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USE OF LOGGING WASTE IN TECHNOLOGIES FOR DEEP CHEMICAL PROCESSING OF WOOD

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ABSTRACT

The study presents theoretical aspects and modern technologies for processing wood biomass, considers the possibility of obtaining wood chips from felling residues of cutting areas, in particular technological chips that meet the GOST 15815: 1983 “Technological chips. Specifications" standard for use as raw materials in the production of fiberboard. Wood fiber obtained from similar in size and quality indicators according to GOST 15815: 1983 technological chips, pre-treated in a defibrator, was subjected to a refining process at a low concentration, in particular using the developed design of the disks of the refiner of fibrillating action while regulating the main parameters of the process. The resulting wood-fiber mass was characterized by an improvement in the fractional composition of fibers, their size and quality indicators. As a result, improving the quality of the wood-fiber mass provides an increase in the physical and mechanical properties of wood-fiber boards under all other equal production conditions, which excludes the use of binding resins, and may indicate the possibilit of effective processing of logging waste.

KEYWORDS: Wood biomass, felling residue, logging waste, refinement process, wood fiber pulp, refiner disc structure.

INTRODUCTION

Nowadays, when the demand for wood is constantly growing, its integrated utilization is of particular importance. In the coming years, satisfaction of the needs of national economy in timber will be possible through efficient use to the fullest extent possible, by increasing the volume of forest harvesting (Zyryanov et al. 2010). In this regard, the main direction of the timber complex development is to improve utilization of all harvested wood pulp. This requires further improvement of the production profile of forest and woodworking industries, development in the production of industrial chips, wood boards, plywood, container board and other substitutes for commercial wood (Pirayesh et al. 2013, Lubke et al. 2014, Ihnat et al. 2017, 2018). Improving utilization of wood biomass, involving low-quality, low-value wood, felling residue, logging and wood conversion waste in processing is an issue of high priority (Ihnat et al. 2017, 2020, Ammar et al. 2018, Irle et al. 2018).

However, the problem of processing logging waste has not yet been fully resolved. In practice, they are ploughed in, burned, or simply left for digestion. But recycled wood is a valuable natural raw material that can compensate for the needs in the production of a number of marketable products (Bezrukikh et al. 2014). In our opinion, one of the priority directions of using logging waste in the form of lops, branches, and tops is processing into chips. In turn, technological chips are rather widely used in various industries. With moisture content of at least 40%, it can be a raw material in pulp and paper industry and woodworking industry for the production of container board, technical grades of paper, fiberboard and wood-particle board. Processing of technological chips by power-chemical means enables to produce acids, alcohols, aldehydes, ethers, resin, coal, and gas. Also, technological chips have found application in hydrolysis production (Vasilyev et al. 2001).

Studies (Shyukin et al. 2012, Mokhirev et al. 2014, Mokhirev et al. 2015) have shown that birch wood chips, as well as crushed alder and hazel shrub vegetation, can be an organic filler in the production of wood concrete for industrial premises under construction. Small-sized chips are used as a feed additive, as well as for composting and farm animal and poultry bedding. Fuel chips are intended for combustion in boiler units, apartment stoves and industrial furnaces. For the same purposes, chipped fuel wood is used in briquetted form without adding binders. The fuel briquette production from shredded wood on mobile units is very efficient (Shyukin et al. 2012, Mokhirev et al. 2014, Shegelman 2014).

As a rule, preparation of wood fiber pulp is carried out in several stages of refinement in high-speed disk mills (defibrators, attrition mills, refiners). In the pulp and paper industry, technological chips are subjected to chemical-thermal treatment (boiling chips to produce cellulose), followed by pulp production in refiners. At a certain percentage ratio of cellulose and wood pulp, a certain type of finished product is produced (Borysiuk et al. 2007, Ihnat et al. 2015). Both in the fiberboard production and in the pulp and paper industry, one of the main technological operations is the wood pulp refinement process.

