Research Article
https://doi.org/10.33904/ejfe.1299016

Eur J Forest Eng 2023, 9(2):64-69

Investigation of the Process of Obtaining Flour from Wood Greens of Coniferous Species

Mikhail A. Zyryanov, Sergey O. Medvedev, Irina G. Shvetsova*

Lesosibirsk Branch of Reshetnev Siberian State University of Science and Technology, Lesosibirsk662543, Russia

Abstract

An analysis of the waste generation process from wood during logging operations is presented in this paper. The authors presented the concept of a device that can produce flour from green coniferous wood. An evaluation was also conducted regarding the quantity of waste derived from logging residues obtained directly from cutting sites, as well as the potential areas for utilization. The use of coniferous wood waste as a potential raw material for the production of various types of products is also noted. The concept of a mobile knife installation has been proposed for the generating flour from the greenery of coniferous trees, directly at the logging site. A multifactorial experiment was planned and implemented in order to determine the optimal design and technological parameters for the proposed installation and design of an industrial device. The investigation was conducted utilizing both analytical and experimental techniques. The use of a mobile installation for the production of flour from green coniferous wood, in conditions of logging operations, will expand the raw material base for the manufacture of products using pine needles, as well as reduce the amount of waste generated during the wood harvesting process. It will have a positive impact not only on the ecological situation of the environment, but also on the likelihood of a forest fire occurring and spreading.

Keywords: Greenery of coniferous wood, Disintegration, Wood, Experiment, Logging waste, Logging operations, Mobile unit.

1. Introduction

In forest industry, only the tree trunk has been considered valuable until recently, and everything else, including the crown, was considered waste. It led to littering of the cutting area and the creating favorable environment for the habitat and reproduction of forest pests and the occurrence of forest fires (Mokhirev et al., 2020).

Only 700,000 tons of wood waste are used, less than 3-4% of the potential raw materials in wood processing enterprises. An analysis of the processes of formation and use of logging waste has shown that, coniferous tree greenery has a wide application as a raw material for the production of coniferous flour, which is used as the main raw material for the production of essential oil, bioactive preparations, vitamin flour for birds and animals, and also fertilizers.

Woody greens are a type of forest raw material consisting mainly of living cells of coniferous trees, young shoots and bark. These plant cells include proteins, carbohydrates, vitamins, enzymes, yellow and green pigments, sterols, trace elements, as well as other elements required for plants, animals, and humans (Davydenko and Bulaev, 2018). Due to the growing demand for wood raw materials, its complex and rational use is becoming increasingly important. Hence, increasing the use of wood biomass in the production process is an important direction for the development of the forest industry. x Technology and equipment have been developed to increase the coefficient of integrated use of wood (RF Patent No. 2673858, IPC RU 95/00 (150302), C04B 26/26 (150302) Device for chip disintegration in aerodynamic environment: No. 2017135882) for the collection of logging waste, the separation of needles and its further grinding into coniferous flour.

In turn, industrial waste generated from wood raw materials and logging waste can harm forest lands. In order to mitigate the harm inflicted upon forest plantations, a legally binding document has been established, which serves as the primary instrument for regulating relations in the field of forest management in Russia. This document is known as the Forest Code of the Russian Federation (FCRF, 2006).

2. Materials and Methods

The objective of the research was to the process of crushing the green part of coniferous wood and using it as a potential raw material, thus reducing waste generation after logging operations. The raw material for

*Corresponding Author: Tel: + 7 990 0099887 E-mail: milyaevairen@yandex.ru
Received: 18 May 2023; Accepted: 18 October 2023

grinding consisted of pine, spruce, and larch needles procured directly from the forestry site. One distinctive characteristic of coniferous vegetation is the varying length of needles, ranging from 1.5 cm to 7 cm, and the needles' thickness ranges from 1-2 mm. Three experiments were conducted to determine the optimal technological and design parameters of the device, with ten experiments for each species of coniferous greenery.

