Wood Fibre Recapture from Process Water during Wet-forming of Fiberboard: Process Modelling with Environmental and Economic Assessment

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This article presents the rationale for modelling the process of internal recapture of wood fibre from wastewater in fibreboard production using conventional refining methods and a new refiner disc design. New experimental studies to obtain mathematical dependencies for confirming the possibility of reusing cellulosic fines in comparing conventional and new refiner discs for fibreboard production are presented. Models reflecting the internal reuse of cellulosic fines from wastewater were developed. In this article, for comparative assessment of the efficiency of the proposed technologies, an environmental and economic assessment of cellulosic fines in modelling the process of its obtainment in fibreboard production was performed.

DOI:10.15376/biores.18.1.1330-1346

Keywords: Wood fibre; Flotation; Wood fibre recapture; Wood industry waste; Wood fibre recapture modelling; Refiner discs

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INTRODUCTION

One of the most important technological stages in fibreboard production is the wood fibre refining process. When refined by disc refiners, wood fibres are subjected to various influences and thereby change in terms of their properties. The main working part of refiners are refiner discs. The design of their working surface greatly influences the efficiency of the refining process, the quality parameters, and the composition of the resulting wood fibre semi-finished product. The composition and dimensional and quality parameters largely determine the quality of finished boards (Vititnev 2019; Vititnev *et al.* 2021b).

Currently, the quality characteristics of semi-finished wood fibre products and the physical and mechanical properties of fibreboards made from them often do not comply with the requirements of GOST 4598 (2018). Fibreboards have begun losing their competitive appeal when compared to other construction and finishing materials currently available on the market, such as OSB (oriented strand boards), particle boards, plywood, *etc.* The process of updating all the costly refining equipment used to make semi-finished products in fibreboard production is quite challenging. Nevertheless, the preservation and restoration of technological lines for fibreboard production using the “wet” method is reasonable both from an economic and environmental point of view. Requirements of standards regulating the environmental safety of boards and their physical and mechanical properties determining their further use in various industries are becoming more stringent

(Gao *et al.* 2011; Mancera *et al.* 2011; Ihnat *et al.* 2017, 2018, 2020; Song *et al.* 2018; Li *et al.* 2019; Park *et al.* 2020).

At present, researchers from Yu. D. Alashkevich's school have studied many theoretical problems related to the development of various types of refiner disc designs for refining cellulose fibre in the pulp and paper industry (Nabieva 2004; Kovalev 2007; Kozhukhov 2015). However, there remain problems related to wood fibre refining in fibreboard production that are yet to be studied.

The design of refiner discs for making semi-finished wood fibre products in fibreboard production has remained essentially the same for approximately 70 years, and, as studies by the authors (Chistova 2010; Zyryanov 2012; Vititnev 2019) show, it has been inadequately effective due to the predominance of the chopping effect. Consequently, a significant amount of fine fibre fraction (up to 44 to 45%) is formed in the total mass of the semi-finished product, which negatively affects the quality of the finished product and production efficiency in general. The reason why this happens is that refiner discs traditionally used in fibreboard production are designed and manufactured by relying on many years of practical experience. Despite the application of the latest technologies and equipment, the lack of a theoretical basis to justify the choice of a specific refiner disc design depending on the production conditions and the type and quality of the source feedstock keeps hampering the development of the industry and lowering product quality and profitability.

As wood fibres are ground in the refining process, an unequal proportion of fibre fractions is formed in the semi-finished product, in particular, a significant amount of fine fraction. At the stage of moulding and forming a wood fibre mat, a certain amount of fine fraction leaves the sieve filter section and enters the wastewater, thus reducing the quality of the wastewater, further contaminating machine parts, forming slime, *etc.* (Yablochkin *et al.* 2004; Hebert-Ouellet *et al.* 2017; Vititnev *et al.* 2021a; Voinov *et al.* 2022).

Studies by these authors (Vititnev *et al.* 2021b) note that changing the refiner disc design may help ensure an adequate fibrillating effect during wood fibre refining, and therefore obtain a high-quality semi-finished product predominated by relatively long and thin fibrillated fibres with a high length-to-diameter ratio while reducing the amount of fine fraction (up to 28 to29%). However, it is impossible to fully prevent the formation of fine fraction and its ingress into wastewater. Therefore, it is important to not only obtain a high-quality semi-finished wood fibre product, but also prolong its life cycle. This can be achieved by recovering secondary fibres and returning them to core production.

There are possible ways to recover waste: by returning it to the production cycle after proper preparation (regeneration), and by extracting useful components for reuse (recuperation) (Kormishkina 2017). One of the most common ways to capture value from waste cellulosic fibers is by incinerating them. Products can include steam energy, heating, and electrical power. In many progressive countries, returning secondary waste to core production has been a common practice for more than 15 years. These countries include Finland, Sweden, Japan, and Germany (Hebert-Ouellet *et al.* 2017).