The refinement process is the most important and energy-intensive technological stage of these industries, as a result of which wood fibers acquire certain geometric dimensions, properties, and composition (Laskeev 1967, Alashkevich et al. 2010, Chistova 2010, Bordin et al. 2011, Kerekes 2011, Li et al. 2011, Hua et al. 2012, Zyryanov 2012, Lubke et al. 2014, Gharehkhani et al. 2015, Forouzanfar et al. 2016, Berna et al. 2018, Vititnev 2019, Przybysz et al. 2020), which directly affects the quality of manufactured products (Laskeev 1967, Alashkevich et al. 2010, Chistova 2010, Zyryanov 2012, Ihnat et al. 2015, Tikhonova et al. 2015, Vititnev 2019). Refiner disks are the working body of refiners, design features (Olson et al. 2003, Nabieva 2004, Alashkevich et al. 2010, Li et al. 2011, Vikharev 2019, Vititnev 2019, Cai et al. 2020) of which, along with the main factors of the refinement process (a working gap between the disks, fiber concentration, rotor speed, etc.) are of paramount importance that determines the effect on wood fibers, their destruction nature, and, respectively, final dimensional and qualitative characteristics and the composition of wood fiber pulp (Gorski et al. 2012). As shown by numerous studies, the scientifically based choice of the refiner disk working surface, depending on the type of processed raw materials and the required quality indicators of wood fiber pulp when regulating the main factors of the refinement process, enables to ensure high efficiency of the refiner and, therefore, efficiency of the entire production (Strand and Mokvist 1989, Nabieva 2004, Bordin et al. 2008, Alashkevich et al. 2010, Chistova 2010, Zyryanov 2012, Vititnev 2019).

The possibility of using technological chips produced from logging waste as raw materials for manufacture of environmentally friendly high-quality products is confirmed by research carried out as part of fiberboard production.

MATERIALS AND METHODS

Materials

In order to analyze the amount and type of waste generated from logging, a preliminary experiment was carried out at 9 logging sites in the Krasnoyarsk Territory, Russian Federation. At these logging sites, felling residues were collected from each felled tree. The number of trees of various species is 140 with the diameter from 16 to 68 cm. The felling residues were divided into branches, large lops, small lops, tops. Chips were produced from each type of felling residues using a chipper. Chips were evaluated for fractional composition and compared with various purpose chips required for production. The qualitative characteristics and chip dimensions are similar to those of the chips produced from logging waste and comply with the standards GOST 15815: 1983. Wood fiber produced from pretreated technological chips in a defibrator of the fiberboard production workshop of Segezha group "Lesosibirskiy LDK No. 1" in the Krasnoyarsk Territory was subjected to a refinement process at low concentration, according to the plan of experimental studies (Vititnev 2019).

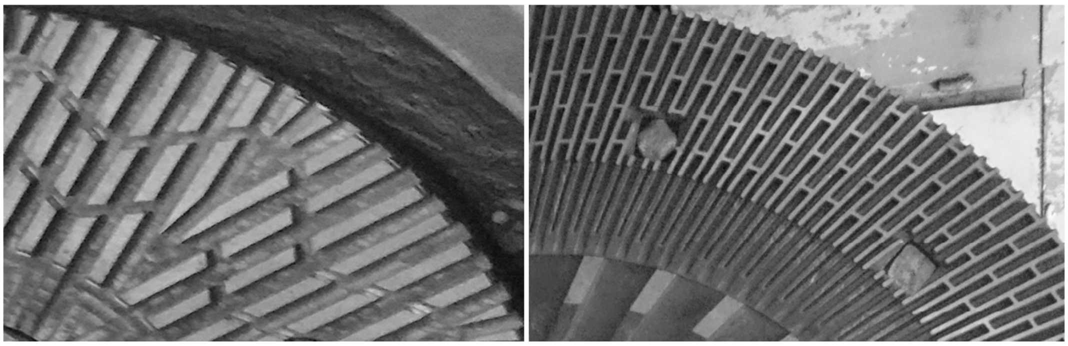
Methods

Tab. 1 shows chip characteristics in accordance with GOST 15815: 1983, GOST 17462: 1977 “Forest industry production. Terms and definitions", and TU 13-735: 1983 “Technological chips from small trees and twigs", which were used to evaluate the quality parameters of wood raw materials from felling residues.