Currently, coniferous wood greens are grinding on installations of abrasion-crushing, impact, splitting, and breaking action. To date, a laboratory installation has been developed for grinding coniferous wood greens; the scheme is shown in Figure 1. As can be seen from the scheme, woody greenery is fed through the bulk loading spout (5) into the working chamber (3) is diverted by a rotating rotor (1), creating an airflow, to the walls of the working chamber (3). Wood needles, attracted by knives rotating in a circle 2, begin moving in a layer of moving material. Knife 2, passing through the air layer of the product, hits the particles on the work surface and grinds them into coniferous flour. Softwood flour, smaller than the size of the sieve 4, is removed from the working chamber.

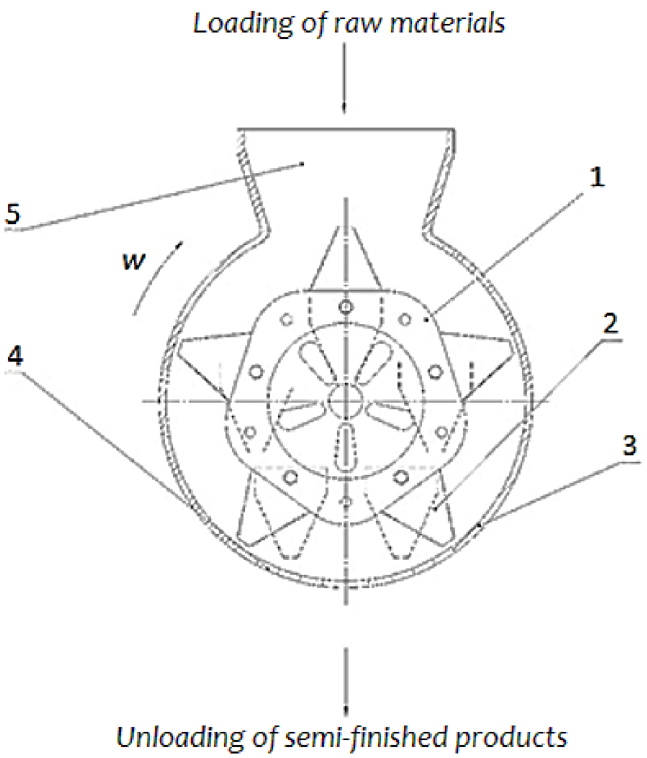

Figure 1. The scheme of the device for the production of coniferous flour. 1 – rotary part; 2 – knife; 3 – device body; 4 – separator with holes; 5 – bulk loading spout.

In the working chamber of the device designed for the production of wood flour, a material is to be crushed. This material is thrown to the periphery of the chamber by centrifugal force and rotates in a circular motion, resulting in a thin layer of it.

The needles are crushed under the mechanical action of the rotor blades. The cutting process is carried out due to the force applied by the knife to the crushed material. The rotor of the device for the production of softwood flour from softwood greenery rotates in the grinding chamber closed by the separator, and the raw material is loaded through the inlet by the feeder under the impact of the rotor knives.

In producing coniferous flour with this device, the action of the primary knives on the needles of woody greens is most effective. In all such devices, the speed at which the material enters the impact zone is independent of the primary impact speed, which will correspond to the circumferential speed of the rotor blades.

When the product particles hit the knife, they acquire a speed equal to the peripheral speed of the contact point during its time. At this time, the raw material particles bounce back at a speed exceeding the peripheral speed of the knife due to the action of elastic forces.

Grinding in the device for the production of coniferous flour occurs due to the impact-reflective action between the knives and the body of the grinding chamber. Since the raw materials constantly fall into the grinding zone and are subjected to the circular movement of the knives under the influence of centrifugal force, contact between the raw materials and the knives is observed only in the air-productive layer, which implies the same wear of the working surface of the knives.

3. Results and Discussion

In order to determine the optimal technological and design parameters of the device, laboratory studies were carried out in the form of an active experiment. To solve the problem effectively, it is necessary to obtain a system of equations that establishes the quantitative dependence of the qualitative characteristics of coniferous flour on the input technological and design parameters of the device for the production of coniferous flour. This system of equations will determine the mathematical model of the entire grinding process as a whole by solving the tasks set in the work. The main characteristics of the regression models that accurately describe the production process of obtaining coniferous flour were selected by the experimental research program according to the theory of mathematical statistics.

