Investigation of the process of shredding coniferous sawdust in a crusher with a two-way material supply system

A A Zykin
Polytechnic Institute, Vyatka state university, Moskovskaya street, 36, Kirov 610000, Russian Federation

E-mail: zykin.andrey@mail.ru

Abstract. Russia is one of the main countries in the extraction and processing of forest resources. Waste from wood processing is still one of the cheapest energy sources. Therefore Russia is actively developing and introducing technologies for processing waste from the forest industry. The technology for producing fuel pellets and briquettes is widespread. One of the operations of this technology is the preliminary grinding of the feedstock. Nowadays, traditional hammer mills are used for this, which are used in the feed industry. As a result of the analysis of the designs of such crushers, it was revealed that when grinding materials with a low specific gravity, their potential is not fully utilized. A hypothesis has been put forward that an increase in the productivity of hammer crushers when grinding materials with a low specific gravity is possible due to a change in the conditions for introducing raw materials. To test this hypothesis, a crusher with two feed necks and a vortex chamber was developed. Research has been carried out to study the influence of the conditions for entering the shredded material into the crushing chamber. The performance of the crusher is determined with three ways of feeding the shredded material.

1. Introduction
Russia is one of the main countries in the extraction and processing of forest resources. Waste generated from wood processing is still one of the cheapest energy sources, despite the ethical problems arising from this [1]. Waste generation is observed at all stages of logging and timber processing [2]. In this case, the amount of waste can reach 39% [3]. Therefore, at present, Russia is actively developing and introducing technologies for processing waste from the forest industry. In particular, the technology for producing fuel pellets and briquettes is widespread. One of the operations of this technology is the preliminary grinding of the feedstock to the required size [4]. Today, manufacturers offer to use traditional hammer crushers for crushing wood waste, which are used in the feed industry [5, 6, 7, 8, 9]. In this case, the supply of material can be carried out both forcibly and with an air flow [10, 11, 12, 13].

As a result of the analysis of the designs of such crushers and observation of their working process, it was revealed that when grinding materials with a low specific gravity (in particular sawdust), their potential is not fully utilized. A hypothesis has been put forward that an increase in the productivity of hammer crushers when grinding materials with a low specific gravity is possible due to a change in the conditions for introducing raw materials. To test the hypothesis put forward, a crusher was developed with two feed necks located in different directions and tangentially relative to the end surface of the crushing chamber, and a vortex chamber located in the collision zone of the flows of shredded material coming from multidirectional necks [14]. The aim of the work is to evaluate the working process of a
crusher with a modernized material supply system for milling materials with a low specific gravity in terms of energy efficiency.

2. Materials and Methods

The general view of the developed crusher is shown in figure 1. The main elements of the crusher are a fan, a rotor and a sieve (figure 2).

![Figure 1](image1.png)

**Figure 1.** General view of the hammer crusher: *a* – with installed boot pipes and removed cover; *b* – with installed cover and without boot pipes.

![Figure 2](image2.png)

**Figure 2.** The main elements of the crusher: *a* – fan; *b* – hammer rotor; *c* – sieve.

In hammer crushers, operating according to the classical way, the source material enters the crushing chamber by an air flow, which is created by a fan and a hammer rotor, and moves along a sieve [15, 16, 17, 18]. The speed of particles of the shredded material is 30–50% of the linear speed of the rotor hammers [19]. Thus, the speed of collision of the working bodies and particles of the shredded material will be equal to the difference in the speeds of particles and working bodies. Consequently, the design of the crusher, in which the movement of the feed material coincides in the direction with the movement of the working bodies, does not provide effective crushing of the source material.

In the developed crusher, the boot necks 2 and 3, located in different directions and tangentially relative to the end surface of the crushing chamber 5, change the direction of the air-product flow in the grinding zone (Figure 3). The initial material entering the crushing chamber with an air flow through multidirectional necks has mismatched particle velocity vectors in the area of flow contact. This causes a decrease in the speed of particles in the area of action of the working bodies, increasing the relative...
speed of collision of the shredded material. This will increase the grinding efficiency. In this case, the residence time of the particles of the starting material in the grinding zone will increase. This will extend the exposure time of the working bodies to the shredded material and increase the uniformity of the particle size distribution. The vortex chamber 7, located in the zone of contact between the flows of the shredded material, will enhance the effect created by the multidirectional necks, reduce the speed of movement of the shredded material in the grinding zone and increase the time of action of the working bodies.

The crusher (figure 3) works as follows. Grindable material as a result of the vacuum created by the hammer rotor 6 and the fan 4 is fed through the main boot neck 3 and the auxiliary boot neck 2 in the material boot zone to the crushing chamber 5. Two streams of material collide and mutually decelerate due to their multidirectionality and the action exerted on the flows by the vortex chamber 7. The formed air-product layer due to the rotation of the hammer rotor 6 moves along the sieve 9 and slows down, colliding with the air coming from the boot necks 2 and 3 product flow. This leads to an increase in the relative speed of collision of working bodies and particles and, accordingly, to an intensification of grinding, an increase in the productivity of the crusher, as well as an increase in the quality of the finished product. After the material is crushed to the desired particle size, controlled by the diameter of the openings of the sieve 9, it is removed from the crushing chamber 5 through the discharge neck 8.

Figure 3. Structural and technological diagram of a hammer mill: 1 – cover; 2, 3 – main and auxiliary boot necks; 4 – fan; 5 – crushing chamber; 6 – hammer rotor; 7 – vortex chamber; 8 – discharge neck; 9 – sieve; 10 – case; - - - - - - - - direction of movement of the shredding material; - - - - - - direction of movement of the shredded material; - - - - direction of spin of the rotor.

