Influence of technical parameters of disk-shaped reactor on productivity of heat treatment of crushed wood

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Abstract. The existing installations for heat treatment of the crushed wood are analyzed. The technology of heat treatment of the crushed wood in the devices of disk-shaped type is offered. The results of modeling for the purpose of determination of interrelation of the key design and technological parameters of the disk-shaped device are presented. It is established that the major factors, affecting duration of stay of the material in a device, are the speed of rotation of the mixer, the number of mixers and the number of rakes on the mixer.

1. Introduction

In recent years there is an increased interest of researchers in the processes of heat treatment of wood filler in the production of composite materials [1-3]. The spectrum of composite materials in these works is quite wide: from composites with mineral binders to materials with polymer matrixes.

Ayrilmis N. et al. [4, 5] investigated the effect of preliminary thermal treatment of wood raw materials on the properties of MDF (medium density fibreboard). The results of the studies indicate a decrease in the thickness of the swelling of the composite and a certain decrease in the mechanical properties within the limits meeting the requirements of the standard for medium density fibreboard. Garcia R. et al. [6] confirm the absence of statistically significant differences in mechanical properties between standard MDF panels and panels made from wood subjected to heat treatment.

Westin M. et al. [7] analyzed the effect of pre-heat treatment of wood filler in the production of wood-polymer composites on biological resistance. The authors found that samples after infection with three types of fungi and staying for 10 weeks in the ground and marine environment showed an increase in the stability of composites based on thermomodified filler to rot in both mediums. Moreover, wood polymer composites from pre-thermally treated wood buried in the ground retained resistance to the action of terrestrial microorganisms after 47 weeks. Similar studies were conducted by a scientific group led by Hosseinaei O. [8]. They also observed an increase in resistance to the decomposition of wood polymer composites based on thermomodified wood.

From the latest domestic studies in the field of the effect of thermal modification of wood on the properties of wood-filled composite materials, a series of studies conducted at the Kazan National Research Technological University [9, 10] can be identified.

An analysis of the changes in properties and characteristics of plywood created on the basis of thermally modified veneer is presented in [10]. On the basis of the conducted experimental studies, a decrease in the swelling pressure and water absorbing capacity of the veneer was revealed, corresponding to an increase in the degree of processing of the material. The author carried out studies
of the permeability of thermo-modified veneer sheets with liquids, which showed a gradual decrease in permeability with an increase in the degree of heat treatment, followed by an increase in permeability at high degrees of thermal modification. The author explains this phenomenon by the joint action of the processes of constriction of pores as a result of thermal shrinkage and their plugging by products of decomposition of wood at low degrees of thermal modification and "puncturing" the veneer pores from the decomposition products with deeper heat treatment.

The results of the presented studies indicate an increased interest in the problems of thermal processing of crushed wood in the processes of production of wood-filled composites. This is announced by an increase in the performance characteristics of these materials and the expansion of the scope of their possible application.

At the same time, various types of reactors (screw, drum, belt, shaft units, etc.) are used for thermal processing of crushed wood raw materials, among which there are disc type apparatuses characterized by the possibility of efficient processing of raw materials of different fractional composition. However, the currently available methods for calculating such reactors are based primarily on material and thermal balances. Such models are not suitable for optimization calculations in order to improve the quality of the obtained products.

In this regard, the development of a mathematical model of the process of heat treatment of crushed wood in the tray type reactors and the determination of the main design and technological parameters of equipment are an urgent task.

2. Materials and methods
Thermal treatment of the crushed wood material was carried out on laboratory installation 1, the scheme of which is shown in fig. 1. It consists of a tray reactor, a circulating agent system for processing 2, air displacement system 3, control system 4, charging device 5, shutter 6, horizontal trays with overflow holes 7, 8, agitators 9, 10, engine 11, inclined partition 12, valve 13; gas flue 14, electric heaters 15, 16, gas blowers 17, sealed container 18, thermocouple 19.

The installation works as follows. Initially, the heating of tray reactor 1 is carried out. Electric heaters 15 and 16 and blower 17 are activated. The movement of the gaseous coolant occurs from top to bottom in a closed loop. At the same time, the heated stream washes the surface of the trays and, passing through the overflow holes, enters flue 14 and returns through the pipeline to electric heaters 15 and 16, from where, with the help of blower 17, it is again sent to the heat treatment chamber. After apparatus 1 is warmed up in the air, acicular vent 20 is opened and carbon dioxide is fed into the chamber with open valve 13. In this case, the carbon dioxide expels air from apparatus 1. At the same time, electric heaters 15 and 16 and blower 17 operate to maintain the temperature in the chamber at a predetermined meaning. After reaching in the apparatus a concentration of carbon dioxide above 80%, recorded with a gas analyzer operating in the range of 0-100%, feeding of crushed feedstock 21 to upper plate 7 of reactor 1 begins from loading device 5. As a result of feeding a certain portion of raw material, shutter 6 is closed.
Figure 1. The disk-type reactor for torrefaction of the crushed wood.

