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DEVELOPMENT OF THE ENERGY-SAVING TECHNOLOGY OF THERMAL MODIFICATION OF WOOD IN SATURATED STEAM

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ABSTRACT

The possibility of technology of thermal modification of green wood without pre-drying is shown for the first time. Carrying out the process in a saturated high pressure steam followed by vacuum drying due to the accumulated material energy is offered. The aim of the development of this technology is to reduce the energy consumption for the process and improve the final quality of the material, namely the absence of smell of thermo wood and crack formation on the surface of the material.

An experimental setup for of high-moisture wood in a saturated high pressure steam, which allowed us to obtain advices on regime parameters of accelerated thermo modification of wood in the saturated steam without prior drying was created.

Keywords: thermo wood, steam, energy saving technology, thermal modification.

INTRODUCTION

Around the world in recent years there is the development of new technologies in the field of building materials, particularly wood, aimed primarily to improve the physical, mechanical and decorative properties of the source material as well as to make it more resistant (BOONSTRA *et al*. 2007), elastic and durable (BOONSTRA *et al*. 1998).

Wood as a building material has many positive properties, but relatively short lifetime, low shape stability and the presence of fungal infection (CALONEGO *et al*. 2010) reduce its competitiveness in comparison with metals and synthetic materials.

Until recently, the most common method to modify the properties of wood and fight the fungus was the chemical processing of wood by impregnation or surface treatment by organic oils or inorganic salts, the toxic effect of which stops the development of fungus, but it has a negative impact on the environment. In this regard, one of the top priorities in the technology of processing of wood in recent times is thermo modification of wood, which produces environmentally friendly thermo wood with decay resistance, durability (BOONSTRA *et al*. 1998) stability of the geometric dimensions (EVANS 1990), an attractive aesthetic appearance (BEKHTA and NIEMZ 2003) and beautiful tone from light brown to dark brown (DZURENDA and DELIISKI 2012, KLEMENT and MARKO 2009). Thermal modification of wood allows you to offer consumers products that meet the highest demands and also gives the ability to produce the thermo wood with desired properties.

A recognized leader in the production of thermo wood in the world is the Finnish company VTT, which has developed the technology of thermal modification of wood in superheated steam Thermowood® (SAFIN and FATHULLOVA 2014). In addition, the largest global manufacturers of thermo wood are Valutec Oy and Tekmaheat Oy (Finland); Baschild (Italy); "Superior Thermowood" (Canada); "Mühlböck-Holztrocknungsanlagen" (Austria), Tre Timber (Estonia), The major Russian company is "Prominvest DIARSO" and LLC "West-wood Rus"(SAFIN and FATHULLOVA 2014).

A common feature of the known methods of thermo modification of wood is a temperature range of heat treatment from 180 to 240 ^{0} C, due to physic-chemical processes occurring in the wood at a given temperature, contributing to the color change of the material and its physical and mechanical characteristics (HILL 2006). The darkening of colors in proportion to the growth temperature, processing time and moisture content of the wood is common for all the methods of thermal modification. Changing the temperature of heat treatment allows achieving the desired color of wood and the degree of resistance to environmental conditions (DZURENDA 2013, DZURENDA and DELIISKI 2014). The fundamental differences are the time of treatment from 16-180 hours and the processing environment: in a protective atmosphere of superheated steam (Termowood, PLATO-Wood and WEST-WOOD), in a protective atmosphere of inert gas - nitrogen (Retification), in the environment of organic oils (Thermoholz) (SAILER *el al*. 2000).

Despite the high cost of water vapor and, as a consequence, the energy intensity of the process, many manufacturers of thermo wood opted vapor as the most optimal treatment agent to obtain thermo wood of high quality, highlighting the advantages in high heat transfer coefficient, high resistance to fire and the quality of the finished product, determined by the uniformity of color over the entire cross section of thermo wood. However, such factor as superheated steam chosen by many manufacturers of thermo wood as agent processing along with the use of long pre-drying of materials, which significantly increases the energy consumption for the process prevents the wide application of the technology of thermo modification of wood in the environment of water vapor, gradually being displaced by the less energy-intensive and not always providing high quality products methods of heat treatment (PERRE and KEEY 2006).

In this connection the development of the energy-saving technology of thermal modification of high moisture wood assortment in the environment of saturated steam without pre-drying is relevant.

THEORY

Technological process of thermal modification of wood in a saturated water vapor consists of the following main phases: temperature rise in the apparatus to 180–220 °C by feeding saturated steam from the steam generator, the treatment of wood at high temperature and pressure of saturated steam within 4–8 hours for the purpose of thermal modification of material, vacuum for drying of the treated wood (Fig. 1).

