients of skewness and kurtosis, correlation coefficients between variable parameters, and regression coefficients from the initial and experimental data.

In the case of simultaneous grinding and mixing of feed ingredients, the hammer mill combines the performance of two technological operations, each of which must meet its own zootechnical requirements. Therefore, the results of the efficiency of the hammer mill in this embodiment should be evaluated in two directions:

- grinding quality (average particle size and uniformity of fractional composition) of mixtures of the initial components compared to the option of processing each component separately;
- uniformity of redistribution (mixing) of all components in the resulting feed.

To determine the homogeneity of mixing, we proposed a method that involves the use of a control component of cast iron powder with a particle size of no more than 0.5 mm. The main advantage of the proposed component is that it can be easily separated from the samples taken using a permanent magnet.

Results and discussion

In accordance with the data obtained, graphs were constructed that reflect the nature of the effect of the hammer speed on quality indicators (Figs. 4, 5, 6) and the efficiency of the process of in-line preparation of compound feed by a hammer mill. These graphs show that in the studied interval of the hammer speed (V_m = 50-80 m·s^{-1}), the uniformity of mixing of components practically does not change within insignificant limits and is at a sufficiently high level: P = 92-95%. This level fully meets the current zootechnical requirements (at least 90%). The grinding quality indicators (average product particle size or the grinding module M and uniformity of its fractional composition - estimated by the coefficient of variation ν) are most significantly affected by the speed of hammers and the size of the sieve openings, to a less extent - by the angle of their girth around the crusher working chamber, and the density of hammers on the drum almost does not change these indicators. Thus, with an increase in the size of the sieve openings by 1.5 times (from 4 to 6 mm), the grinding module M increases by 33-56%, and the coefficient of variation ν decreases by 6-22%; an increase in the girth angle from 60o to 240o (i.e. 4 times) increases the M index by 12-25%, and the coefficient ν decreases by 20% (Fig. 5); a twofold increase in the density of hammers (coefficient K_g from 0.66 to 1.1) reduces the grinding modulus to 5% without changing the coefficient v (Fig. 6). For the first time we conducted a study with simultaneous grinding and mixing of feed components in a hammer mill. The error of the experimental data was up to 2%.

In our experiments, the experimental hexagonal hammers provided an increase in plant productivity from 6 to 24% and a decrease in specific energy consumption by 4 to 23%. The lower values correspond to the variants with a sieve at a girth angle of 60° and d_o = 5 mm, and the density of hammers on the drum K_g = 0.66.

The noted efficiency of hexagonal hammers is explained by the fact that they enhance the radial components of the velocity of the particles of the grinding products, which improves the conditions for their sifting through the sieve openings and reduces the time spent in the working chamber.

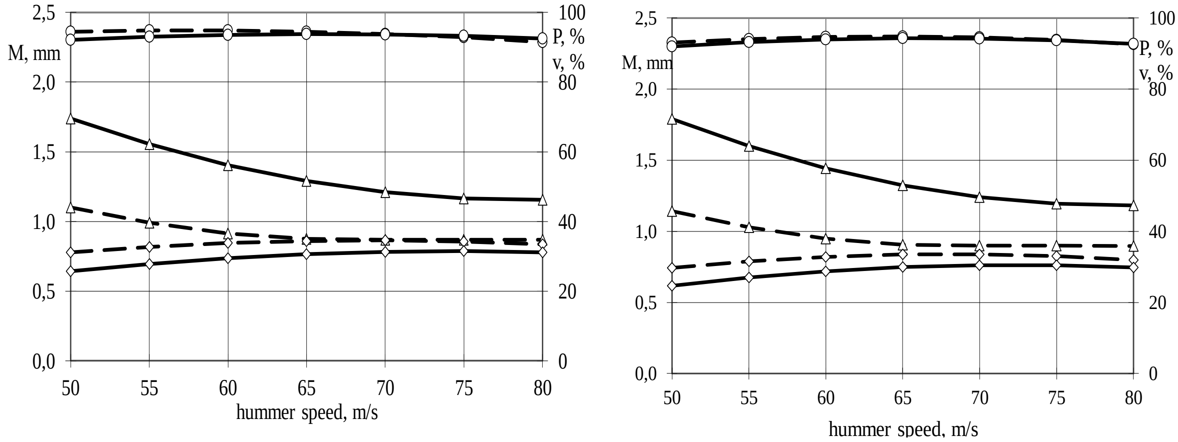


Fig. 4. **Effect of the speed of hammers of rectangular (left) and hexagonal (right) shape (K_g = 0.88) on quality indicators of the feed preparation process when using sieves with holes with a diameter of 4 mm (- - - -) and 6 mm (----) and α_p = 150°:** Δ – grinding module; ◊ – coefficient of variation of the fractional composition of the grinding products; ○ – uniformity of mixing components

