Investigation of the influence of the pattern of a disc mill set on the process of obtaining powdered pulp

D Yu Vasilyeva, L V Yurtaeva, R A Marchenko, E V Kaplyov, D E Zyryanov and N S Reshetova

Reshetnev Siberian State University of Science and Technology 31, Krasnoyarsky Rabochy Ave., Krasnoyarsk, 660037, Russian Federation

E-mail: 2052727@mail.ru

Abstract. On the market of pulp and paper products, new requests for more narrowly targeted products appear every year. To stay competitive in the market, manufacturers need to use not only traditional types of fibrous materials, but also use with excellent characteristics from the usual cellulose. The article discusses the role of the knife process of pulp grinding. A method for producing powdered cellulose with preliminary grinding in a disk mill is proposed. The paper-forming properties of the pulp and the degree of polymerization of powdered cellulose, depending on the degree of grinding, are given.

1. Introduction

The grinding of the pulp prior to paper casting has a decisive influence on both the papermaking process and the properties of the finished product. The main purpose of the process of grinding fibrous materials is:

1) imparting a certain structure to the fibrous material in relation to the dimensions of the fibres along the length and thickness in order to provide the required structure to the paper web;
2) imparting a certain degree of hydration to the fibrous material, on which the creation of adhesion forces between fibres largely depends [1].

Before grinding, cellulose fibres have low plasticity, poorly developed surface and little hydration, as a result of which the fibres are poorly interwoven with each other on paper sheet. A sheet of paper obtained from unmilled fibres is characterized by unsatisfactory structure, appearance and physical and mechanical properties. Such a sheet of paper has a cloudy, uneven clearance, high porosity, bulk and low strength.

This is due to the fact that long and coarse fibres are woven into flakes, and do not allow the formation of a homogeneous sheet structure on the mesh of the paper machine.

Grinding of fibrous semi-finished products is carried out in grinding devices of periodic and continuous action - rolls, conical and disk mills, refiners. Regardless of the type of grinder, the principle of fibre grinding is the same. It consists in the fact that the fibrous suspension flows in a continuous flow to the knives of the working body of the apparatus, which consists of fixed knives (stator) and rotating knives.
located on a drum, cone or disk (rotor). Passing between the rotor and stator knives, the gap between which can be adjusted, the fibres are subjected to the cutting action of the edges of the knives and are shortened or split in the longitudinal direction, crushed by the end surfaces of the knives and fibrillate.

Continuous improvement of the grinding process and related equipment is primarily due to the need for:

- ensuring the required quality of the finished product;
- depletion of the raw material base and involvement in the production of increasingly low-quality fibre raw materials and semi-finished products;
- the desire to reduce excessive energy consumption for grinding [3].

In this regard, at the Reshetnev University, the Department of Machines and Apparatus for Industrial Technologies is researching the process of obtaining powdered pulp with preliminary grinding of the pulp in an experimental disk mill [4].

The purpose of this work was to study the effect of the pattern of the grinding set of an experimental disk mill on the process of obtaining powdered pulp.

The research tasks included:

- mechanical processing of pulp using grinding sets with different knife profiles;
- determination of the morphological properties of the fibrous suspension;
- chemical treatment of pulp;
- determination of the viscosity and degree of polymerization of powdered pulp, depending on the degree of grinding.

2. Experimental part

Samples of bleached sulphate softwood pulp (BSSPs) and bleached sulphate hardwood pulp (BSHP) (semi-finished product of ROP JSC "Ilim Group", Bratsk) were used as raw materials. The raw materials were processed by mechanical and chemical methods. The processing of the fibrous suspension at a concentration of 1% mechanically was carried out in a disk mill (figure 1).

Disc mill specifications:

| Parameter                                      | Value       |
|------------------------------------------------|-------------|
| overall dimensions of the disc mill, m        | 0.95x0.6x0.8; |
| knife gap, mm                                  | 0 ÷ 6;      |
| the number of revolutions of the rotor shaft, rpm | 0 ÷ 2000;  |
| knife set material                             | Steel 40XH;|
| rated motor power, kW                          | 22          |
| the number of revolutions of the output shaft of the engine, rpm | 750         |

![Figure 1. Schematic of an experimental knife grinding plant. 1 – pulper, 2 – belt drive, 3 – injection pipe, 4 – circulation pipe, 5 – fastening, 6,7,8 – electric motor.](image-url)
The design and technological characteristics of the drawings of sets with a straight and curved shape of knives, developed by a group of scientists from the Department of Machines and Apparatus of Industrial Technologies, considered in this work, are presented in figure 2 [5, 6].

![Figure 2](image1)

**Figure 2.** Scheme and characteristics of knife grinding sets. (a) a traditional eight-sector set with a rectilinear shape of knives with an angle of 45°, (b) a set with curved crescent-shaped knives.

Based on the data from literary sources of the values of the second cutting length and the contact area of the rotor and stator knives, it can be assumed that, all other things being equal, the greatest chopping effect will be achieved when using a set with a straight-line shape of knives. The curvilinear shape of the knives, in turn, will reduce the forces acting on the fibre tangentially, i.e., fibrillation will prevail.