Next, engine 11 is turned on, and agitators 9 and 10 are rotated with a small predetermined speed, ensuring that the crushed wood remains in the reactor for about 40-50 minutes.

After passing the trays, the material enters lower unloading ramp 12, which is guided into sealed container 18 for accumulation and gradual cooling. After cooling, the processed material is discharged from vessel 18 for further investigation. For the study, room-dry shavings of various types of wood were used. To ensure the process of heat treatment of crushed wood, the temperature of the medium in the reactor was maintained at 200-260 °C.

3. Results

When developing the physical picture of the process of heat treatment of crushed wood in a tray reactor, it was stated that the areas of overflow holes of all the reactor trays should be equal. In order to determine the duration of the stay of a particle on one plate, it is necessary to find the length of its path \( \ell_{\text{mov}} \), which affects the dimensions of the reactor. From this, the dependence of the motion length of the particle on plate \( \ell_{\text{mov}} \) on the radius of central overflow hole \( R'_{\text{centr}} \) of the odd plates and \( \Delta R'_{\text{side}} \) was found (provided that their areas are equal).

An approximate range of the path length of the particle from 1 to 4 m with the dimensions of the lateral overflow gap of even plates from 30 to 50 mm corresponds to the radius of the central overflow hole of odd plates in the range from 400 to 500 mm, which is in complete agreement with the general ideas about the design solutions of the dishwashers [9]. Hence, the dependence of the internal radius of the reactor on the radius of the central overflow hole of the odd plates was determined. The indicated dimensions of the central overflow hole are characterized by internal diameters of the reactor in the range of about 3 to 8 m, which is consistent with the literature data [2, 11].

The time of motion of the particle along the plate depends on the average radial component of the instantaneous velocity. In connection with this, a simulation was carried out to determine the dependence of the magnitude of the mean radial component of the instantaneous velocity on the various technical characteristics of the equipment. In particular, the dependences of this parameter on the angle of rotation of the \( \alpha \) blades with respect to the radius of the plate at various angular velocities.
of the mixer and the radius of the overflow holes are presented.

The change in the angle of installation of the blade on the mixer with a radius of the central overflow hole of 300 mm does not significantly affect the time of movement of the material. The most noticeable change is observed at a radius of the central overflow hole - 500 mm. Here, when the blades are mounted on a mixer at an angle of 45 °, the highest values of the given particle velocity on the plate are achieved. Thus, in large-diameter production reactors the residence time of the particle on the tray can be controlled in particular by the angle of rotation of the blades, so further calculations will be carried out for the blades installed at an angle of 30 and 45 °.

To determine the residence time of the particle at rest between the blades, modeling was carried out for various amounts of blades (fig. 2). At the same time, it was found that with increasing the speed of the stirring device, the time of the material stay in a stationary state is reduced.

![Figure 2. The change in the residence time of the particle at rest between the blades as a function of the angular speed of rotation of the mixer.](image2)

The curves characterizing the dependence of the total residence time of a particle on one plate on the angular velocity of rotation of the mixer are presented in fig. 3.

![Figure 3. Dependence of the residence time of the particle at rest on the number of mixers on the plate for i = 6 pcs.](image3)

It has been found that the staying of the particle at rest has a more significant effect on the total length of the material on the plate than the time when the particle is in motion.

In the course of mathematical modeling, calculations were carried out to determine the minimum
necessary size of the lateral gap, ensuring unimpeded spillage of the processed raw material onto the underlying plate. The size of the side gap is influenced by the particle size and the height of the layer of the processed material on the plate, the speed of rotation of the mixer and the radius of the plate itself.

The next step in the process of modeling the wood particle torrefaction reactor [7, 8] is to find the number of plates in the apparatus necessary for thermal modification of the entire crushed material. The calculations were made based on the results of the experimental studies of the change in the average densities of thermally modified crushed wood raw materials [9]. At the same time, the number of trays in the reactor was selected from the required degree of material processing.

Using the kinetic curves of the density variation of the crushed wood raw material during the thermal modification, the total time of thermal modification was determined depending on the degree of material processing, the results of which are shown in fig. 4.

![Figure 4](image)

**Figure 4.** The degree of thermomodification of pine chips at various processing temperatures.

### 4. Conclusion

The influence of the basic design parameters of the tray reactor on the productivity of heat treatment of crushed wood is established. As a result of the simulation, the main parameters of the equipment that influence the quality of heat treatment of crushed wood were identified, the analysis of which allowed us to propose a new design of the reactor.

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