The market for recycled fibre is steadily developing and is being introduced in most industries. Recycled fibre can serve as a low-cost alternative to new wood fibre in many products (Grossmann and Zelm 2016). In addition to cost saving, wood fibre recycling has several other advantages. First, it prolongs the life cycle of the feedstock and allows the creation of new products without any additional deforestation (Ihnat *et al.* 2015a,b, 2018; Irle *et al.* 2018). Second, it prevents the accumulation of wood waste and the formation of landfills. Third, recycling fibre means reusing it, and if it is recycled efficiently (under market conditions), it brings both economic and environmental benefits (DaCunha *et al.* 2016; Viger-Gravel *et al.* 2017; Ihnat *et al.* 2018; Zeng *et al.* 2018).

One method to recover wood fibre and reuse it in the core production of fibreboards, paper, and cardboard is by recapturing it directly from white water (Michanickl 1996; Miao *et al.* 2013; DaCunha *et al.* 2016;Grossmann and Zelm 2016; Viger-Gravel *et al.* 2017; Ihnat *et al.* 2018, 2020; Zeng *et al*. 2018; Hernandez *et al.* 2021).The most widely used methods of recapturing fibre from wastewater involve sedimentation flotation with subsequent dehydration by various methods (Hubbe *et al*. 2016; Voinov *et al.* 2022).

Authors (Rubinskaya 2007; Vititnev *et al.* 2021a) studied wood fibre recapture from wastewater and its return to core production while retaining its physical and mechanical characteristics. These studies were conducted using conventional refiner disc types. The types of fibreboard waste mentioned above account for 16 to 32% of the total production amount of semi-finished wood fibre products in this industry and pose a serious problem, as they are currently unused or only partially used at existing fibreboard plants. According to technological process regulations, wood fibre waste is normally not used in fibreboard production. A part of this waste is sometimes utilised in core production.

However, the use of conventional equipment to make semi-finished wood fibre products leads to the formation of a significant amount of fine wood fibre fraction, which negatively affects the physical and mechanical properties of the finished fibreboards. In the work (Vititnev 2019), a new design of refiner discs for making semi-finished wood fibre products was developed and theoretically justified. This new design has had a positive effect on the dimensional and quality characteristics of the resulting semi-finished wood fibre products.

Based on the foregoing, the authors may conclude that the use of fundamentally new refiner discs to grind wood fibre, together with flotational recapture of fibre from white water, will provide the highest efficiency of fibreboard production and therefore guarantee the best values of environmental and economic assessment indicators of wood fibre recapture when modelling its production process.

The aim of this study is to model the process and the environmental and economic evaluation of the capture from industrial water using dispersive flotation save-all of wood fiber and its return to the main composition wood pulp using various designs of refiner disks in the production of fibreboard.

EXPERIMENTAL

Internal wood fibre recycling is a technology that allows recycling wood fibres extracted from white water within the technological process of “wet” fibreboard production and reusing the fibres in the production cycle.

The conventional method of fibreboard production does not suggest such an approach to recycling. This internal wood fibre recycling is completed using the dispersive flotation method to recapture fibre and does not require any additional treatment of cellulosic fines, which Rubinskaya (2007) shows.

According to the theory, wood fibre flotation is based on the process of selective wetting (Friedrichsberg 1984), *i.e.*, on the fixation of a particle on the surface of an air bubble dissolved in water, as shown in Deryagin *et al.* (1986). It is described in such concepts of surface physics and chemistry as hydrophobicity, hydrophilicity, contact angle, three-phase wetting perimeter, and hydrophobisation.

As the modern flotation theory shows, the required particle flotation rate can be achieved not only at $\theta > 90°$, but at any values $\theta = 0°$, which significantly expands the range of how the process can be applied. This is proved in Friedrichsberg's (1984) work using film flotation as an example.

Studies conducted in Rubinskaya's (2007) research prove the effective application of this method for recapturing wood fibre in "wet" fibreboard production.

Unlike the existing technology, the use of cellulosic fines in core production allows for the reuse of wood resources in a partially closed system. Unlike other types of recycling, this technology allows using wood fibre for its intended purpose.

The closed-cycle technology for wood fibre use in fibreboard production consists of several successive stages (Fig. 1).

The core production section in fibreboard production where wood fibre prepared in the core production process can be collected is the moulding machine. More precisely, it is the white water containing considerable amounts of wood fibre. To use recycled fibre in core production, white water is collected for further direction to the flotation save-all equipment. There, the flotation process itself takes place, in which the wood fibre floats to the surface, after which the fibre-containing suspension forming on the water surface is collected. The fibre-containing suspension is moved to a special hopper, from where it is pumped into a headbox and into the main wood fibre composition. Thus, the cycle restarts, following the principles of the circular economy.

