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# ДОСЛІДЖУВАННЯ ВПЛИВУ ПАРАМЕТРІВ СИТОВОЇ СИСТЕМИ БАРАБАННИХ ПОДРІБНЮВАЧІВ ДЕРЕВИНИ НА ФРАКЦІЙНІСТЬ ТЕХНОЛОГІЙНИХ ТРІСОК

***Установлено закономірність змінювання величини відсотка некондиційної фракції в загальній масі технологійних трісок залежно від параметрів ситової системи барабанних подрібнювачів деревини. Одержано рівняння регресії, за допомогою якого можна розрахувати відсоток некондиційної фракції з урахуванням кількості секцій східчастого сита, величини радіусної відстані між ситом і барабаном та вологості деревини. Установлено раціональні параметри ситової системи барабанних подрібнювачів деревини.***

***Ключові слова:*** *барабанний подрібнювач деревини, ситова система, технологійні тріски, східчасте сито, кількість секцій.*

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# INVESTIGATION OF THE INFLUENCE OF THE SCREEN SYSTEM PARAMETERS OF DRUM WOOD CHIPPERS ON THE FRACTIONAL COMPOSITION OF INDUSTRIAL WOOD CHIPS

***A pattern has been established in the variation of the percentage of substandard fraction of wood chips in the total mass of industrial chips depending on the parameters of the screen system of drum wood chippers. A regression equation was obtained, which can be used to calculate the percentage of substandard fraction, taking into account the number of sections of the stepped screen, the radial distance between the screen and the drum, and the moisture content of the wood. Optimal parameters for the screen system of drum wood chippers have been established.***

***Keywords:*** *drum wood chipper, screen system, industrial chips, stepped screen, number of sections.*

## Problem formulation

Improving the efficiency of wood chipping is a pressing task for the woodworking and bioenergy industries due to growing demands for uniformity in the fractional composition of wood chips and energy efficiency in technological processes. In drum wood chippers designed to produce wood chips for fuel pellets, significant losses in productivity and energy consumption are caused by the irrational kinematics of chip particles movement on a smooth cylindrical screen, which results in a large percentage of the chips produced being of substandard size (over 6 mm) and requiring additional chipping (rechipping).

Therefore, improving the design of the screen by giving it a stepped geometry, which changes the conditions for transporting and sorting chips, is an urgent scientific and practical task.

The formation of a homogeneous fractional composition of industrial chips with the lowest possible percentage of substandard fraction in their total mass is a determining factor in the energy and resource efficiency of wood chipping and the effectiveness of the subsequent use of chips. In drum chippers, the conditions for separating particles in the product discharge zone play a significant role, which to a certain extent depend on the design features of the screen surface and its spatial arrangement relative to the chipping drum.

The use of a stepped screen changes the nature of the interaction between chip particles and the working surface, the conditions of their retention within the zone of chipping, and the likelihood of repeated chipping, which directly affects the ratio of standard to substandard fractions.

At the same time, the magnitude of the radial distance between the screen and the drum (the distance between the inner radius of the screen surface and the radius of the working surface of the drum) determines the duration of the chips' staying in the working zone, the intensity of the mechanical impact of the structural components on the wood particles, and the probability of the chips passing through the screen surface. Despite the practical significance of these parameters, their complex influence on the process of forming the fractional composition of industrial chips remains insufficiently substantiated, which necessitates systematic experimental investigation of this issue.

## Reviewing the latest studies and publications.

One of the relatively few experimental studies in this field was published in the journal Forests (MDPI) [1], which provides a detailed analysis of the distribution of wood particle sizes depending on the size of the drum chipper screen. The results showed that smaller screen sizes significantly increase the proportion of fine fractions (less than 10 mm) in the total output, while larger screens increase the proportion of medium and large fractions (over 45 mm). This is due to the fact that increasing the size of the screen reduces the time that chips remain in the chipping zone, which reduces the probability of them being further chipped. For example, when the screen size is reduced from 80 mm to 40 mm, the proportion of fine fractions increases significantly, while the proportion of fractions between 45 and 63 mm decreases or is completely absent.

Currently, all wood chippers [2–4] employ a plate screen of cylindrical shape to sort wood chips, this screen being positioned at a specified distance from the working surface of the drum. An analysis of these technical reviews shows that the design of drum chippers, including the condition of the blades and the presence of a screen, affects the quality (dimensional uniformity) of the chips. Currently, there are no studies on the impact of a stepped screen on the fractionation of industrial chips.