In order to establish control points and determine the rate of release of water by the mass, the mass was taken to determine the degree of grinding, measured in Schopper-Riegler degrees, from 15 to 75° SR. The rotor speed - 1500 rpm and the knife gap - 0.1 mm were chosen as the most effective, in terms of the duration of grinding and the degree of fibre development, on the basis of studies previously conducted at the Department of Machines and Apparatus of Industrial Technologies [7]. Before hydrolysis, the cellulose samples were dried in the open air. The hydrolysis process was carried out at a temperature of 85 °C in a 7% hydrochloric acid solution. The degree of polymerization (DP) was determined in accordance with the methods for the analysis of wood and cellulose, based on the classical methods of organic chemistry [8].

![Figure 3](image2)

**Figure 3.** Dependence of the degree of grinding on the DP of powdered pulp. 1 - traditional eight-sector set with rectilinear knives with an angle of 45°, 2 - set with curved crescent knives.
As can be seen from figure 3, with an increase in the degree of grinding, regardless of the type of set, the degree of polymerization of powdered pulp decreases. Moreover, the smallest DP values are achieved when using a set with a straight-line shape of knives. For samples from the BSSPs ground on a set with a straight knife, the degree of polymerization decreases by 23.5%, for samples milled on a set with a crescent-shaped knives - by 15%. 

Figure 4. Dependence of morphological properties on the degree of grinding. 1- traditional eight-sector set with rectilinear knives with an angle of 45 °, 2 - set with crescent-shaped curved knives.

Figure 4 shows the morphological properties of BSSPs, PP at different degrees of grinding, ground using a set of different shapes of knives.

From the presented experimental data, regardless of the method of processing the pulp, the characteristics of the morphological properties of the fibre have the same quality characteristics with different patterns of the knife grinding set. Moreover, after mechanical and chemical processing of the pulp, the weighted average length and content of broken fibres decrease, and the proportion of fines increases. For example, the weighted average fibre length decreased on average by 14.18 %.

Thus, the traditional eight-sector rectilinear knife set is the most effective for obtaining powdered pulp by mechanical-chemical means.

3. Conclusions
During machining, regardless of the pattern of the knife sets, the fibres under the action of the edges of the knives are crushed by the end surfaces of the knives, shortened and split in the longitudinal direction.

The possibility of using a preliminary knife method of grinding fibrous materials to obtain powdered pulp is shown.

As a result of acid hydrolysis, the lowest value of DP of powdered pulp was achieved when using a set with a rectilinear shape of knives.

Acknowledgments
The study was carried out under the Government Order issued by the Ministry of Education and Science of Russia for "Deep Conversion of Plant Material" by the Research Laboratory team under the project "Technology and Equipment for Plant Biomass Chemical Processing" (subject number: FEFE-2020-0016).
References

[1] Xiao J 2011 Experimental study of biomass pyrolysis based on three major components: hemicellulose, cellulose, and lignin *Industrial & Engineering Chemistry Research (Ind Eng Chem Res)* 18 10424-33

[2] Baruah J and Deka R C 2020 Greener production of microcrystalline cellulose (MCC) from Saccharum spontaneum (Kans grass): Statistical optimization *International Journal of Biological Macromolecules* 154 672-82

[3] Alashkevich Yu D and Reshetova N S 2013 *Theory and Design of Machinery and Equipment in the Industry* (Krasnoyarsk: SibSTU)

[4] Zyryanov D E, Kaplev E V, Yurtayeva L V and Alashkevich Yu D 2021 The effect of the fibre mass grinding process on the production of powdered cellulose *Proc. of the II All-Russian Sci. and Practical Conf. of Students and Young Scientists on Modern Trends in the Development of Chemical Technology, Industrial Ecology and Technosphere Safety* (St. Petersburg: HSE SPb GUP TD) 231-5

[5] Alashkevich Yu D, Kovalev V I, Kharin V F and Mukhachev A P 2007 *Grinding Typeface* Pat. of the Russian Federation 2307883, IPC D 21 D 1/30, B 02 C 7/12 No. 2006110647/12 appl. 03.04.2006, publ. 10.10.2007

[6] Alashkevich Yu D, Kovalev V I and Kozhukhov V A 2018 *Grinding Headset for a Disc Mill* Pat. of the Russian Federation 2670523 IPK7 D21 D1/30, B 02 C 7/12 No. 2017141364 appl. 27.11.2017; publ. 23.10.2018

[7] Shurkina V I, Yurtayeva L V, Marchenko R A, Fedorova O N and Alashkevich Yu D 2017 Investigation of the properties of fibrous mass when using a headset with a curved shape of knives *Proc. of the XXI Int. Sci. and Practical Conf. (Krasnoyarsk: Publishing House of the SibSU)* 169-71

[8] Obolenskaya A V 1985 *Practical Works on the Chemistry of Wood and Cellulose* (Moscow: Forest industry)