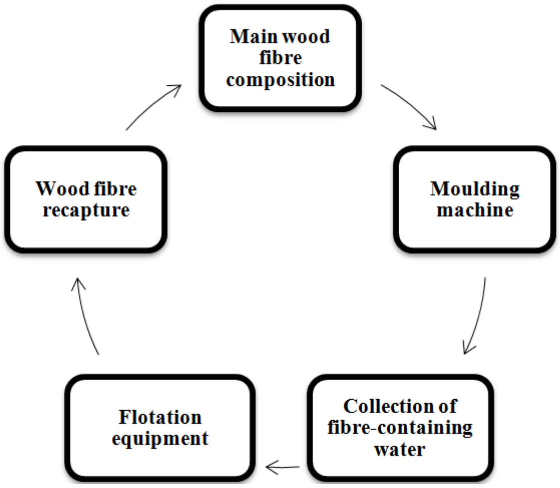

Fig. 1. Illustration of a closed-loop cycle for wood fibre use in fibreboard production

Wood fibre waste subjected to thermal treatment at high temperatures and pressures is an "inactivated" fibre that, when treated again in high-speed cutting mills, is no longer capable of forming strong inter-fibre bonds in the resulting finished boards because of a process called irreversible keratinisation (Thiffault *et al.* 2018).

Methods for Conducting Experimental Studies

Initial raw materials for fiberboard production were technological chips from sawmill residues and low-quality wood from the raw materials warehouse, mixed conifers (99±1%), mainly from Siberian pine, which corresponds to GOST 15815 (83) Process Chips. Specifications. The raw materials were provided by the fibreboard plant of the Lesosibirsky LDK No. 1 Company of Segezha Group.

As the investigated material, wood fiber semi-finished material with different quality characteristics and fractional composition after refining was obtained under all other equal conditions using the traditional (Braun and Sparish 2006) and the new design of the refiner discs (Vititnev *et al.* 2017). Elements of these are shown in Fig. 2.

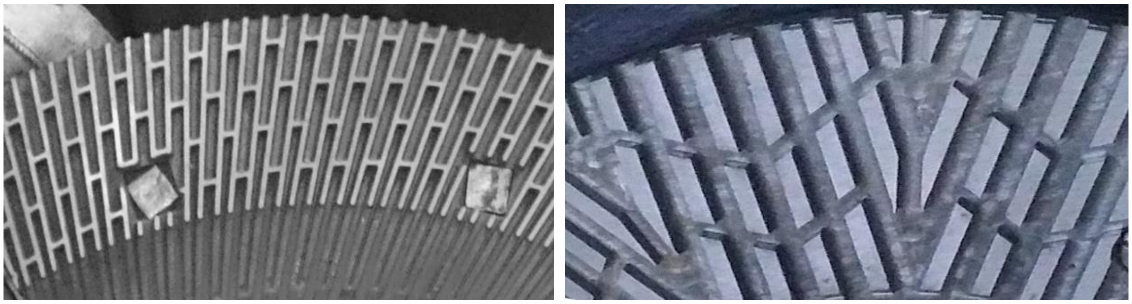
(a) **(b)**

Fig. 2. Structural element of refiner discs of traditional (a) and new (b) design

The difference in the dimensional and quality characteristics of the semi-finished product is due to the design features and the relatively efficient action of the new refiner discs (Fig. 2b) because of the fibrillating effect on wood fibres during their refining (Vititnev 2019; Vititnev *et al.* 2022).

To conduct research of comparative evaluation of efficiency of addition of captured fiber to the basic mass composition when using different designs of refiner discs, captured wood fiber from underflow water in the production of wood-fiber boards was used. During the course of the work, a semi-industrial flotation save-all plant Universal-SM1 (Rubinskaya 2007) (Fig. 3) based on dispersion flotation method was used for wood fiber capturing.

Fig. 3. Semi-industrial flotation save-all - SM1

Figure 4 shows a functional diagram of a dispersive flotation save-all (Vititnev *et al.* 2021a) that gives a visual representation of the flotation stages and their mutual influence.