The most important part of conducting an experimental study is its planning. Experiment planning is an activity aimed at choosing the number of experiments necessary to solve a problem with a certain required accuracy, and the conditions under which they should be carried out. The main purpose of planning an experimental study is to maximize the accuracy of measurement results and maintain statistical reliability by conducting a certain number of experiments.

A three-factor experimental study was the main method used to obtain a statistical and mathematical description. Based on the analysis of literary sources and a series of preliminary experiments, the main technological parameters of the device for processing woody greens, including rotor speed, separator cell size and raw material moisture content, which most affect the crushing of needles, were determined. Table 1 shows the steps and ranges of variability of the analyzed factors during the experiment. As a result of the analysis of the coefficients of instability variation and the results of a series of preliminary experiments, the variation intervals of the studied factors were determined, and a multifactorial experiment was planned.

Formulas relating normalized and natural values are represented by the following equations:

$$\begin{cases} X_1 = \frac{n-2750}{750}; \\ X_2 = \frac{b-3}{2}; \\ X_3 = \frac{W-30}{30} \end{cases} \quad (1)$$

Statistical test for the results of the experimental study were conducted in accordance with the theory of mathematical statistics. The average value of the parameter was calculated using the Equation 2:

$$\overline{Y} = \frac{1}{n}\sum_{i-1}^{n} y_i, \quad (2)$$

where y_i: a single value of the parameter under study and n: number of measurements of the research sample. The variance of single values was determined by the following formula:

$$S^2 = \frac{1}{n-1}\left(\sum_{i=1}^{n} y_i^2 - n\overline{y^2}\right), \quad (3)$$

where n-1=f is number of degrees of freedom of sampling.

The size of the variation is characterized by the standard deviation of single values:

$$s = \sqrt{S^2}. \quad (4)$$

The coefficient of variation was determined by the following formula:

$$V = \frac{s}{\overline{Y}} \cdot 100\%. \quad (5)$$

The mean square error of the average value of the factor under study was determined by the following formula:

$$S\overline{y} = \frac{s}{\sqrt{n}}. \quad (6)$$

The accuracy index of the average value is calculated using the following formula:

$$\varepsilon = \frac{S_{\overline{y}}}{Y} \cdot 100\% = \frac{s}{\overline{\overline{Y}}\sqrt{n}} \cdot 100\% \quad (7)$$

The error in standard deviation was calculated by the following formula:

$$S_s = \frac{s}{\sqrt{2n}}. \quad (8)$$

The following input parameters of the process of grinding wood greens of coniferous species were studied in the work:

- rotor rotation speed- n, min^{-1};
- the size of the separator cells - b, mm;
- humidity of needles - W, %.

This method was chosen as an experimental method used to obtain a mathematical model of a complex multifactorial process in order to derive equations for a statistical and mathematical description of the process under study (production of coniferous flour).

In order to ascertain the impact of the rotor speed, the size of the separator cells, and the humidity of the crushed raw materials on the size of the crushed pine needles, an experiment was conducted. The results of the experiment were utilized to construct the graphical dependencies depicted in Figures 1-3.

Analyzing the dependence shown in Figure 3, it can be concluded that the raw materials are well crushed when using sieves with a mesh size of 1-5 mm. This is due to the fact that when using a sieve with a smaller mesh size, the raw material clogs the separator and cannot leave the installation chamber. On the other hand, when using sieves with a larger size, the raw material is removed before it is crushed.