Tab. 1: Chip characteristics.

Chip type	Chip length (mm)	Chip thickness (mm)	Cut angle (°)	Bark mass fraction (%)	Rot mass fraction (%)	Purpose
Technological	12-15	< 5	30-60	1.5	0.3	pulp and paper industry
	10-35	< 5	30-60	15	5	fiberboard production
	10-60	< 5	30-60	15	5	wood-particle board production
Fuel	5-50	< 5	-	20	5	combustion
Small-sized	15-30	< 5	-	-	5	feed additive, compost, bedding

At the premises of the laboratory of the Industrial Technology and Machine Engineering Department of Siberian State University, Krasnoyarsk, an original scientifically grounded design of fibrillating refiner discs (Vititnev et al. 2018, RU 2652177) for the wood fiber pulp preparation in the fiberboard production was developed. The main studies of wood fiber pulp refinement process using discs with new design were carried out on an MD single-disk experimental refiner, a unit as close as possible to an industrial refiner, all other production conditions being equal. Fig. 1 shows the geometry of the working surface of the author's refiner disks (RU 2652177) and the traditional double-sided design (Braun and Sparish 2006, RU 2288313).



(a) (b)

Fig. 1: Geometry of the working surface of the refiner disks: (a) the author's design, (b) the traditional design.

Subsequently, we evaluated the dimensional and qualitative characteristics (grinding degree – DS; fractional composition – large (F_l), medium (F_m), small (F_f) fractions; average length – L_a and diameter – d_a of fibers, their ratio L_a/d_a) of the produced samples of wood fiber pulp, according to known methods, as well as gluing, casting of wood fiber mat and pressing of finished boards at the enterprise of Segezha group "Lesosibirskiy LDK No. 1", all other fiberboard production conditions being equal. When gluing wood fiber pulp, we used a standard formulation, except for the use of binders, hardening additives in the form of phenol-formaldehyde resins (Mersov 1989, Chistova 2010, Zyryanov 2012, Vititnev 2019).

Grinding degree (DS) of the wood fiber pulp was measured with a special Defibrator-Second device by Defibrator brand (Sweden) commonly used in fiberboard production. Depending on the refinement degree, the pulp can be characterized by different fluid loss (drainage), expressed in seconds in measuring units of the grinding degree DS (Mersov 1989, Chistova 2010, Zyryanov 2012, Lubke et al. 2014, Ihnat et al. 2015, Vititnev 2019).

Wood fiber pulp fractional composition (F_l, F_m, F_f, %). Fiber fractionation was carried out on a FVG-2 fractionator by passing a certain amount of wood fibers through sieves with openings corresponding to the groups of qualitative evaluation (Laskeev 1967, Chistova 2010, Zyryanov 2012). As a result of fractionation, fibers of certain fractions were weighed separately from each sieve, and their weight was expressed as a percentage of the total weight.

Arithmetic mean length (L_a, mm), diameter (d_a, mm) of fibers, their ratio (L_a/d_a). When dividing the wood fiber mass into fractions, the arithmetic mean values of the average length (L_a), fiber diameter (d_a), their ratio (L_a/d_a), characterizing fiber destruction, intensity of their size change in the longitudinal and transverse directions, were measured, determining specific surface area and fiber flexibility. Geometric parameters were determined by microscopic measurement of at least 100 fibers for each sample using a Hitachi TM-3000 digital microscope at magnification up to 1000x, after which the fibers were categorized into suitable fractions (Laskeev 1967, Chistova 2010, Zyryanov 2012, Ferritsius et al. 2018).

Evaluation of physical and mechanical properties of finished board products was carried out in accordance with the standards GOST 4598: 2018 “Fibre boards by wet way of production. Specifications", EN 622-2: 2004 “Fibreboards. Specifications. Part 2: Requirements for hardboards, NEQ" during tests in accordance with GOST 10633: 2018 “Fiberboards. Test Methods".