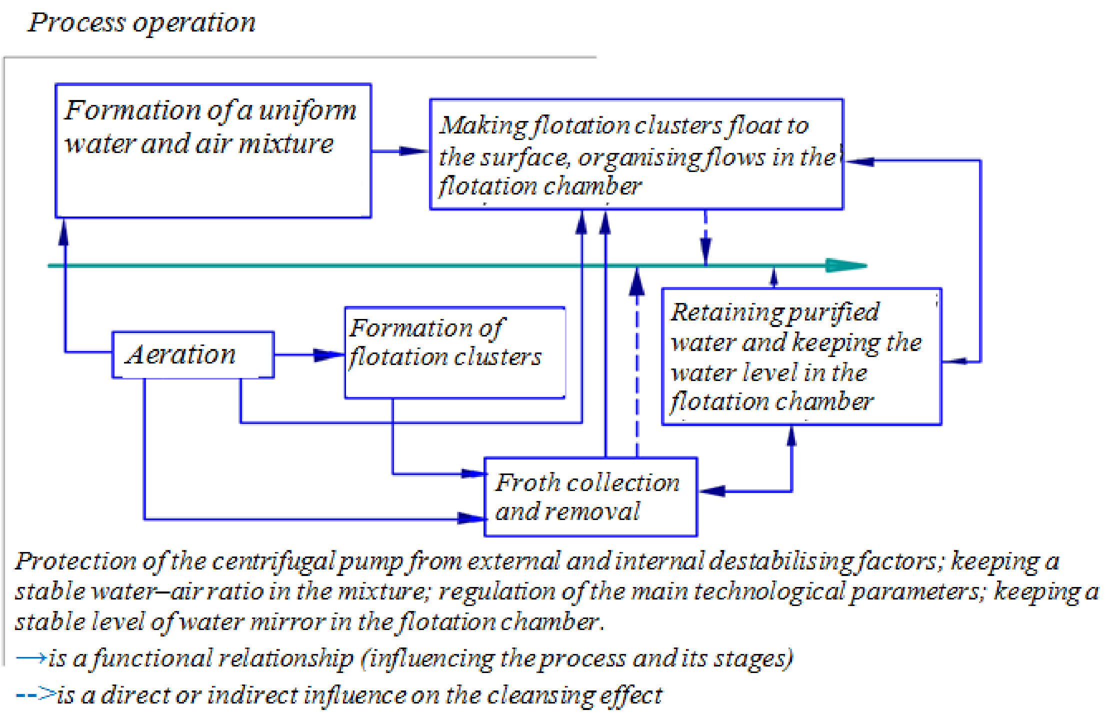

Fig. 4. Functional diagram of a dispersive flotation save-all (Vititnev *et al.* 2021a)

In this method, wood fibre is recaptured when it rises to the surface and is immediately collected from the surface by the specially-designed parts of the equipment and moved to a special accumulation hopper, from where it is directly fed back to the production cycle. It is clear that the cellulosic fines were fed to the studied wood fibre composition to obtain fibreboard samples containing cellulosic fines obtained using conventional and new refiner discs. Adding of trapped fiber, mattress forming, and finished product pressing were carried out at the Central Laboratory of the Lesosibirsky LDK No. 1 company of Segezha Group. All other conditions for fibreboard production were kept the same. As a result, the physical and mechanical properties of finished boards were assessed, in particular the static bending strength (σ_i, MPa) and density (ρ, kg/m^3).

Thus, it was possible to compare the efficiency of adding the captured fiber to the basic mass composition using different designs of refiner discs, as well as to compare the physical and mechanical properties of the finished boards.

Recapturing wood fibre from white water in the production of fibreboard containing wood fibres creates a fibre-containing sediment that must be returned to core production, which was the purpose of planning the current experiment for determining the physical and mechanical parameters of fibreboards depending on the variations of the amount of cellulosic fines in the main composition. The experiment was conducted in two stages: in the first stage the wood-fiber semi-finished product and the captured fiber were used when using traditional refiner discs, in the second stage when using new refiner discs.

In the work, one-factor experiments were planned to determine the dependences of the physical and mechanical characteristics of finished fiberboards on the mass fraction of the trapped fiber in the main composition.

Table 1 shows the input and output parameters of these experiments.

Table 1. Experiment Input and Output Parameters

Parameter	Designation
Input Parameters (Controllable Factor)	
Mass fraction of cellulosic fines from wastewater per unit volume(%)	q
Output Parameter (Controllable Factors)	
Static bending strength of fiberboard using traditional refiner discs (MPa)	σ_{irf1}
Density of fiberboard using traditional refiner discs (kg/m^3) (ρ, kg/m^3)	ρ_1
Static bending strength of fiberboard using new refiner discs (MPa)	σ_{irf2}
Density of fiberboard using new refiner discs (ρ, kg/m^3)	ρ_2

Based on numerous theoretical and experimental studies (Chistova 2010), on the addition of trapped fibers in the basic composition of the wood-fiber mixture obtained by using different designs of refiner discs, the processing of the results obtained in the work obtained functional dependence: σ_{irf1}, σ_{irf2}, ρ_1, $\rho_2 = f\,(q)$.

Processing of Research Results

The results of the experiment were processed using Microsoft Office 2007 (version 12, Microsoft, Redmond, WA, USA). During the processing of single-factor experimental studies, mathematical models were obtained. The obtained models made it possible to establish the dependences of bending strength and density of wood-fiber boards on the mass fraction of secondary fiber in the main wood-fiber composition when using different designs of refiner discs. The resulting models were adequate at a confidence level of 95 to 99%. The values of the coefficient of determination (R^2) were close to unity. The significance of the coefficients was evaluated according to the method (Borovikov and Borovikov 1998) based on Student's t-test and showed their significance. The models were tested by Fisher's F-criterion, which showed their adequacy.

Method for Determining the Dimensional and Qualitative Characteristics of Wood Fibres the Main Composition, Finished Product Physical, and Mechanical Properties

During the implementation of single-factor experiments, the qualitative indicators and composition of wood-fiber semi-finished product were evaluated and used as the basic composition and obtained with different designs of refiner discs: degree of refining (DC); fractional composition (F_l, F_m, F_f, %); average length (L_a, mm); average diameter (d_a, mm); length-to-diameter ratio (L_a/d_a).