The influence of the conditions for entering the shredded material into the crushing chamber was investigated. Determined the performance indicator of the crusher with three ways of feeding the shredded material: 1 - through the main boot neck; 2 - through the auxiliary boot neck; 3 - simultaneous boot through the main and auxiliary boot necks. To carry out the research, the boot nozzles were made with the ability to install, remove and change their places (Figure 1).

The work of the crusher was evaluated according to the following criteria: $y_1$ – capacity; $y_2$ – the weighted average particle size of the crushed material; $y_3$ – the degree of grinding; $y_4$ – power consumption; $y_5$ – specific energy consumption. Coniferous sawdust was used as a starting material. The weighted average sawdust particle size was 31.25 mm. Sawdust moisture is 7.5%. The experiments were carried out at an air temperature of $+23^\circ$ C. The power consumed by the crusher's electric motor was fixed by a system consisting of a «CICUTOR» CVMk-2 and power quality analyzer and a control panel. Samples of the finished product were scattered on a laboratory sieve shaker LR-3 and weighed
on a laboratory balance VNM-3/30 and VKT-500. Grinding time was recorded with an SDS-pr1 stopwatch. Drying of samples with material in determining its moisture content was carried out in a KVS-G16 / 250 drying cabinet.

Specific electricity costs were determined by the expression:

\[ q = \frac{P}{Q}, \]  
\[ (1) \]

where \( q \) – unit power consumption, kWh / t; \( P \) – power consumption of the electric motor, kW; \( Q \) – crusher throughput, t / h.

When determining the throughput, samples of the shredded product were taken for a given period of time in the steady operating mode of the crusher. Next, the throughput of the crusher was calculated using the formula:

\[ Q = 3.6 \frac{G}{T}, \]  
\[ (2) \]

where \( G \) – is the mass of the sample, kg; \( T \) – sampling time, s.

Grinding degree is determined by the formula:

\[ \lambda = \frac{D}{d}, \]  
\[ (3) \]

where \( D \) – the equivalent particle diameter, mm; \( d \) – the weighted average particle size of the finished product (grinding modulus), mm.

Before each experiment, a control measurement of humidity was carried out. Samples for determining moisture content were taken in accordance with the well-known technique [20, 21]. The moisture content was determined by thermal drying of the samples in an oven. The moisture content was determined by the formula:

\[ W = \frac{m_i - m_i^*}{m_i} \times 100\%, \]  
\[ (4) \]

where \( m_i \) – weight of material before drying, kg; \( m_i^* \) – weight of material after drying, kg.

To obtain objective results, a sample for analysis was selected so that it was possible to estimate the parameters of the entire batch of material from it. For this purpose, the average sample was taken in at least 5 different places in each batch of the finished product. Materials from each cavity were thoroughly mixed to obtain an average sample, while the presence of impurities was monitored. About 0.2 kg of the product was taken from the mixed mass in at least 5 different places and placed in a polyethylene bag provided with a label. The selection of the starting material was carried out in a similar way.

The granulometric composition of the starting material and the finished product was determined in triplicate by sifting 0.1 kg of each average sample taken on a classifier [20, 21]. The weighted average particle size was calculated by the expression:

\[ L = \frac{\sum_{i=1}^{n} D_i M_i}{\sum M_i}, \]  
\[ (5) \]

where \( D_i \) – average particle size in \( i \)-group, mm; \( M_i \) – particle mass in \( i \)-group, kg; \( \Sigma M_i \) – sample weight, kg.

3. Results and discussion

The research results are presented in the form of diagrams (figure 4).
Figure 4. Influence of the conditions of feeding the crushed material on: \(a\) – productivity of the crusher; \(b\) – the weighted average size of the finished product; \(c\) – the degree of grinding of the material; \(d\) – power consumption of the crusher electric motor; \(e\) – specific energy consumption; 1 – material supply through the main boot neck; 2 – material feeding through the auxiliary boot neck; 3 – simultaneous feeding of material through the main and auxiliary boot neck.

The analysis of the results obtained shows that the maximum throughput is achieved with the simultaneous supply of material through both boot necks and is 441 kg/h (figure 4 a). Thus, the shredding intensity in the crusher with material feeding according to the third scheme is 110% higher than when using the second material feeding scheme and 19% higher than in comparison with the first material feeding scheme.

The weighted average particle size of the finished product is practically the same (the discrepancy is 6%) and varies from 3.71 to 3.95 mm (figure 4 b). The weighted average particle size allowed for granulation should not exceed 4.5 mm [22]. That is, the resulting product meets the requirements for it.

Grinding degree ranged from 8.42 to 7.91 (figure 4 c). Consequently, one cannot speak of the advantage of any investigated constructive scheme over another in this parameter.

The maximum power consumption was 6.98 kW when feeding material according to the third scheme, and the minimum 4.91 kW when feeding material according to the second scheme (figure 4 d). Since the installed power of the crusher electric motor was 7.5 kW, it can be concluded that it is advisable
to use the third scheme of material feeding.

A more objective picture is provided by the indicator characterizing the unit costs of electricity (figure 4 e). The smallest value, equal to 15.83 kWh / t, is observed when the material is fed according to the third scheme. When feeding material according to the second scheme, the highest specific energy consumption is observed. Their value is 23.38 kWh / t.

Thus, in terms of the totality of all parameters, the best performance indicators are provided by the scheme of simultaneous loading of the crushed material through the main and auxiliary boot necks.

4. Conclusion
The studies carried out have shown a clear advantage of the scheme of simultaneous supply of the shredded material through the main and auxiliary boot necks with the installation of a vortex chamber between them. In this case, the maximum productivity of the crusher is 441 kg / h, the power consumption is 6.98 kW, and the specific energy consumption is 15.83 kW h / t.

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