The obtained results of experimental studies were processed in the STATISTICA-6 software package and Microsoft Excel 2007 using the Quasi-Newton method; the results reliably describe the investigated wood fiber pulp refinement process using a new design of the refiner disc surface.

RESULTS AND DISCUSSION

Results of the process of producing chips from felling residues

The preliminary experiment results showed that the tree diameter is the factor affecting most significantly the amount of logging waste. The dependency diagram presented in Fig. 2 shows that an increase in the tree trunk diameter to 30-34 cm decreases the content of logging waste from 12% to 9.5%. A further increase in the tree trunk diameter reduces the percentage of logging waste content, which reaches 8.4% with the diameter of 66-68 cm.

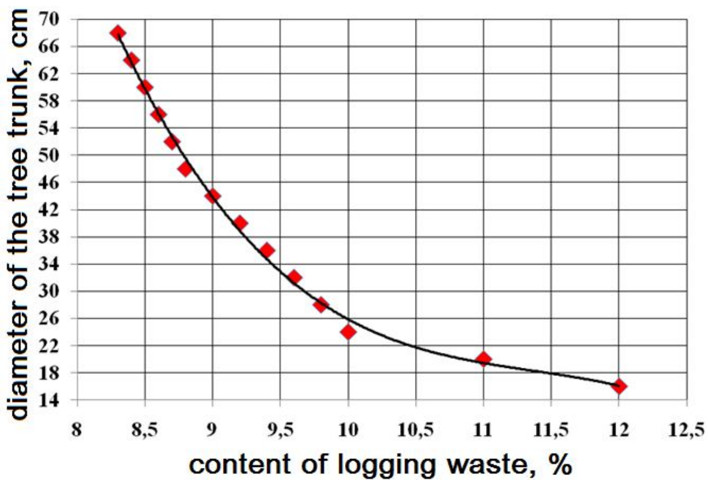


Fig. 2: Dependency of logging waste volume on tree trunk diameter.

The dependency diagram presented in Fig. 3 shows that the volume of lops fluctuates within 3-4.5% of the entire tree volume, branches are 4.5-6.5%, tops are 0.5-1%.

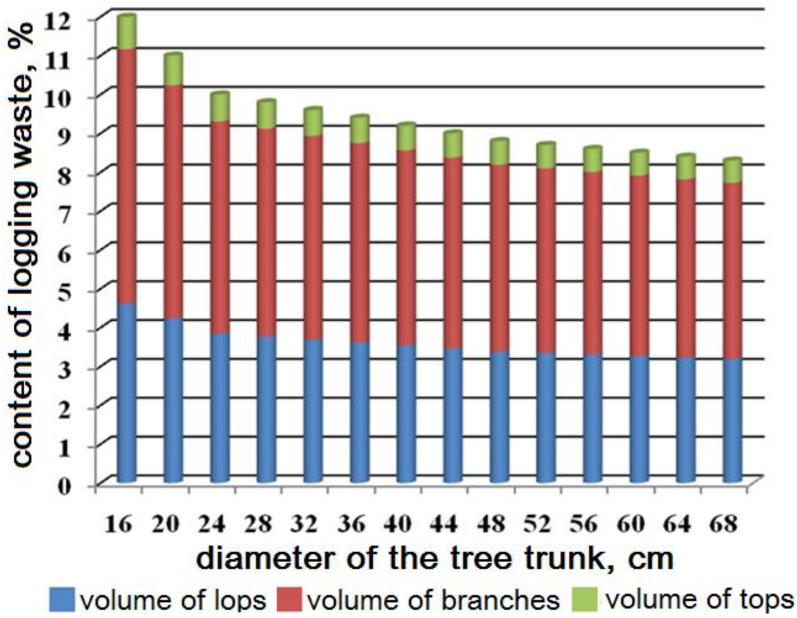


Fig. 3: Dependency of the contents of various logging wastes on tree trunk diameter.