The degree of refining of wood-fibre pulp was determined using the Defibrator-Second device by the Sunds-Defibrator company (Stockholm, Sweden) used in fibreboard production. The methodology is presented in the works of the authors (Chistova 2010; Zyryanov 2012; Vititnev *et. al* 2021).

Fractional composition of semi-finished product (F_l(>4 mm), F_m(4-1.5 mm), F_f (1.5-0.04 mm), %). The fibre fractioning device filters a certain amount of wood fibres through sieves with cell sizes corresponding to the qualitative assessment categories (Chistova 2010; Zyryanov 2012; Vititnev 2019). After fractioning, these fibres collected from the sieves were weighed separately, and the weight of every fraction was expressed as a percentage of the total pulp content.

In the fraction separation of fibrous semi-finished products on the FVG-2 fractionator, the wood fibre lengths and diameters were measured by microscopic measurement using a Hitachi TM-3000 digital microscope with a 3,000x magnification. The geometric characteristics were determined according to the known methodology (Chistova 2010; Zyryanov 2012; Ferritsius *et al.* 2018; Vititnev 2019) with the assessment of at least 100 fibers for each sample by calculating the arithmetic mean of length and diameter, followed by the calculation of their ratio.

The physical and mechanical properties of finished fibreboards were assessed in accordance with GOST 4598 (2018), EN 622 (2004), and GOST 10633 (2018).

Methodology for Assessing the Environmental and Economic Efficiency of Wood Fibre Recovery Using Different Types of Equipment for Making a Wood Fibre Product

In our opinion, when evaluating the efficiency of wood fiber capture, attention should be paid to the environmental and economic components of this process. The environmental and economic assessment of wood fiber capture using traditional and new refiner disks was carried out according to the method presented in the authors' work (Vititnev *et al.* 2021a).

RESULTS AND DISCUSSION

Theoretical Study Results

Based on the above technologies for the use and processing of recycled wood fibres, this article presents the authors' model of the process of internal recycling of wood fibre recovered from wastewater in fibreboard production (Fig. 5).

Modelling the process of the internal use of recovered wood fibre combines all stages of wood feedstock processing. Thus, at the first stage, wood chips are prepared considering the technology used and the ultimate goal, *i.e.*, making a specific type of product.At the second stage, wood fibre is obtained in two grinding degrees. It is one of the most important stages in obtaining wood pulp that requires a new approach to ensure a better fibre quality and, consequently, a better quality of finished products.At the third stage, wood fibre is recovered from white water after processing it in the moulding machine.

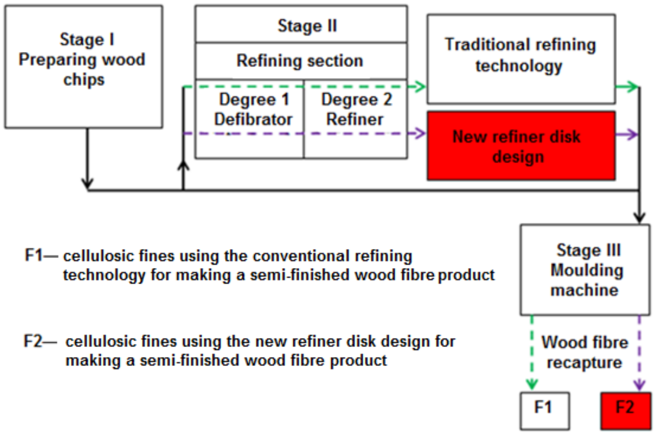

Fig. 5. Model of the process of internal recycling of cellulosic fines from white water

F1 and F2 represent two versions of the same production stage at which it is possible to collect fibre for reuse.

F1 is the section of the technological process where wood fibre produced using the conventional refining technology is extracted from white water using a dispersive flotation save-all. At this stage, no additional treatment of recycled fibre is required, and it directly enters the wood pulp before the moulding machine.

F2 is the section of the technological process where wood fibre produced using refiner discs of the new design is extracted from white water using a dispersive flotation save-all. At this stage, no additional treatment of recycled fibre is required, and it directly enters the wood pulp before the moulding machine.

From the previous studies (Rubinskaya 2007; Morozov 2016), it follows that this resource recycling technology does not require addition of phenol formaldehyde resin for finished fibreboards to retain their physical and mechanical properties.

When modelling wood fibre recapture in fibreboard production, a comparative environmental and economic assessment of the process can be performed using the parameters presented in the authors' work (Vititnev *et al.* 2021a).

Experimental Study Results

Vititnev's 2019 study established that using the new type of refiner disc improves the parameters and composition of semi-finished wood fibre products (Fig. 6) compared to traditional refiner discs (Vititnev 2019).

Figure 6 shows comparison photographs of semi-finished wood fibre products made using refiner discs of conventional and new designs (100× magnification). In addition, the quality of the resulting wood fibre product can be assessed visually.

