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Thermal modification of wood by the method of thermo-mechanical dehydration with pressure drop

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Abstract: *Thermal Modification of Wood by the Method of Thermo-Mechanical Dehydration with Pressure Drop*. The results of experimental research of thermal wood processing by the method of high temperature drying with pressure drop are presented. Drying was carried out cyclically by heating the material under pressure to the temperature 100-140 ^oC followed by pressure drop. After that the temperature was raised up 160-210 ^oC and the samples were processed briefly in those conditions. This treatment is shown to be effective for large-sized wood.

Keywords: Drying, pressure drop, thermal modification, thermo-mechanical dehydration

INTRODUCTION

Increasing the efficiency of thermally modified wood (TMW) production is an important task. Analyzing different methods of production TMW showed that in most cases the cost of production depends on the organization of the drying process. Equipment with drying process and thermal modification combined together has a significant advantage. However, at present drying process in such equipment is much longer than the time of thermal modification. This disadvantage can be eliminated by using the intensive method of thermo-mechanical dehydration with pressure drop. This method was proposed in 1926 by H. Fleissner for drying and grinding coal (Mikhailov 1967). In the scientific activities of Heat and Mass Transfer Institute (Kozhin and Gorbachev 2009) it was shown that in certain conditions this method can be used for drying large-sized wood. According to this method, wet material is heated cyclically in a sealed chamber under the pressure of interstitial gas followed by rapid pressure drop.

MATERIALS AND METHODS

Technology of cyclically heated material under pressure to the temperature 120-140 ^oC in a sealed chamber filled with an inert medium (steam, CO_2, N_2) followed by pressure drop was developed. On the Figure 1 you can see the diagram of the production process. It includes next stages:

Preparatory stage. The wood is placed in a chamber which evacuated and then a drying agent is supplied: neutral gas (CO_2, N_2) or superheated steam.

After that the temperature is raised steadily to 100 - 140 ºC. During this time the pressure increase too.

The first stage of modification - thermo-mechanical dehydration with pressure drop. Due to the heating of the wood and the evaporation of the moisture contained in it, the pressure in the chamber increases. When the pressure is reached set parameter or after a set period of time (cycle time) pressure is released to atmosphere. The molar vapor stream moves through the material under the influence of the pressure drop and takes out some part of the moisture in the form of liquid particles, which reduces heat consumption for drying. When pressure is released due to the heat accumulated by the material, active evaporation takes place. The moisture content (W) of wood is measured and if this parameter more than 8%, the heating process with subsequent pressure drop is repeated again until the moisture content of the wood becomes less than 8%.