Table 1. Ranges and steps of changes in the analyzed factors during the experiment

Factor name	Designations		Step	Range		
	Natural form	Normalized form		Lower (-1)	Main (0)	Upper (+1)
Rotor rotation speed, min^{-1}	n	X_1	750	2000	2750	3500
The size of the separator cells, mm	b	X_2	2	1	3	5
Humidity of needles, %.	W	X_3	30	0	30	60

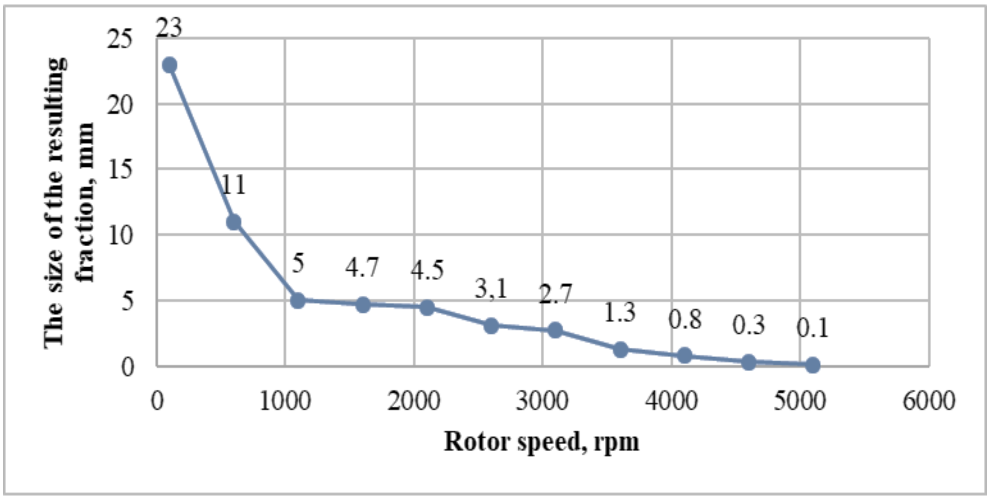

Figure 2. The dependency graph of the resulting fraction size on the rotor speed

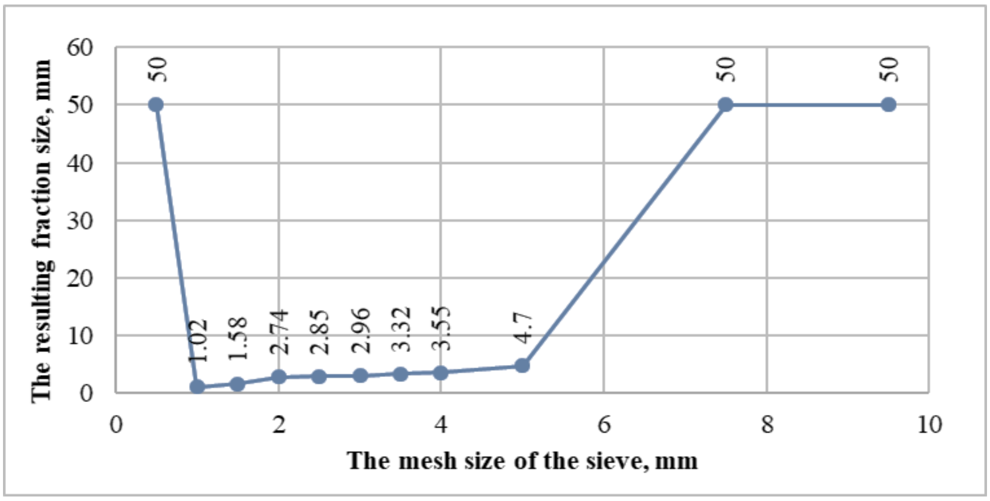

Figure 3. The dependency graph of the resulting fraction size on the mesh size of the sieve