Also, there are no studies on the effect of the radial distance between the screen and the drum in drum-type wood chippers on the fractionation of chips. In existing works, including [1–4], this parameter is considered only indirectly in the context of the size of the screen or operating modes, but not as an independent factor that directly affects the fractional distribution of the chips.

In modern drum wood chippers, the radial distance between the screen and the drum is not a standardized parameter and depends on the design of the specific chipper, the type of screen, and the intended use of the wood chips. Typically, the radial distance is constant along the entire length of the screen [2, 3]. The manufacturers rarely publish this parameter as a separate specification, however, based on technical descriptions, engineering calculations, and operational guidelines, the following typical engineering ranges can be identified

Typical values for the radial distance between the screen and the drum:

• 10–25 mm – for chippers designed to produce relatively fine and uniform chips (increased intensity of rechipping).

• 25–45 mm – the most common working range for universal drum chippers.

• 45–70 mm – for equipment where priority is given to productivity and the reduction of particle re-fragmentation (most of the large fractions).

Occasionally, a plate-type screen of cylindrical shape is installed in the chipping chamber for industrial chips with different radial distances to the drum: the largest distance is near the lower counter-blade and the smallest is near the upper counter-blade [4]. This arrangement of the screen causes the edges of the holes to form as if in the shape of micro-steps. which finely grind the industrial chips in the chipping chamber like micro-counter knives. With this screen arrangement, the number of large-sized industrial chip particles is reduced, but their chipping is still insufficient.

Based on the analysis of the wood chipping process in drum chippers, the study of their design, operating principle, and the main parameters affecting the size and quality of the obtained chips, stepped plate screens were developed in accordance with the declarative utility model patent [6]. A working model of a drum wood chipper [7] has also been developed, which, by eliminating all secondary factors as much as possible, provides an oppotunity to experimentally study, with a high degree of accuracy, the process of chipping wood into industrial chips.

**Setting the task.**

It is necessary to identify the patterns of influence of the stepped screen design and its radial distance to the working surface of the chipping drum on the formation of the fractional composition of industrial chips. To do this, along with theoretical substantiation, it is necessary to experimentally determine how changes in the geometric parameters of the stepped screen 1 and its relative positioning in the chipping chamber 6 with the knife drum 3 affect the conditions for particles passing through the screen surface, the intensity of their re-chipping, and the proportion of the acceptable fraction in the total product throughput (Fig. 1).

**The purpose of the study** – to identify the patterns of influence of the number of sections of a stepped screen and the magnitude of the radial distance between the screen and the drum on the percentage of substandard fraction in the total mass of wood chips, and to recommend rational parameters of the screen system (a parameterized stepped volumetric structure of an arc-shaped screen) for drum wood chippers.

**Solving the problem.**

In order to investigate the influence of the number of sections of the stepped screen, the radial distance between the screen and the drum, as well as wood moisture content on the percentage of substandard fraction in the total mass of chips, a mathematical experiment planning method was used. The experimental variables were as follows: $X_1$ – number of screen sections $n$; $X_2$ – radial distance between the screen and the drum $d$, $X_3$ – wood moisture content $W$. All the factors are quantitative, controllable, and manageable.

The investigated indicator $P_{substd}$ is the percentage of substandard fraction in the total mass of wood chips.

This indicator was determined as follows:

$$P_{substd} = (m_{substd} / m_{tot})100\%,$$

where $m_{subsd}$ is the mass of the substandard fraction of chips (with dimensions exceeding 6 mm), kg; $m_{tot}$ is the total mass of chips, kg.