The process of thermal modification of wood begins with the purging of the apparatus with steam to remove air from the working chamber, which subsequently contributes to a more intensive heat and mass transfer between the wood and the treatment agent due to the absence of the phase resistance. Next comes the phase of increasing of temperature and, as a consequence, of increasing of pressure steam environment in the apparatus. The law of increasing temperature (SAFIN *et al*. 2014) allows preventing uneven heat treatment at a cross section of wood.

After reaching the ambient temperature 180–220 °C heat treatment of the material for a given temperature happens to achieve the required degree of treatment. The temperature and duration of heat treatment depends on the desired properties and color of the final material. At this stage, the greatest change in chemical composition of wood caused by degradation of the least heat-resistant components, separation of the reaction water, carbon dioxide and some other products happens.

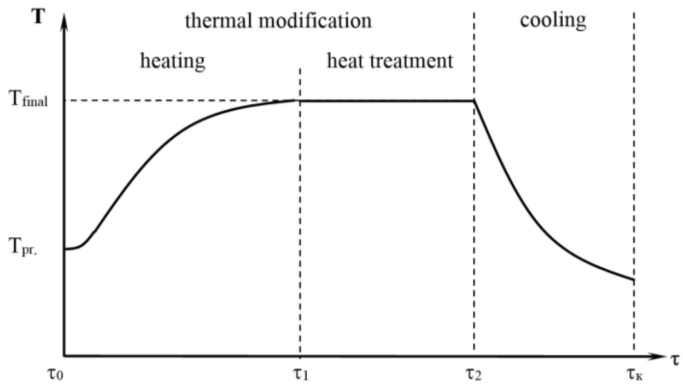

Fig. 1 Scheme of the process of thermal modification of wood.

After the stage of heat treatment in the water steam of high pressure cooling stage begins carried out by pressure relief to atmospheric values and further vacuumization, the main purpose of which is the drying of the material. Drying of the material occurs at the expense of thermal energy previously accumulated by the material, and cooling of the wood due to the intensive evaporation of moisture. The process for simultaneously drying and cooling ends when the wood temperature is about 20 °C. The moisture content of thermally modified material as a result of such drying can be reduced by 25–35 % depending on the species, initial moisture content and thickness. If further drying of lumber is necessary, cycle «heating – vacuumization» can be repeated several times.

MATERIAL AND METHODS

To study the kinetics of thermal modification of wood in an environment of saturated steam an experimental setup a schematic diagram of which is shown in Fig. 2.was created.

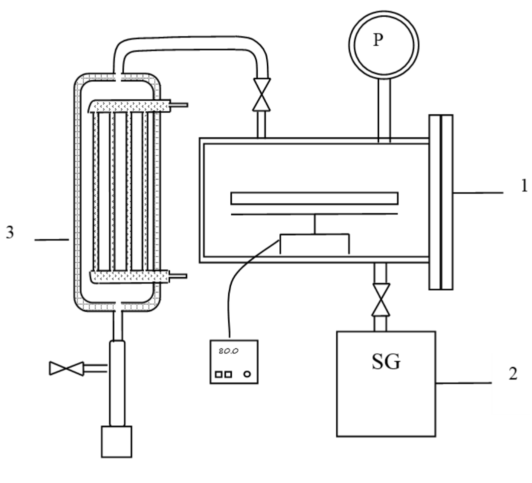

Fig. 2 Scheme of the experimental setup of thermal modification of wood in saturated steam.

The installation includes a chamber for thermal modification of samples of wood 1, a steam generator 2 and a refrigerator condenser 3. Samples of pine, birch, oak with the thickness of 10–60 mm, the width of 50 mm, length along the fibers of 200 mm and different moisture content of U = 20–80 % are treated.

The experimental setup allowed us to conduct a study of the impact of various operating and design parameters on the kinetics and dynamics of processes. 80 samples of wood are treated during the experiment.

The analysis of the content of volatiles in heat-treated wood was determined by heating of thermally modified samples of pine in glass beakers. During this process substances evaporating from wood condensed on glass plates. Then the plates were removed from the glass beakers, and the degree of contamination of the glass surface by volatiles substances, determined by measuring the intensity of light, reflected at a certain angle with the help of a photoelectric gloss tester, indirectly characterized the purity of wood samples from volatiles, causing a burnt smell.

RESULTS AND DISCUSSION

To determine the optimal treatment agent of thermal modification of wood, which allows intensifying the process of heating the material to a predetermined value and to make the process less energy intensive, a comparative analysis of the processes occurring during thermal modification of wood in saturated and superheated steam, is conducted. Data on the thermal modification of lumbers in superheated water vapor were taken from (SAFIN and SHAIKHTDINOVA 2011). As a result of modeling the dependence of time of warming up lumber at S = 50 mm with the initial moisture of 20 % to the required treatment temperature during warming up of pine in superheated and at the same width and initial moisture in saturated steam is shown (Fig. 3).