The experiment results presented in Tab. 2 show that technological chips can be produced from: large lops of pine, spruce, birch; pine tops and small lops. Felling and logging waste of the remaining species can be used for small-sized and fuel chips production. This is due to the peculiarity of the microstructure of wood tops, lops, branches and different density of the wood species. The higher the density of the wood and the larger the diameter of the waste, the more technological chips are obtained. With a lower density of wood and the diameter of the waste, chips are obtained in smaller sizes than technological ones.

Tab. 2: Experiment results.

Wood species	Waste type	Diameter (cm)	Chip type
Pine	Tops	5-16	Technological
	Small lops	4-10	Technological
	Large lops	> 10	Technological
	Branches	< 4	Small-sized
Spruce	Tops	5-16	Small-sized
	Small lops	4-10	Small-sized
	Large lops	> 10	Technological
	Branches	< 4	Small-sized
Fir	Tops	5-16	Small-sized
	Small lops	4-10	Small-sized
	Large lops	> 10	Fuel
	Branches	< 4	Small-sized
Birch	Tops	5-16	Fuel
	Small lops	4-10	Small-sized
	Large lops	> 10	Technological
	Branches	< 4	Small-sized

Thus, the research results show that 8-11% of pine and 3-4% of birch and spruce logging waste are suitable for producing technological chips.

Refinement process results

As an example, Figs. 4-5 show graphical dependencies indicating the effect of the working gap between the discs (*g*) and wood fiber pulp concentration (*c*) when using the author's design of the refiner disks (RU 2652177) on the change in some dimensional and qualitative characteristics of fibers: grinding degree (*DS*), average length (L_a), length-to-diameter ratio (L_a/d_a) and the ratio of their fractions: large (F_l), medium (F_m), small (F_s) in the total mass.

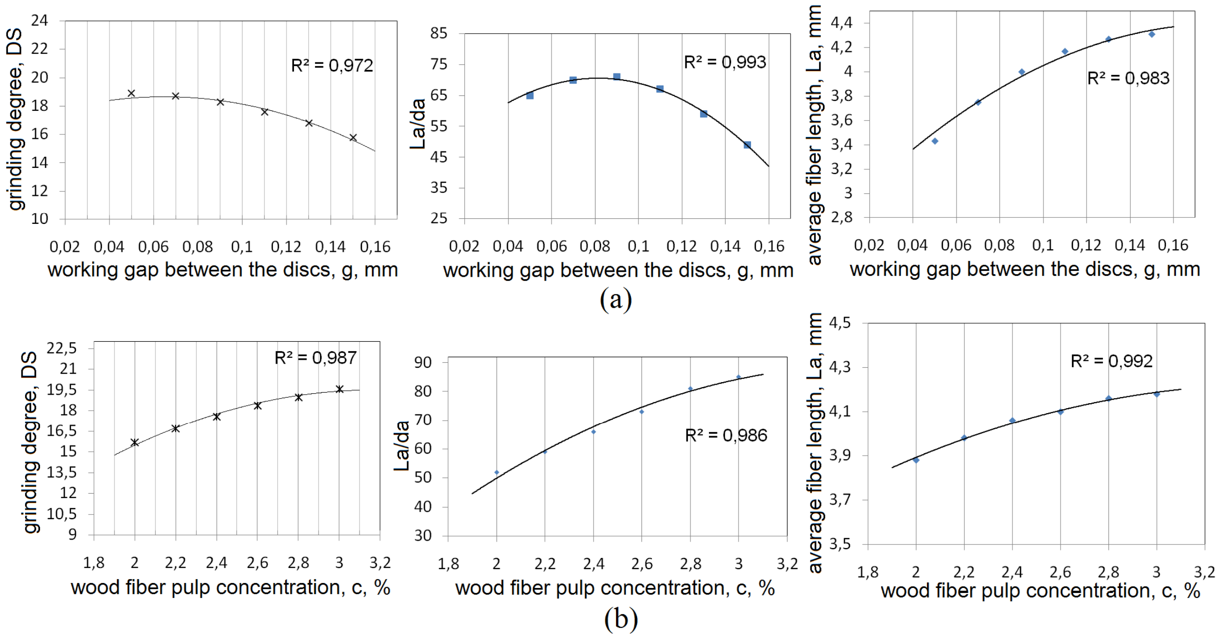


Fig. 4: Dependency of wood fiber pulp qualitative characteristics on refinement process parameters effect: (a) working gap between the discs, (b) wood fiber pulp concentration.