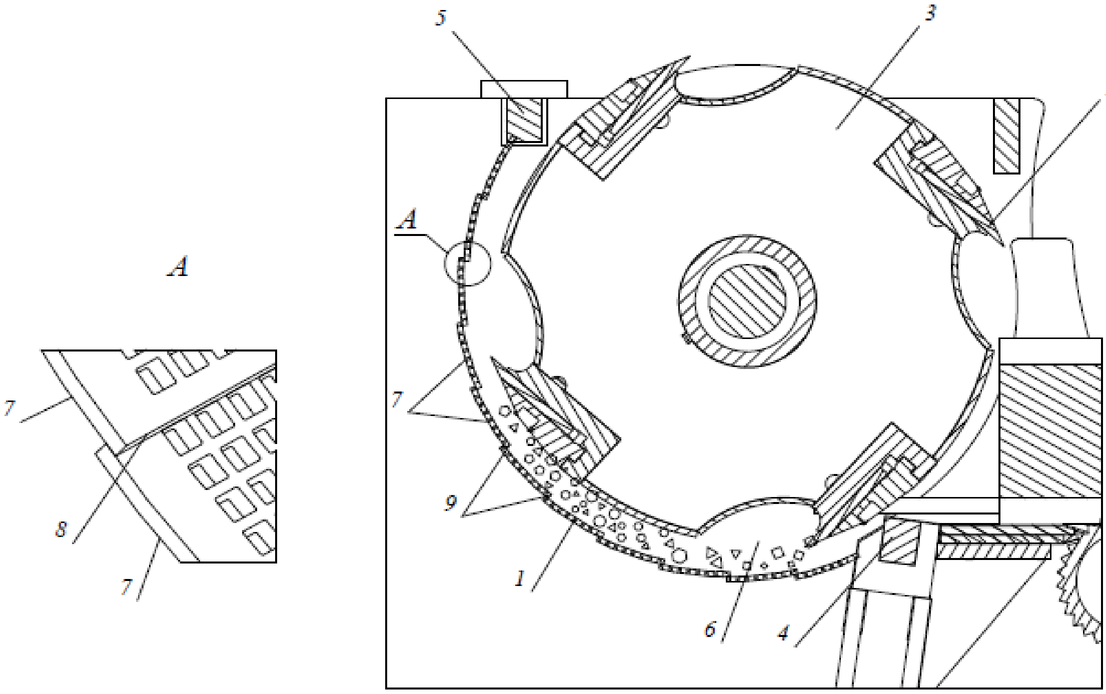


*Fig. 1.* **Structure of a drum wood chipper with a stepped plate screen [4]**
**1 – screen; 2 – chipping knife; 3 – knife-equipped drum; 4 – lower counter-blade; 5 – upper counter-blade; 6 – chipping chamber; 7 – section; 8 – longitudinal edge of the section; 9 – steps.**

To experimentally investigate the effect of the number of sections on wood chipping productivity, three plate-type screens with identical 8 mm × 8 mm holes and with different numbers of sections (3, 7, 11) were designed and manufactured (Fig. 2). The screen mounting structure is designed in such a way that the screens can be installed on the wood chipper with different radial distances between the screen and the drum.

*a* *b* *c*

*Fig. 2.* **Stepped screens with different numbers of sections: a – eleven; b – seven; c – three**

The values of the other factors were constant.

To obtain the regression equation for the percentage of the substandard fraction $P_{substd}$ in the total mass of wood chips, a second-order *B*-plan was applied. It is assumed a priori that the factors are interrelated and that the process under study is described with sufficient accuracy by a second-order polynomial.

The mathematical model of the process takes the form:

$$y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum_{1 \le i < j \le k} b_{ij} X_i X_j,$$

where $y$ is the value of the output parameter; $b_0$ is the intercept term of the regression equation; $b_i$, $b_{ii}$, $b_{ij}$ are coefficients that express the effects of the first- and second orders, and pairwise interactions; $X_i$, $X_j$ are independent variables; $k$ is the number of factors being studied.

Description of the identified key variables is presented in Table 1.

*Table 1*

**Variable factors and conditions for their variation**

| Variable Factors | Designation | Рівні варіювання Variation levels | | | Variability interval |
|---|---|---|---|---|---|
| | | Lower ( – ) | Middle ( 0 ) | Upper ( + ) | |
| $X_1$ – the number of screen sections, pcs | *n* | 3 | 7 | 11 | 4 |
| $X_2$ – radial distance between the screen and the drum, mm | *d* | 15 | 20 | 25 | 5 |
| $X_3$ – wood moisture content, % | *W* | 20 | 30 | 40 | 10 |

For the specified plan, levels and variability intervals were selected in the range of interest (see Table 1).

The formulas linking normalized and natural designations of factors are as follows:

$$X_1 = \frac{n-7}{4}; X_2 = \frac{d-20}{5}; X_3 = \frac{W-30}{10}.$$

To avoid systematic errors arising from the influence of uncontrolled input factors, the tests were randomized prior to the experiment, according to [7], and the experiments were performed in accordance with the obtained sequence of tests (Table 2).