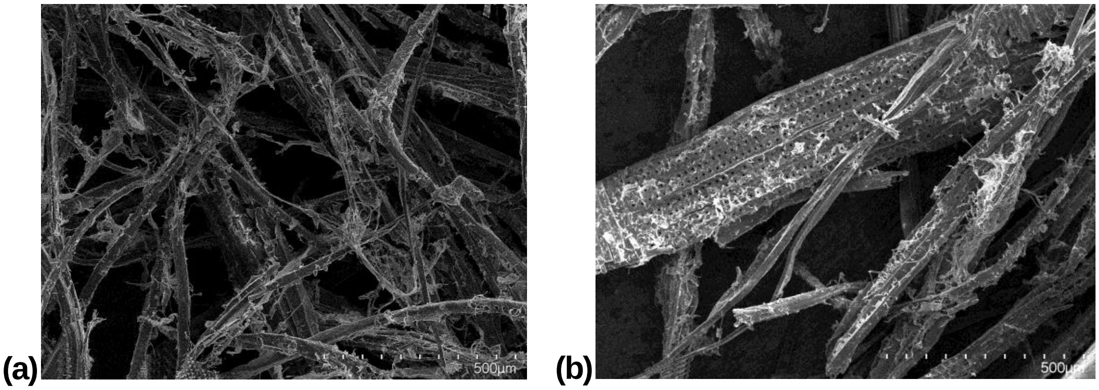

Fig. 6. Photographs of semi-finished wood fibre products with a refining degree of 20 DS (100× magnification) made using refiner discs of new (a) and traditional (b) design

Because of the efficient action of the new refiner disc design, the total mass of the semi-finished product predominantly contains long, relatively thin, and therefore flexible, fibrillated fibres (Fig. 6a), ensuring adequate inter-fibre interaction. Thus, it becomes possible to use cellulosic fines from white water and reuse relatively large quantities of it in the main composition of the wood pulp.

In this work, the authors studied the possibilities of using the fibre-containing sediment present in the main wood fibre composition when using different types of refiner discs: cellulosic fines using the existing refining method when making a semi-finished wood fibre product; and cellulosic fines using refiner discs of the new design when making a semi-finished wood fibre product.

Experiments were conducted to assess the physical and mechanical parameters of the finished fibreboards, such as their static bending strength and density. The experiments showed that cellulosic fines retain all of their properties that are inherent in the initial fibre, and does not require any additional treatment (such as refining and gluing), unlike when using the existing cellulosic fines methods. Therefore, wood fibre recovered using flotation save-allcan be utilised as part of the main wood fibre composition (Rubinskaya 2007).

To establish the maximum possible mass fraction of the cellulosic fines in the initial wood fibre composition without reducing its quality and the physical and mechanical properties of finished products, the ultimate static bending strength and density of the finished boardswere determined. The experiment obtained mathematical models describing the dependence of fibreboard static bending strength and density on the mass fraction of recycled fibre in the main composition.

The dependence of the static bending strength on the studied parameters, taking into account the inclusion of recycled fibre obtained using traditional (Eq.1) and new (Eq.2) refiner discs in the main wood fibre composition, is represented as follows,

$$\sigma_{\mathrm{irft}}=35.413+0.379q_1-0.07q_1^2 \tag{1}$$

$$\sigma_{\mathrm{irft}}=39.629+3.05q_2-0.328q_2^2 \tag{2}$$

where q is the mass fraction of cellulosic fines from the excess process water sent to the save all system.

The dependence of the density on the studied parameters taking into account the inclusion of recycled fibre obtained using the traditional (Eq.1) and new (Eq.2) refiner discs in the main wood fibre composition is represented by the following expression,

$$P=888.96+20.369q_1-1.4167q_1^2 \tag{3}$$

$$P=911.07+3.5952q_2-0.333q_2^2 \tag{4}$$

where q is mass fraction of cellulosic finesfrom wastewater

Figures 7 and 8 are graphical representations of the dependencies that are built based on the obtained models showing the influence of the input factor on the output value.

According to studies (Leonovich 2005; Rubinskaya 2007), this is due to the activation of the fiber contact surface necessary for chemical interaction and the formation of hydrogen bonds at the hot-pressing stage. Some portions of fine fibers have a highly developed specific surface area and increased segmental mobility (Leonovich 2005; Rubinskaya 2007). At the fiber contact interface, lignin structures penetrate each other, followed by the formation of carbon–carbon bonds that significantly strengthen the inter-fibre interaction (Leonovich 2005; Rubinskaya 2007).

It is the authors' (Chistova 2010; Zyryanov 2012) opinion that the preservation of the physical and mechanical properties of boards is because the effectiveness of structure formation of a wood fibre mat is influenced not only by the degree of pulp refining, but also by the fractional composition of the semi-finished product that determines the morphological characteristics of the wood fibre. The predominance of fine substances in the form of fibril plasm (Group A) and mehlstoff (Group B) in the total mass of the fine fracture characterised by large values of the length-to-diameter ratio, which is several times higher than this indicator in other fractions, has a large specific surface area. Thus, these fractions ensure the formation of bonds in boards and to a certain degree improve the formation of their structure (Chistova 2010; Zyryanov 2012).