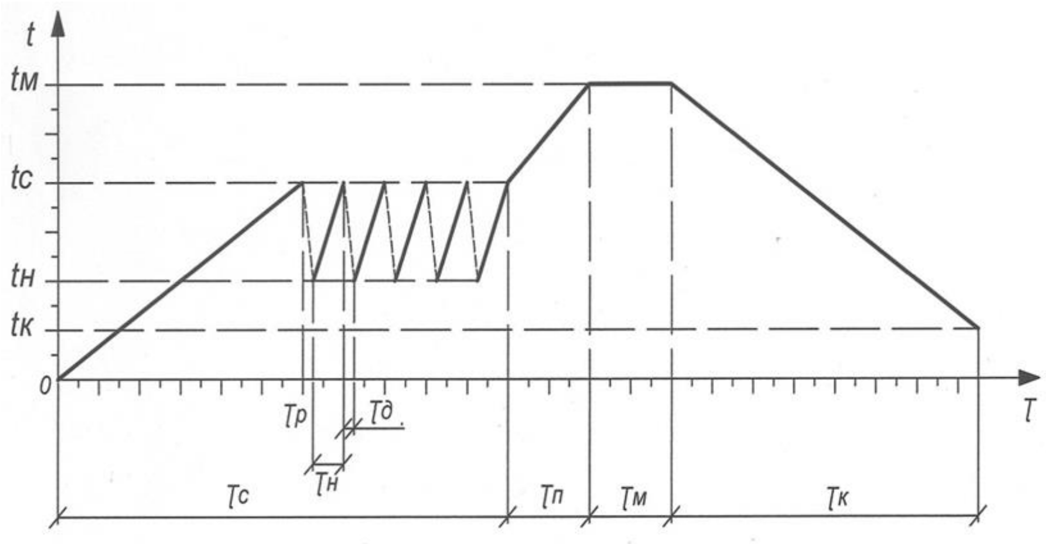

Figure 1. Diagram of the thermal modification by the method of thermo-mechanical dehydration with pressure drop. $\tau_{с}$ – drying time; $\tau_{р}$, $\tau_{д}$ – time of pressure drop, $\tau_{н}$ – material heating time; $\tau_{п}$ – time of raising the temperature to thermal modification; $\tau_{м}$ – thermal modification time; $\tau_{к}$ – cooling time, $t_{м}$ – temperature of the sample during thermal modification; $t_{с}$ – material temperature during drying; $t_{н}$ – saturation temperature; $t_{к}$ – material cooling temperature.

The second stage is a high-temperature treatment of timber. The temperature inside the chamber is increased to between 160 ºC and 210 ºC. When the target level has been reached, the temperature remains constant for 0,5–2,5 hours depending on the end-use application.

The speed of raising the temperature in the chamber is 40 ℃ / h. There are two classes of heat treatment: «Thermo S» and «Thermo D». Thermo-S class treated wood in 160–180 ^{o}C, and Thermo D – 180–210 ^{o}C.

Table 1. Classes of heat treatment.

Classes of heat treatment	Wood species	Temperature	Treatment time
Thermo S	Softwood Pine Spruce Fir	160 – 180 ^{o}C	1 – 1,5
	Hardwood Beech Ash Oak	150 – 170 ^{o}C	0,5 – 1
Thermo D	Softwood Pine Spruce Fir	180 – 210 ^{o}C	2 – 2,5
	Hardwood Beech Ash Oak	170 – 200 ^{o}C	1 – 1,5

The final stage is cooling and moisture conditioning. Depending on the heat treatment temperature and the type of wood it takes 5 to 15 hours. At this stage it should paid attention to the temperature difference between the timber and cooling air, which may cause cracking. After cooling re-moisturising takes place to bring the wood moisture content to a useable level 5–7%.

The kinetics of thermo-mechanical dehydration by the pressure drop method was studied in the laboratory installation shown in Fig. 2. For the study were used cylindrical pine samples 0.1 m in diameter and 0.9 m long with an initial moisture content W = 69%. The sample was heated in a sealed stainless steel autoclave filled with carbon dioxide.