*Table 2*

**Experiment planning matrix in normalized designations**

| Test number | Sequence of conducting three repeated tests | $X_1$ | $X_2$ | $X_3$ |
|---|---|---|---|---|
| 1 | 5, 11, 23 | –1 | –1 | –1 |
| 2 | 22, 24, 41 | +1 | –1 | –1 |
| 3 | 9, 28, 32 | –1 | +1 | –1 |
| 4 | 21, 36, 39 | +1 | +1 | –1 |
| 5 | 4, 15, 27 | –1 | –1 | +1 |
| 6 | 7, 14, 20 | +1 | –1 | +1 |
| 7 | 6, 8, 30 | –1 | +1 | +1 |
| 8 | 25, 31, 33 | +1 | +1 | +1 |
| 9 | 2, 13, 19 | –1 | 0 | 0 |
| 10 | 1, 17, 34 | +1 | 0 | 0 |
| 11 | 3, 10, 29 | 0 | –1 | 0 |
| 12 | 18, 26, 37 | 0 | +1 | 0 |
| 13 | 12, 35, 38 | 0 | 0 | –1 |
| 14 | 16, 40, 42 | 0 | 0 | +1 |

In addition to fourteen tests of the orthogonal part of the plan, three tests were conducted under conditions corresponding to the middle level, which are necessary, in particular, to verify the adequacy of the hypothesis.

The experimental data were processed using the KoefRR 5.0 program, developed at the Department of Technological Machines and Technical Service of the Ukrainian National Forestry University, according to [7].

As a result of computerized processing of the experimental study results, regression coefficients were obtained. The regression equations (in normalized factor designations) for the percentage of substandard fraction in the total mass of industrial chips $P_{substd}$ are as follows:

$$P_{substd} = 19.52 - 0.53X_1 + 9.92X_2 - 0.21X_3 + 0.84X_1^2 + 0.99X_2^2 - 0.56X_3^2 + 1.3X_1X_2 - 0.3X_1X_3 + 0.58X_2X_3$$

The calculation of the Fisher F-criterion confirms the adequacy of the equation (F□ = 1.39 < F□ = 4.53).

Analyzing the regression equation in normalized factor designations, the following conclusions can be drawn.

Of all the factors studied, the radial distance between the screen and the drum, *d* ($b_2$ = 9.92), influences most significantly on the percentage of substandard fraction in the total mass of chips, $P_{substd}$, to a lesser extent - the number of screen sections, *n* ($b_1$=−0.53), and the least effect on the percentage of substandard fraction is produced by the wood moisture content, *W* ($b_3$=−0.21). The dependence of $P_{substd}$ on all the factors within the studied range is nonlinear, since $b_{11}$ = –0.84; $b_{22}$ = 0.99; $b_{33}$ = –0.56.

Among the various factors affecting $P_{sudstd}$, the most significant is the interrelationship between the number of screen sections and the radial distance between the screen and the drum ($b_{13}$ = 1.3). The relationship of the radial distance between the screen and the drum with the moisture content of the wood ($b_{23}$ = 0.58) has a less significant effect on the percentage of the substandard fraction in the total mass of chips, and the relationship between the number of screen sections and wood moisture content ($b_{13}$ = –0.3) has the least significant effect. A plus sign "+" next to the coefficient means that as this coefficient increases, the percentage of $P_{substd}$ increases, while a minus sign "–" means that the percentage of $P_{substd}$ decreases.

Thus, the analysis of the regression equation shows that variations in the number of screen sections and the radial distance between the screen and the drum in wood chippers will affect the percentage of substandard fraction in the total mass of chips (Fig. 3). Moreover, this effect occurs in interaction with the moisture content of the wood.

