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To cite this article: D B Prosvirnikov et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 221 012010

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Mechanization of Continuous Production of Powdered Cellulose Technology

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Abstract. The article presents the mechanization of the process for obtaining powdered cellulose using the technology of steam explosion treatment of lignocellulosic material. The presented unit combines the methods of steam explosion treatment and acid hydrolysis of cellulose-containing raw materials.

1. Introduction
Powder cellulose is a finely dispersed product of the hydrolytic destruction of cellulose, most fully released from the cell wall of vascular plants by the crystalline part of the cellulose chain. The structure of cellulose chains itself combined into a bundle of microfibrils is an amorphous and crystalline areas interleaved along the chain direction. In crystalline sections of cellulose there is a crystallographic orientation of macromolecules and a strong intermolecular interaction. In the amorphous regions, however, only the overall longitudinal orientation of the chains is retained and there is no strict order of the location of the chain sections [4]. Thus, when exposed to cellulose, amorphous areas are first destroyed, and then crystalline areas. In the complete hydrolytic destruction of cellulose, a breakdown of glycosidic bonds occurs and the product of complete destruction of cellulose is glucose [2]. Thus, the essence of the methods for obtaining powdered cellulose is a strictly controlled incomplete treatment of cellulosic material.

2. The background for using lignocellulosic raw materials for the production of powdered cellulose
For the first time microcrystalline cellulose was accidentally discovered in 1955 by Dr. O.A. Battista and Patricia Smith in the laboratory, while they were trying to create a strong viscose cord for automobile tires from cellulose. The discovered features of the structure and properties of the new material, as well as the possibilities of its application, were used as the reason for the organization of its industrial production [1, 3]. Thus, powdered cellulose became of practical interest.

A characteristic feature of powdered celluloses, and in particular of microcrystalline cellulose, is the ability to form gel-like dispersions in water. Due to the ability to be dispersed in a water medium, microcrystalline cellulose has a highly developed hydrophilic surface. Gels of MCC have a high
ability to retain water. Since powdered celluloses have a large specific surface area, therefore surface activity increases, they show high sorption properties.

The complexity of the processes for the production of powdered cellulose, when natural resources are used as feedstock, lies in the fact that such raw materials apart the cellulose itself contain a significant number of foreign compounds. These include lignin, hemicelluloses, various extractives and a small percentage of mineral substances [11]. For the production of powdered cellulose from plant cellulose-containing raw materials, it is first necessary to isolate the cellulose itself. Further operations are to hydrolyze the isolated cellulose, which leads to the destruction of glycosidic bonds in amorphous sections of the chains. Thus, the process of production of powdered cellulose from the original plant material consists of two essentially different stages of impact on the organic material. Particular attention should be paid to the fact that the productivity of the subsequent stage of hydrolytic degradation depends on the initial stage of cellulose evolution [6]. After all, the use of not fully isolated cellulose containing inclusions of other components of plant raw materials significantly worsens the effect of subsequent steps aimed at directly affecting the cellulose chains themselves. Also, the complexity of obtaining powdered cellulose on an industrial scale is to integrate most of the operations into a combined production stream. This is due to the fact that, as a rule, traditional methods of isolation of cellulose have a long duration in time, which considerably complicates the organization of a continuous flow. One promising way of pretreating wood pulp with the subsequent production of cellulose is the steam explosion method, which allows processing almost any cellulose-containing raw material [7, 9].

To date, more interesting are the methods for obtaining powdered celluloses from various plant raw materials with a high content of cellulose. For example, in Brazil, research is focused on the use of waste from various industries, from fruit plantations to the recycling of cellulose materials.

According to the mentioned above, it is of practical interest to provide optimized methods for the industrial production of powdered celluloses that, in addition to integration and combining all operations for the production of powdered cellulose into one continuous process, allow the processing of not only wood raw materials.

An important aspect is that the process of isolating cellulose from plant material is itself laborious and, as a rule, consists of pulping raw materials using environmentally aggressive reagents. In addition, in the production of powdered cellulose, reagents are also used that pose a threat to the environment. All of the above factors require the search and development of such a technological solution that would simplify and modernize the stage of processing of wood raw materials.

To reduce the use of reagents in the production of cellulose from plant raw materials, it is more expedient to apply the method of steam explosion treatment [8, 10]. This method consists in the fact that with a sudden release of pressure, the fibrous raw material, previously saturated with water steam, is destroyed, and a fibrous dispersed material is obtained at the outlet. After this, residual lignin is extracted from the raw material and is further crushed. Further, the cellulose thus obtained is subjected to acid hydrolysis to reduce the degree of polymerization of cellulose. As a rule, concentrated solutions of mineral acids are used for this [5, 13]. The acid concentration also depends on the reaction temperature. The higher the heating temperature, the lower the acid concentration should be used [12].

Thus, the task of mechanization of the technology of continuous production of powdered cellulose is to combine the method of steam explosion, extraction of lignin and acid hydrolysis of the formed cellulose into a single production cycle. The problem is solved by a series connection of a steam explosion reactor, reactors for intermediate operations and an acid hydrolysis reactor. To move the processed material from one stage of the process to the other, a screw conveyor system is chosen.

3. Installation for continuous production of powdered cellulose

An installation for the continuous production of powdered cellulose (Figure 1) comprises a sequentially connected premixing device, a loading and feeding unit, a reactor for steam prehydrolysis of wood raw materials with a transport system, a steam feed and release system, a steam explosion
reactor, a cellulose fiber acid hydrolysis reactor with a system for supplying and removing acid, a unit for unloading powdered cellulose.