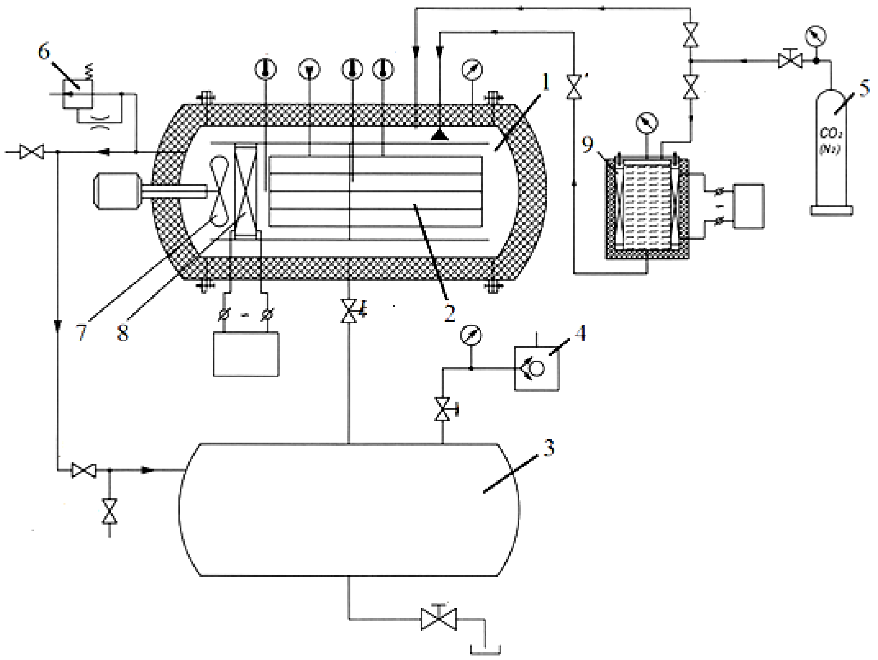

Figure 2. The Scheme of the Experimental Installation. 1 – chamber; 2 – sample; 3 – receiver; 4 – vacuum pump; 5 – balloon with CO_2; 6 – fast-active valve; 7 – fan; 8 – heater; 9 – tank.

RESULTS AND DISCUSSION

Fig. 3 shows the results of measurements taken in the process of drying by pressure drop. It also shows the changing pressure in the chamber during the experiment, the temperature in the material, and the amount of liquid extracted from the material (collected in the condensing tank).

Measurement of the moisture of the sample by the weight method showed that in 8 hours it was possible to reduce it to 11.3%, with no deformation and no appreciable cracks were observed on the sample. Moisture in the center of the sample is lower than moisture at the periphery. The effectiveness of this treatment method decreases with lowering wood moisture below the hygroscopicity limit.

At the first stage of drying with pressure drop it is necessary to control continuously distribution of temperature and humidity in the sample that determines dates of the termomechanical treatment, the rate of pressure drop and parameters of the drying agent. At this stage there is a change in the permeability of wood and as a result in the pressure relaxation time which determines the rate of pressure drop. According to this method of drying the level of stress in the sample depends both on pressure drop and on the distribution of moisture near hygroscopicity limit. Stresses in the sample is caused by a humidity gradient.

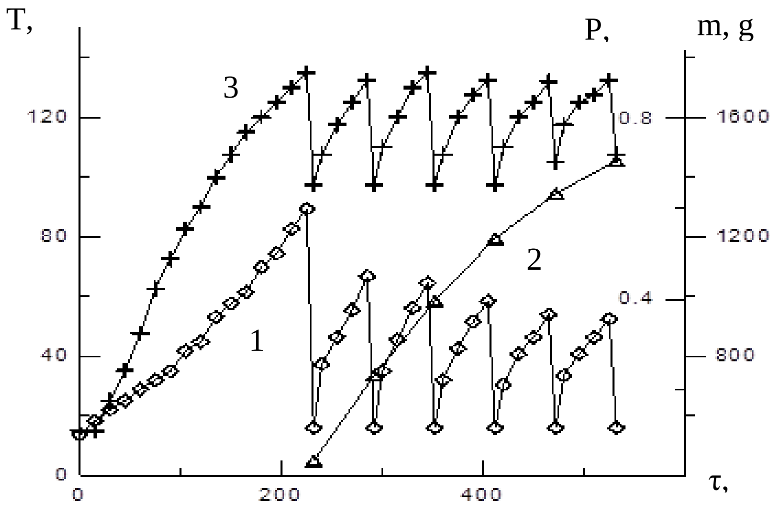

Figure 3. The temperature of the sample and the mass of moisture removed from it during drying pressure drop method. 1 - pressure in the chamber, MPa, 2 - mass of the removed moisture, g, 3 - temperature in the center of the sample, °C.

The results of experimental studies of large-sized wood by the method of thermo-mechanical dehydration at the temperature t = 120-160 °C with pressure drop, as shown in Fig. 4, demonstrate the effectiveness of this method on the initial stage of thermal wood modification wood. The photo shows samples of heat-treated pine wood 0,2 m in diameter.

Figure 4 - Samples after drying.

Thermal modification reduces the mechanical properties of wood, but increases the dimensional stability, moisture resistance and resistance to decay.

Figure 5 - Samples after drying and thermal modification.

A series of experimental tests was carried out on the experimental installation under the following conditions: temperature t = 160-210 °C, pressures p = 0,6-1 MPa, medium - CO_2 or dry saturated vapor. As a result several qualitative samples of thermo-modified pine and oak were obtained, which were then tested for moisture resistance and biostability.