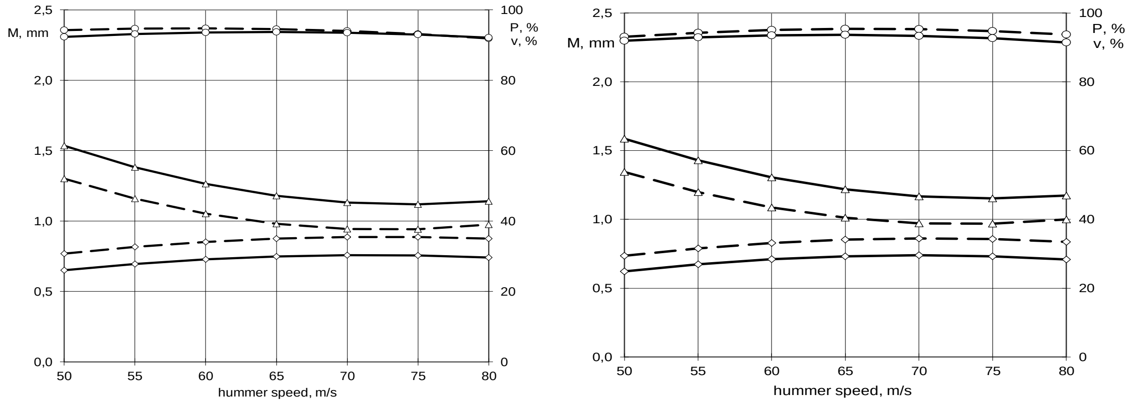


Fig. 5. **Influence of the speed of hammers of rectangular (left) and hexagonal (right) shape (K_g = 0.88) on the quality indicators of the process of feed preparation when using sieves (d_o = 5 mm) with a girth angle α_p = 60° (- - - -) and α_p = 240° (----):** Δ – grinding modulus; ◊ – coefficient of variation of the fractional composition of the grinding products; ○ – uniformity of mixing components

It should be noted that the quality indicators of feed grinding are almost unchanged compared to the use of rectangular hammers: the product size increases by only 2-4%, but the uniformity of its fractional composition improves by the same amount. The indicators of uniformity of mixing components remain practically unchanged (Fig. 4; 5; 6).

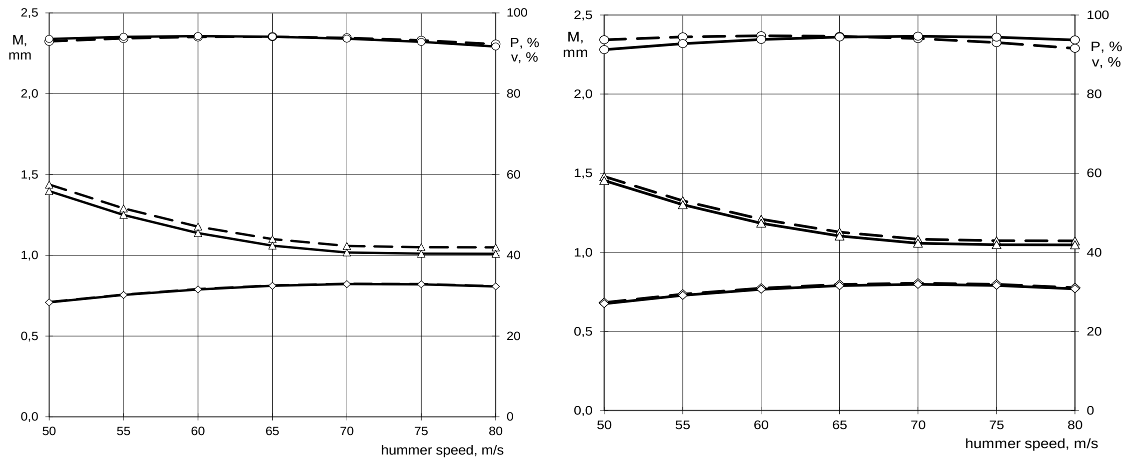


Fig. 6. **Influence of the speed of hammers of rectangular (left) and hexagonal (right) shape at the density of their placement on the drum K_g = 0.66 (- - - -) and K_g = 1.1 (----) on the quality indicators of the process of feed preparation (d_o = 5 mm and α_p = 150°):** Δ – grinding modulus; ◊ – coefficient of variation of the fractional composition of the grinding products; ○ – uniformity of mixing components

Conclusions

1. The proposed rational shape of the hammer, in the form of a symmetrical hexagon, contributes to an increase in the throughput of the sieve surface from 6 to 24% and a decrease in specific energy consumption by 4-23%. The noted efficiency of hexagonal hammers is explained by the fact that they enhance the radial velocity components of the particles of the grinding products, which improves the conditions for their sifting through the sieve openings and reduces the time spent in the working chamber.
2. The use of hexagonal hammers in comparison with rectangular hammers has shown that the quality indicators of feed grinding almost do not change, the product size increases by 2-4%, but the uniformity of its fractional composition improves by the same amount and makes it possible to improve the uniformity of mixing components.

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Author contributions

Conceptualization, methodology, V.Kh. and Yu.R.; research, V.Kh., V.R., Yu.R. and S.P.; data curation, V.Kh. and S.P.; original writing, Yu.R., V.R.; reviewing and revising, V.R. and S.P. All authors have read and agreed with the published version of the manuscript.

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