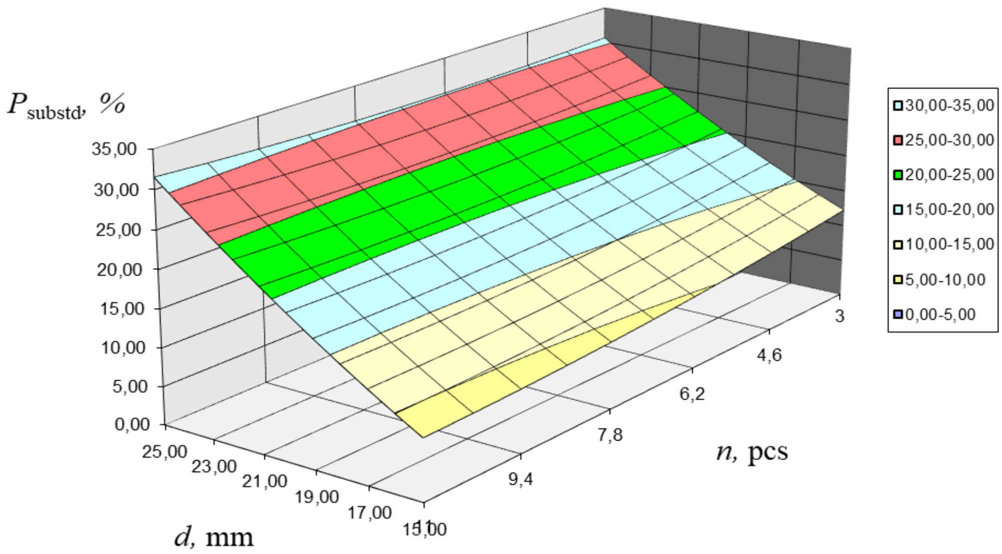


*Fig. 3.* **Graph showing the dependence of the percentage of substandard fraction of industrial wood chips in their total mass on the number of screen sections *n* and the radial distance between the screen and the drum *d* (wood moisture content *W* = 40 %).**

The results of the experimental study showed that the lowest percentage of substandard wood chips was obtained when the radial distance between the screen and the drum was the smallest – 15 mm (Fig. 4). When the distance is reduced from 25 mm to 15 mm, the percentage of substandard wood chips decreases most rapidly when the wood moisture content is *W* = 40 %, ranging from 31.54 % (for 25 mm) to 7.95 % (for 15 mm). In general, with the reduction in the radial distance between the screen and the drum, the percentage of substandard wood chips decreases approximately fourfold (by 75 %).

The second parameter in terms of its impact on reducing the percentage of substandard chips is the number of sections on the screen. At a radial distance of 15 mm between the screen and the drum and when the humidity is 40 %, the percentage values decrease from 12.21 % for a screen with three sections to 7.95 % for a screen with 11 sections (see Fig. 4). In general, when the number of sections in the screen increases from 3 to 11, the percentage of substandard industrial chips in the total mass of chips decreases by approximately 35 %. When the radial distance is 20 mm, this percentage decreases by approximately 10 % when the number of sections in the screen increases from three to 11, and at a distance of 25 mm, it even increases by approximately 3 %.

When the moisture content increases from $W$ = 20 % to $W$ = 40 %, with a distance of 15 mm between the drum and the screen, the percentage of substandard industrial chips in their total mass decreases to 23 % (n=11).

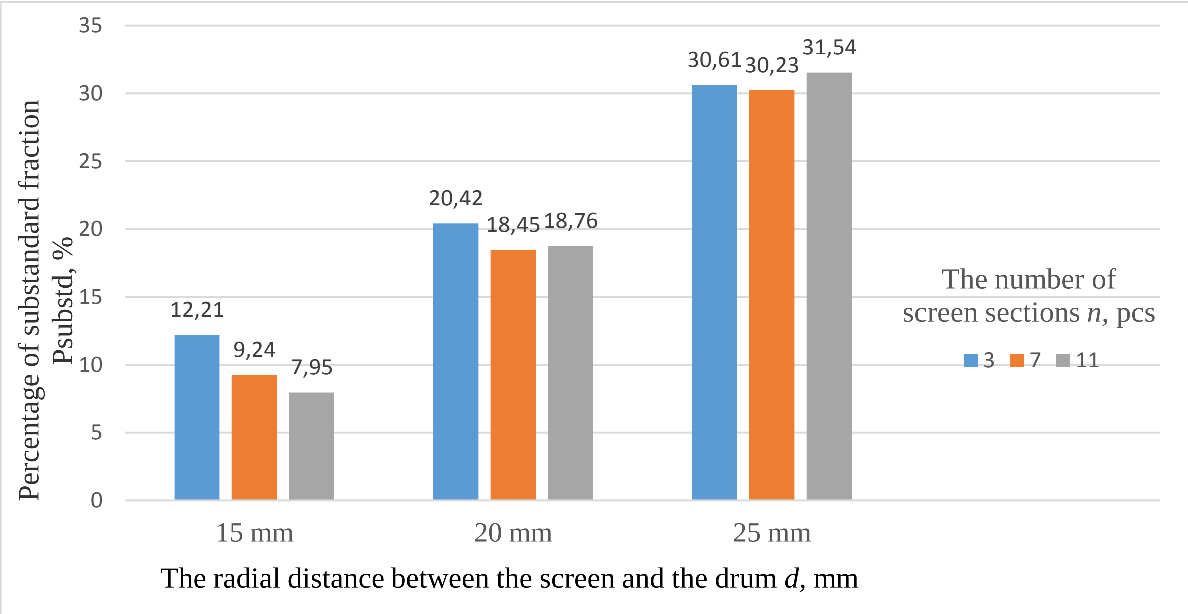


*Fig. 4.* **Diagram showing the change in the percentage of substandad fraction of wood chips depending on the number of sections in the stepped screen and the radial distance between the screen and the drum (wood moisture content $W$ = 40 %)**