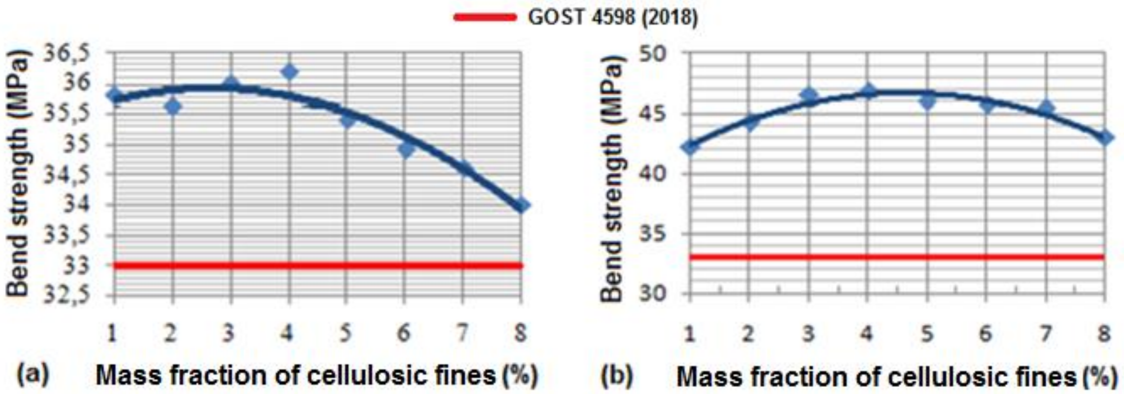

Fig. 7. Dependence of fibreboard bending strength on the mass fraction of cellulosic fines when using traditional (a) and new (b) refiner discs

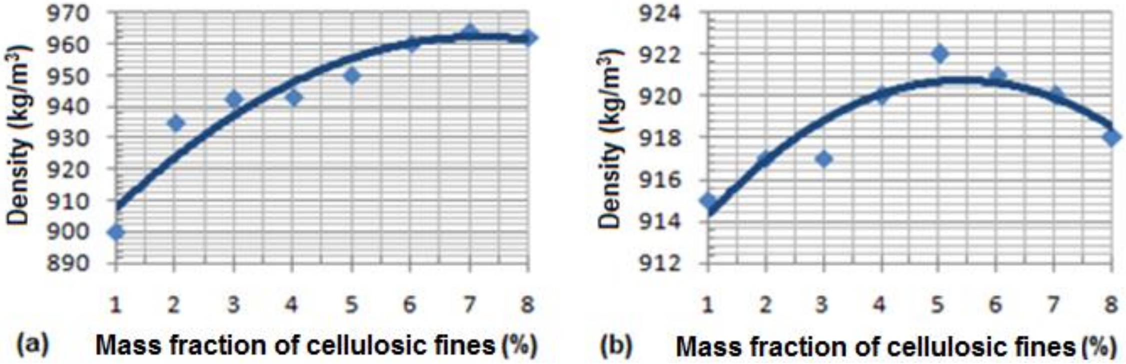

Fig. 8. Dependence of fibreboard density on the mass fraction of cellulosic fines when using traditional (a) and new (b) refiner discs

From analysis of the graphical dependencies in Fig.7, it can be concluded that increasing the mass fraction of cellulosic fines in the wood fibre composition when refiner discs of traditional design (Fig.6b) are used by more than 5% in the main composition affects the strength parameters of the finished boards and significantly reduces them due to the dimensional and quality parameters of the semi-finished products and their composition (L_a= 5.1 mm; d_a=0.146 mm; L_a/d_a= 34; F_l=30%; F_m=25%; F_f=45%). With all other production conditions the same, the use of the new refiner discs allows a semi-finished wood fibre product (Fig.6a) with an improved fractional composition and qualitative characteristics of fibres (L_a = 4.3mm; d_a=0.045 mm; L_a/d_a = 93; F_l=21%; F_m=50%; F_f=29%) to be obtained, while the fine fraction is decreased. The dimensional and quality characteristics of the semi-finished product increase the ultimate bending strength of the finished products, allowing addition of all the recovered fibre to the total mass.

Thus, when the content of cellulosic fines in the main composition is 3.5 to 7%, the value of the bending strength will change from 36 to 34 MPa when using conventional methods of wood fibre production. When using refiner discs of the new design, it will change insignificantly from 44 to 42 MPa. This is because when using refiner discs of the new design, the prepared wood pulp has better quality parameters and composition, while the fine fibre fraction is reduced **(**up to 28 to 29%**)** (Vititnev 2019). This, in turn, entails savings on fibre, as less amounts of it will enter the white water because of its dimensional and quality parameters. This possibility allows the conclusion that the efficiency indicators are high in terms of environmental and economic assessment, which is also established in this article.