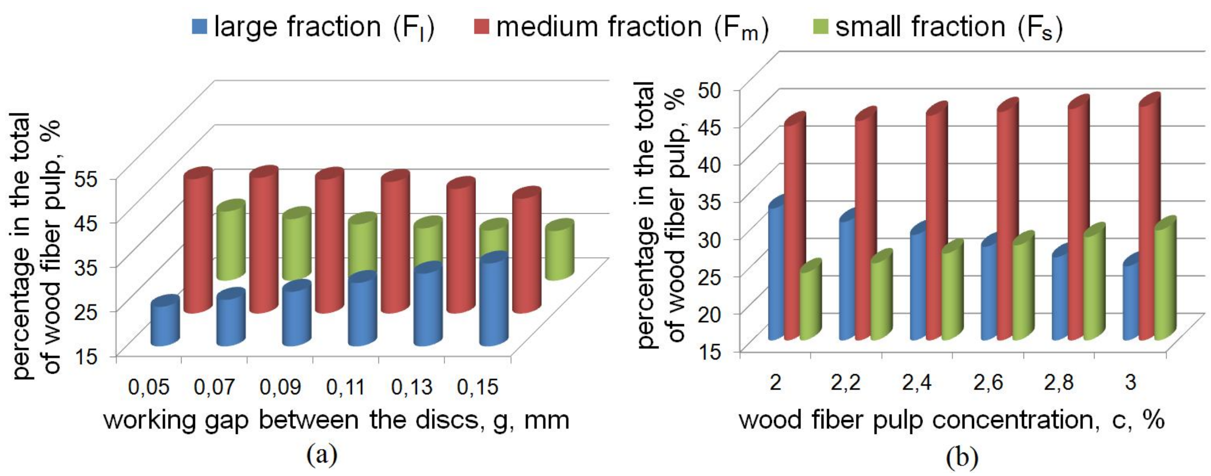
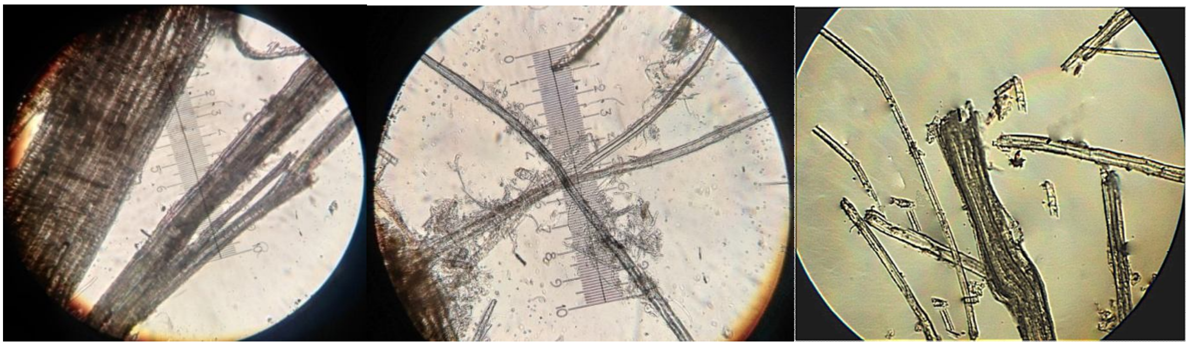


Fig. 5: Dependency of wood fiber pulp fractional composition on refinement process parameters effect: (a) working gap between the discs, (b) wood fiber pulp concentration.