Appearance of samples after 2 weeks of incubation on Serpula lacrymans are shown in the Fig. 6. Samples of the initial pine wood without thermal modification loss there bio-stability 54 % and samples of wood treatment with 200 °C during 80 min (medium - carbon dioxide) – 0,5 %.

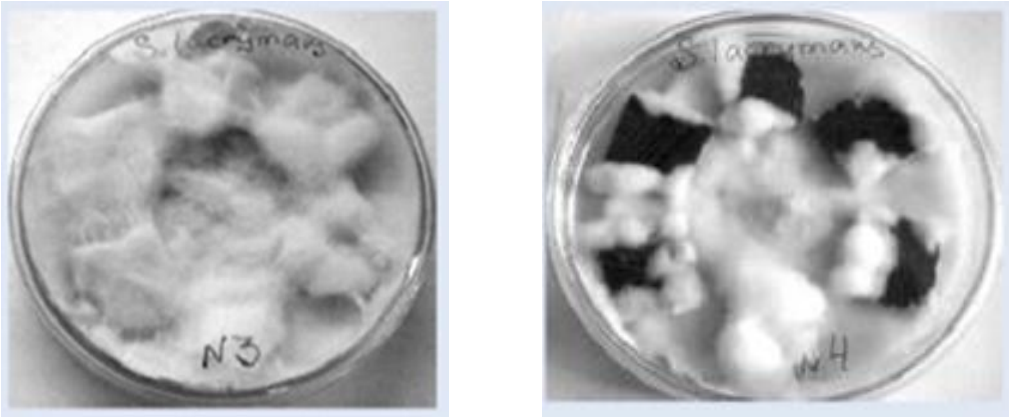

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Figure 6 - Definition of bio-stability properties thermo-modified wood. 1 - native samples; 2 - samples intended for thermal modification.

The color of the treated wood is affected by temperature and processing time. The higher the temperature, the darker the wood. The final color of hard species of wood as well as soft ones usually depends on the change in density as well as wood age. (Gorbachev at al. 2007).

CONCLUSIONS

Analyzing the results of the experiments it is possible to conclude that the effectiveness of treatment wood by the method thermo-mechanical dehydration followed by pressure drop. Drying time of fresh cut round pine 0,1 m to a humidity of 4-10% at temperature of 110-120 ^oC was 7-8 h, it is depending on the initial moisture of the samples. The drying intensity was 1,4-2,5 kg/($m^2 \cdot h$). Application of these technologies allows reduce the drying time of large-sized wood 3 - 5 times and decreasing heat energy costs by 15 - 17 %, compared to existing technologies.

Proposed technology makes it possible to obtain a high-quality thermo-modifed wood by pre-drying, which provides the process without the development of significant internal stresses, and the subsequent supply of CO_2, which removes the stresses arising during heat treatment, and shortens the duration of the cooling steps.

The technology is effective in processing large-sized wood: both rounded and timber with a characteristic size of section up to 230 mm.

Estimates show that using of this technology allows to reduce the cost of production the thermomodified wood by 20-25% due to increased productivity and energy efficiency of the process.

It is possible to introduce this technology on the already existing equipment for thermal modification of wood processing it under the pressure of the gaseous medium.

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Streszczenie: *Termiczna modyfikacja drewna metodą termo-mechanicznego suszenia z redukcją ciśnienia*. Przedstawiono wyniki badań eksperymentalnych obróbki termicznej drewna metodą suszenia wysokotemperaturowego ze spadkiem ciśnienia. Suszenie prowadzono cyklicznie poprzez ogrzewanie materiału pod ciśnieniem do temperatury 100-140 ^{o}C, a następnie redukcji ciśnienia. Kolejno temperaturę podwyższano do 160-210 ^{o}C i realizowano obróbkę termiczną. Modyfikacja tego typu okazała się szczególnie skuteczna w przypadku elementów drewnianych o dużych rozmiarach.

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