The graphical dependencies also show that the output value indicators correspond to GOST 4598 (2018). Studies have shown that wood fibre recovered from recirculated water by flotational treatment should be returned to core production without disrupting the technological process of wood pulp refining, gluing (additional introduction of paraffin and sulfuric acid), and without changing the board pressing temperature mode.

From analysis of the graphical dependencies in Fig. 8, it can be concluded that when using traditional refiner discs (Fig.8a), the mass fraction of cellulosic fines significantly influences the density of the finished boards, which also depends on the amount of fine fraction in the composition of the fibre recovered from white water.

Because a large amount of fine fibre fraction is formed in the total mass when a semi-finished wood fibre product is made using the traditional refiner disc design, it can be recommended to add approximately 5% of the recovered fibre to the total mass (Vititnev *et al.* 2021a).

The experimental studies conducted by the authors also established that when using refiner discs of the new design, wood fibre can be recaptured from the white water and fully returned to production into the wood fibre composition without disrupting the fibreboard production process and without any additional treatment, which was previously impossible. This confirmed the possibility of the environmental and economic assessment of the use of recycled wood resources in fibreboard production by modelling the internal recycling of cellulosic fines from white water.

Comparative Environmental and Economic Assessment of Wood Fibre Recapture

Environmental and economic assessment can be regarded differently. On the one hand, it can be seen as a scientific and technological activity consisting of forecasting effects, assessing them in economic terms, and subsequently developing and adjusting environmental and economic decisions in the production process. On the other hand, it is a mechanism of economic regulation and the associated formal process. In this case, environmental and economic assessment is performed at the level of an individual production facility in terms of a strategic approach (Vititnev *et al.* 2021a).

In accordance with the technological process of fibreboard production and the modelling of wood fibre recapture using conventional and new refiner discs (Fig. 5), two options of grinding conditions were determined that imply different variants of the qualitative characteristics of cellulosic fines. At the wood fibre recapture stage, under-sieve wastewater contains up to 15% of fibre.

At the core production stage, when the flotation save-all is introduced into the technological process, the quantity of waste that can be recovered and returned to core production is 10%, which corresponds to 2,064 m^3 of wood feedstock. The calculation of fees for environmental pollution is regulated by Russian Federal Law No. 7-FZ dated 10 January 2002 *Concerning Environmental Protection*. For 2022, the rates approved for 2018 are applied by including a coefficient of 1.08 (Decree of the Government of the Russian Federation No. 39 dated 24 January 2020).

Table 2. Calculation of the Effect of Recapturing Wood Fibre for Two Ways of Using Refiner Discs

Indicator	Units of Measurement	Value
Quantity of wood fibre that can be returned to core production:	m^3	
– for F1	m^3	2064.79
– for F2	m^3	2949.65
Feedstock cost savings (Es)	EUR	
– for F1	EUR	1219.80
– for F2	EUR	1744.31
Profit from selling recycled fibre (P)		
– for F1	EUR	1935.5
– for F2	EUR	2516.2
Reduced environmental impact fees		
– for F1	EUR	12.93
– for F2	EUR	17.46
Cumulative effect of cellulosic fines (R)	EUR	
– for F1	EUR	3155.3
– for F2	EUR	4260.5

Option F1 is a variant of the technological process section where secondary fibre is extracted from white water with a dispersive flotation device using the conventional approach to refining, while option F2 is a variant of the technological process section where secondary fibre is extracted from white water with a dispersive flotation save-all using the new approach to refining and new refiner disc design. Table 2 gives comparative calculations of feedstock cost savings, profit from selling recycled fibre products, reduced environmental impact fees, and the cumulative effect of wood fibre recapture that shows a significant difference in indicators due to the difference in the quantities of cellulosic fines used in the main composition.

CONCLUSIONS

1. A model of internal wood fibre recycling that clearly illustrates the relationship between the stages of its formation and possible use was developed. The model also shows that traditional wood fibre production methods are significantly inferior to the new approaches. This was established by the authors in a study on cellulosic fines from white water and its reuse in the main composition in wood fibre production using a new refiner disc design.
2. This is the first time such a study has been conducted, as all similar studies up to this point were completed using traditional refiner disc designs. The authors also conducted a comparative assessment of not only environmental and economic indicators, but also the physical and mechanical properties of finished fibreboards, from which it was concluded that the improved quality of the semi-finished product will allow use of larger quantities of cellulosic fines in wood fibre compositions.
3. Expenses related to cellulosic fines and to the new approach to wood fibre production can be recouped with a profit once the further use of products made from recycled feedstock is analyzed and related marketing research is performed.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Centre for Collective Use of KSC SB RAS for supporting their research. This work was completed under the State Assignment issued by the Ministry of Education and Science of Russia for the project: “Technology and Equipment for the Plant Biomass Chemical Processing” by the Plant Material Deep Conversion Laboratory (Subject No. FEFE-2020-0016).

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Article submitted: October 12, 2022; Peer review completed: November 14, 2022; Revised version received and accepted: December 22, 2022; Published: January 3, 2023.
DOI: 10.15376/biores.18.1.1330-1346