Fig. 6 shows wood fiber before and after refinement (Tab. 3), when using the author's design of the refiner discs (RU 2652177) and the traditional double-sided design (RU 2288313) used in the fiberboard production, all other things being equal.



(a) (b) (c)

Fig. 6: Microscopic analysis of the wood fiber pulp (120x magnitude): (a) before refinement, (b) after refinement when using the author's design of the refiner discs and (c) after refinement when using the traditional design of the refiner discs.

Tab. 3: Wood pulp refinement process results when using various types of refiner disc surface.

Wood fiber pulp qualitative characteristics				**Wood fiber pulp fractional composition**			**Fiberboard physical and mechanical properties**	
Grinding degree, DS	Average length of fibers, L_a, (mm)	Average diameter of fibers, d_a, (mm)	Length-to-diameter ratio, L_a/d_a	Large fraction, F_l (%)	Medium fraction, F_m (%)	Small fraction, F_s (%)	Strength, (σ_i), (MPa)	Density (ρ), ($kg \cdot m^{-3}$)
Design of refiner disc RU 2652177								
18	4-4.1	0.05-0.06	70-80	27-28	45-46	27-28	42-44	933-938
Design of refiner disc RU 2288313								
18	5-5.1	0.12-0.13	38-44	28-30	26-27	44-45	32-34	850-862

The photograph presented in Fig. 6a shows that after preliminary processing in a defibrator, the wood fiber mass has a low grinding degree (10 DS) and is mainly the share of large fraction fibers ($F_l \approx 48\%$) — non-ground bundles, coarse insufficiently processed fibers ($L_a \approx 8.57$ mm; $d_a \approx 0.32$ mm; $L_a/d_a \approx 26.6$) with low contents of medium ($F_m \approx 32\%$) and small ($F_s \approx 20\%$) fraction fibers, which requires subsequent grinding in an refiner (Vititnev 2019).

After refinement in a refiner, as shown in Fig. 6b and c, and as per the data presented in Tab. 3, it is worth noting that fractional composition of wood fiber pulp and its qualitative characteristics changed. However, when using the traditional design of discs (Fig. 6c), the predominant formation of fiber small fraction ($F_s \approx 44\text{-}45\%$) in the total mass and, in general, insufficient flexibility and fibrillation of the fibers is characteristic, as evidenced by the intensity of decrease in their diameter and, as a result, low values of their length-to-diameter ratio. This indicates low efficiency of the refinement process (Chistova 2010, Vititnev 2019), weak interweaving and interaction of fibers in wood fiber mat, and, as a consequence, the need to use additional binding resins when manufacturing fiberboard to ensure its strength characteristics corresponding to the standard GOST 4598: 2018 board of II grade, group B. The author's design of the refiner disks (Fig. 6b) provides high efficiency of the refinement process due to predominance of the fibrillating effect on the fibers, destroying them through weak bonds. It enables to prepare wood fiber pulp with a predominance of medium fraction (F_m ≈ 46%) consisting of well processed and flexible, fibrillated elastic fibers with almost double parameter L_a/d_a ≈ 70-80 as a result of intensive reduction in their diameter, which provides increase in strength of the fiberboard products and high quality of its manufacturing in accordance with the requirements of the standard GOST 4598: 2018 board of I grade, group A, without using binder resins (Vititnev 2019).

CONCLUSIONS

The presented research results may indicate the possibility of effective processing of felling and logging waste, the use of technological chips made of it, in particular, of coniferous wood, to produce wood fiber pulp with improved qualitative characteristics in its further preparation process in a refiner using the developed design of fibrillating disc surface. An increase in the size and quality characteristics of wood fiber pulp provides good fiber bonding and structure formation in a board, which makes the use of binder resins unnecessary, significantly improving the process's environmental friendliness and performance.

In general, this will allow to increase the efficiency and percentage of wood biomass use significantly, reduce the shortage of high-quality raw materials for board production, and partially, but rationally, solve the problem of recycling waste generated at logging sites.

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