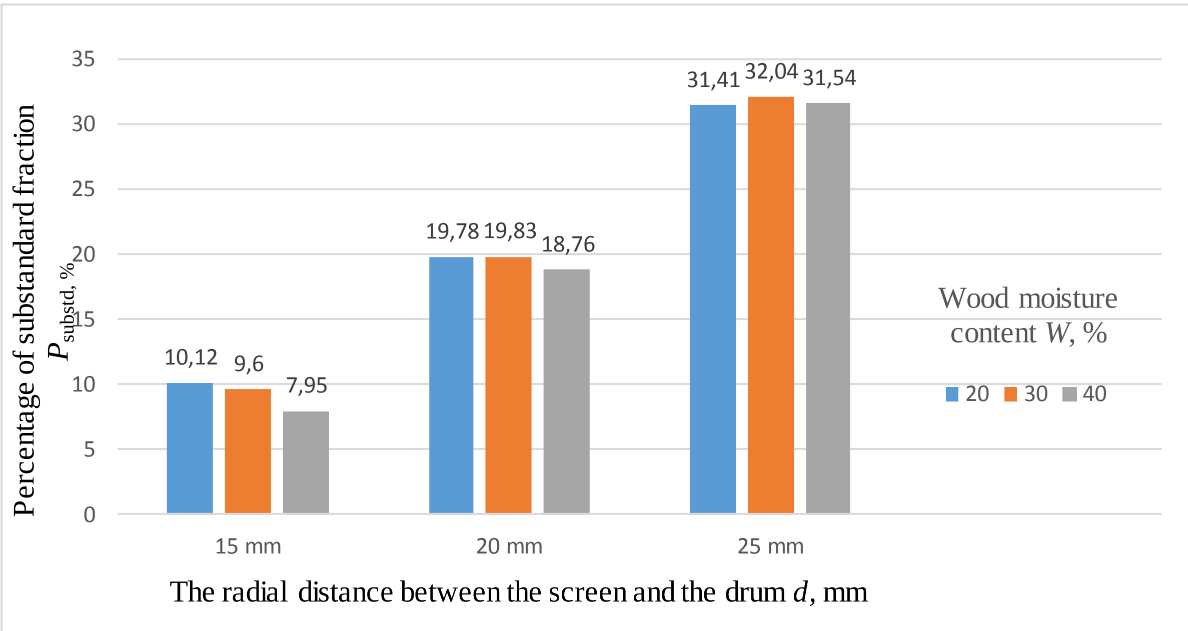


*Fig. 5.* **Diagram showing the change in the percentage of substandard chips in the total mass of chips depending on the radial distance between the screen and the drum and the moisture content of the wood (the number of screen sections is 11)**

However, at a longer radial distance between the drum to the screen of 20 mm, the percentage of substandard fraction of industrial chips in their total mass decreases slightly - by up to 5 %—as the wood moisture content increases from $W$ = 20 % to $W$ = 40 %. And when d = 25 mm, the percentage of substandard industrial chips in their total mass begins to increase.

**Conclusions**

1 A pattern has been identified in the change in the percentage of substandard fraction in the total mass of wood chips depending on the parameters of the screen system of drum wood chippers. A regression equation was obtained, which can be used to calculate the percentage of substandard fraction, taking into

account the number of sections of the stepped screen, the radial distance between the screen and the drum, as well as the moisture content of the wood.

2 The experimental investigation revealed that an increase in the number of sections of the stepped screen leads to a decrease in the percentage of substandard industrial chips in their total mass. Therefore, it is advisable for a stepped screen to have 11 sections. Further increasing the number of sections in the stepped screen will increase the hydrodynamic resistance of the chips and the energy consumption of the process.

3. It has been revealed that, among the factors studied, the reduction in the radial distance between the screen and the drum has the most significant impact on the decrease in the percentage of the substandard fraction. It has been found that the most optimal distance is 15 mm.

4. Based on the study, it is recommended to use the following optimal parameters for the screen system of drum wood chippers: the number of sections of stepped screens is 11, and the radial distance between the screen and the drum is 15 mm.

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