The premixing device 1 is filled with wood raw material and water or an acid solution is fed through the valve 4. The components are mixed by a stirrer 2 operating from the drive 3. Then the portion of the impregnated raw material from the premixing device is tangentially supplied to the loading and feeding unit 5, which is in the form of two channels with pistons arranged at an acute angle to each other. Such construction allows the raw material to be fed into the plant continuously.

The operation of the loading and feeding unit is arranged so that the pistons move alternately in both channels. When the piston 15 is in the lower position, the piston 8 is in its upper position, thereby the portion of the raw material from the premixing device is fed into the channel 6. When the piston 8 starts to squeeze the raw material, the piston 15 rises. And when it is in its upper position, the feedstock from channel 6 enters channel 13. Then the piston 15 pushes the portion of raw material into the reactor for steam prehydrolysis of wood raw material 20, thereby closing the junction of the two channels. Thus, when the piston 15 is in the lower position, a seal is provided at the inlet of the reactor 20 with a continuous feedstock loading.

Fig. 1. Layout of installation for continuous production of powdered cellulose
The reactor for steam prehydrolysis of wood raw material is located vertically. Inside there is a guiding screw channel. Along the axis of the reactor there is a steam supply and release system made in the form of a coaxial perforated pipe. Thus, moving downward in a vertical reactor, the raw material is uniformly saturated with steam and is subjected to steam hydrolysis throughout the all time in the reactor, as a result of which the hemicellulose of the wood raw material dissolves and the processed lignocellulosic feedstock remains, which accumulates in the lower part of the reactor. The lower part of the reactor is connected to the vapor explosion chamber by a hydraulic valve. When the raw material accumulated in the lower part of the reactor is compacted under the weight of the incoming portions of raw materials, a hydraulic valve opens and the raw material enters the steam explosion chamber. The pressure in the chamber is equalized with the pressure in the reactor, after which the valve closes, thereby ensuring the chamber is sealed when performing a steam explosion treatment.

In the lower part of the chamber 24 there is a hydraulic valve 28 for discharging the processed raw material into the tank for alkaline treatment of lignocellulosic fiber 31. When the lower valve is suddenly opened, the pressure in the steam explosion chamber is instantly released. The superheated liquid in the pre-impregnated lignocellulosic raw material boils over the entire volume of the particle, which leads to separation of the latter into fibers.

Due to the sharp depressurization of the chamber 24, the mass in the form of a lignocellulosic fiber explodes at high speed into an alkaline treatment tank 31 operating at atmospheric pressure. To reduce the speed of the fiber discharged from the chamber, a grate 33 is installed in the middle of the tank 31. The resulting steam is discharged into the tank jacket 32. The alkaline treatment tank allows the extraction of lignin and impurities from the lignocellulosic fiber. In the lower part of the tank 31, the lignocellulosic fiber is mixed with the alkali solution by a stirrer 34 operating from the actuator 35. The formed cellulose fiber by the flexible screw conveyor 42 from the tank 31 enters the rinsing device 44 in which the stirrer 45 is mixed with water. Water is constantly removed from the washing zone and a fresh portion of water is fed into it.

From the bottom of the rinsing unit 44, the cellulose fiber is transferred by means of a flexible screw conveyor 50 to an acid hydrolysis reactor 52 operating at atmospheric pressure. The reactor for acid hydrolysis of the cellulosic fiber is arranged horizontally, the nozzles of the reactor acid feed and drain system are distributed along its entire length, and the powdered cellulose discharge unit is equipped with a washing system. The cellulose fiber enters the reactor and is moved within it by a rotating screw 53. The cellulose fiber, being moved in the reactor, is hydrolyzed to the limit of polymerization. The pulp is discharged at the opposite end of the reactor. The mass enters the unloading unit 57, which is equipped with a washing system. The washed powdered cellulose is separated from the wash water by means of a filter 59.

At the output powdered cellulose with a high degree of crystallinity is obtained, which is 0.75-0.85 and a dispersion that is 1.1-1.5 m$^2$/g. Such powdered cellulose can be used in the pharmaceutical and food industry as an E 460 filler. The food stabilizer E460 is used in the food industry for the process of making food products such as bakery and confectionery, some types of sauces and dairy products, which are low in calories. In addition, often the substance is added to the composition of filter materials for the production of food products. In the pharmacological industry, the use of the food stabilizer E460 is of no small importance. So, this additive can be used to make fillers of certain preparations, sanitary napkins, adhesive dental materials. It is also allowed to have the food stabilizer E460 in the composition of cosmetics, creams and dyes. In addition, the use of the food stabilizer E460 is also known in the chemical industry, where it is used in the process of producing refractory ceramic products, rubber, sorbents, polyurethanes and bitumen heat-resistant coatings.

4. Conclusion

The presented installation for the continuous production of powdered cellulose allows to reduce the energy consumption for the movement of cellulose-containing raw materials inside the unit with the provision of sealing. Also, the advantage of this unit is that by combining all the process stages, the consumption of reagents is significantly reduced in comparison with the fact that traditional pulping
processes would be used as a stage for isolating cellulose from plant material. Due to lower consumption of reagents, harm to the environment is reduced.

Acknowledgments
The submissions were received during the execution of the state task within the framework of the "Initiative scientific projects" event on the topic No. 13.5443.2017 / BC "Modification of the physical and chemical properties of wood biomass influencing the performance characteristics of the created materials".

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