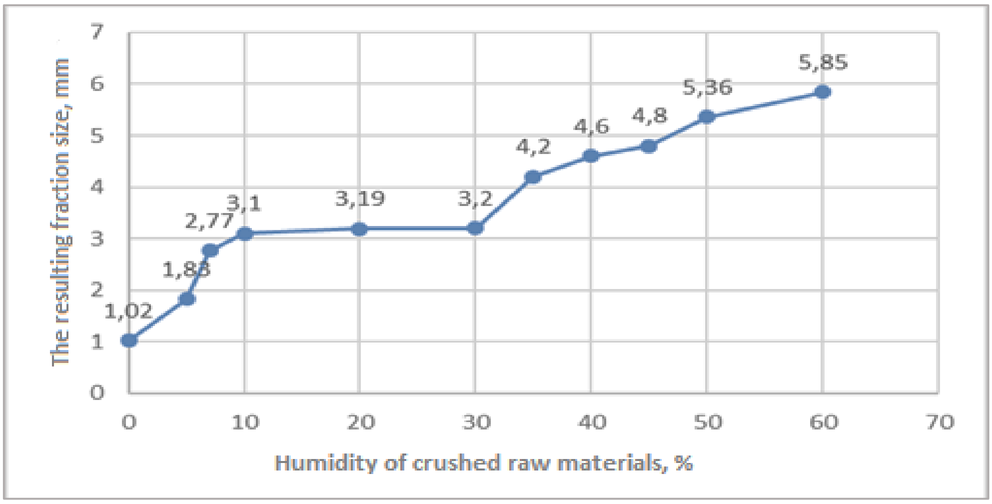

Figure 4. The dependency graph of the resulting fraction size on the humidity of crushed raw materials

Analyzing the dependence graphic shown in Figure 4, it can be said that the crushing of needles occurs at humidity content of the crushed raw materials in the range of 0-60%. It follows from that the smallest particle size is achieved at low humidity of the crushed raw materials. With an increase in the humidity of needles, the size of its particles increases. At humidity W = 0 %, the size of the fraction reaches 1.02 mm. At humidity W = 10 %, the size of the fraction reaches 3.01 mm. At humidity W = 20 %, the size of the fraction reaches 3.19 mm. At humidity W = 30 %, the size of the fraction reaches 3.2 mm. At humidity W = 40 %, the size of the fraction reaches 4.6 mm. At humidity W = 50 %, the size of the fraction reaches 5.36 mm. At humidity W = 60 %, the size of the resulting fraction reaches 5.85 mm.

Previously, the subject matter to which our research is devoted, was addressed in research entitled "Development of innovative technologies for the processing of logging waste in logging conditions" (Zyryanov et al., 2021). This paper also addressed the issue of using felling residues, which increase their volume after logging operations. In the above mentioned scientific work, the actual volumes of the forest resource base are scrutinized on the basis of the Krasnoyarsk Regional Fund. As a result, the most recent technology and equipment for utilizing wood waste obtained directly at the cutting area are proposed. The experiment that we conducted and outlined in the presented scientific work continues to enhance previous scientific advancements on this matter.

In the course of the presented experiment, based on the obtained graphical dependencies, it can be concluded that coniferous flour of the optimal size is obtained at a rotor speed in the range from 2000 rpm to 3500 rpm, with raw material humidity in the range from 0% to 60% and with the mesh size of the separator sieve in the range from 1 mm to 5 mm.

4. Conclusion

The production of coniferous flour will reduce the amount of unused wood biomass left in the cutting area, positively affecting the environment and increasing the coefficient of integrated use of wood. Statistical and mathematical equations and graphs compiled during the processing of the experimental results describing the process of obtaining coniferous flour make it possible to calculate the particle sizes of coniferous flour depending on the design and technological parameters of the investigated installation process.

Ethics Committee Approval: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept: M.Z., I.S.; Design: S.M., I.S.; Supervision: M.Z.; Resources: M.Z., S.M., I.S.; Data Collection: M.Z., I.S.; Analysis: M.Z., I.S.; Literature Search: M.Z., I.S.; Writing Manuscript: M.Z., I.S.; Critical Review: M.Z., S.M.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The research was carried out with the financial support of the Krasnoyarsk Regional Fund for the Support of Scientific and Scientific-Technical Activities within the framework of the scientific project No. 2022110509022 "Development of innovative technology and equipment for processing coniferous wood greens in the conditions of logging operations of the Far North".

Cite this paper as: Zyryanov, M.A., Medvedev, S.O., Shvetsova, I.G. 2023. Investigation of The Process of Obtaining Flour from Wood Greens of Coniferous Species, *European Journal of Forest Engineering*, 9(2): 67-72.

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