According to the curves presented in Fig. 3, it can be concluded that in order to accelerate the process of heating of wood, it is necessary to use a high temperature, which, however, should be chosen taking into account the physic-mechanical properties of wood, changing under the influence of high temperatures. It can also be seen that the time of heating the material to a desired treatment temperature in saturated steam is shorter compared with the time of heating in superheated steam, due to the high heat transfer performance of saturated steam and a good heat-conducting properties of the moist material used for this process.

Another distinctive feature of the presented technology of thermal treatment of wood in an environment of saturated steam are improved final qualities of the material, namely the lack of the smell of thermo wood, which is achieved by repeated steaming and vacuuming of thermo wood while the cooling stage. In this regard, according to the known methods of study of the released volatile matter from the material, the samples of thermally modified pine were studied after a few cycles "steaming - vacuumization". The test results are shown in Fig. 4.

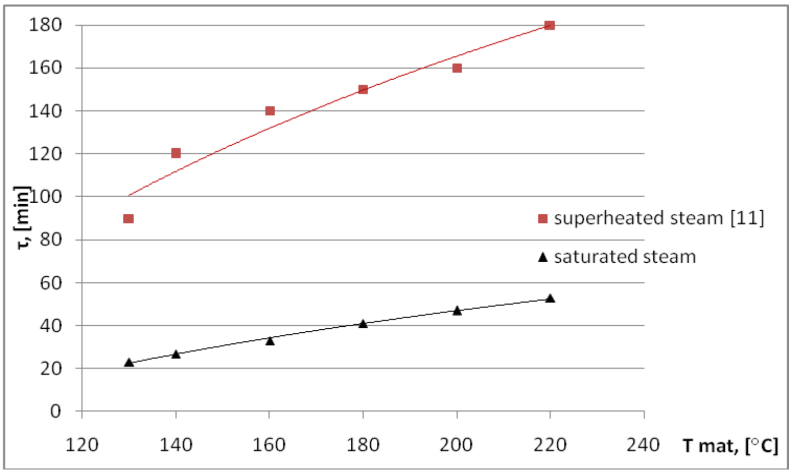

Fig. 3. The time of temperature rise in the center of the sample of pine (at s=50 mm) to the desired temperature when heating in superheated and saturated steam.

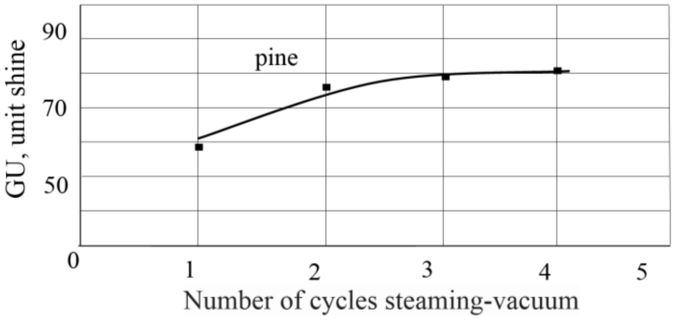

Fig. 4 Study of the degree of contamination of the glass surface by volatiles substances determined by heating of thermally modified samples of pine in glass beakers depending on the number of cycles "steaming - vacuumization".

The given data allow us to conclude that the volatile substances in the thermo wood decreases with each new cycle "steaming - vacuumization", which proves the feasibility of this procedure with the purpose of getting rid of the smell of thermo wood. And a rational cycle for lumber thickness up to 50 mm is 3–4 cycles.

To determine the influence of sample thickness on the intensity of the process of thermal modification the experimental studies on the kinetics of the changes in wood density for different thicknesses of material during thermal modification of wood in the environment of superheated and saturated steam were carried out. During the process in saturated steam for the purpose of reducing errors of experiment curve density is an averaged value being obtained as a result of the series of experiments with multiple identical samples without defects and knots, taken from the same log and heated in identical conditions, but being treated at a predetermined temperature for different times (1 h, 2 h, 3 h, etc.). The results are presented in Fig. 5.

According to the curves presented in Fig. 5, it can be concluded that the thickness of the lumber directly affects the length of treatment. You can also see that the decrease in the density of the material during thermal modification in saturated steam is more intense in comparison with processing in superheated steam.

Table 1 presents the results of experimental studies showing the time dependence of heating of wood in a saturated and superheated steam up to 220 °C from the thickness of the material (10–60 mm) for three wood species (pine, birch, oak).

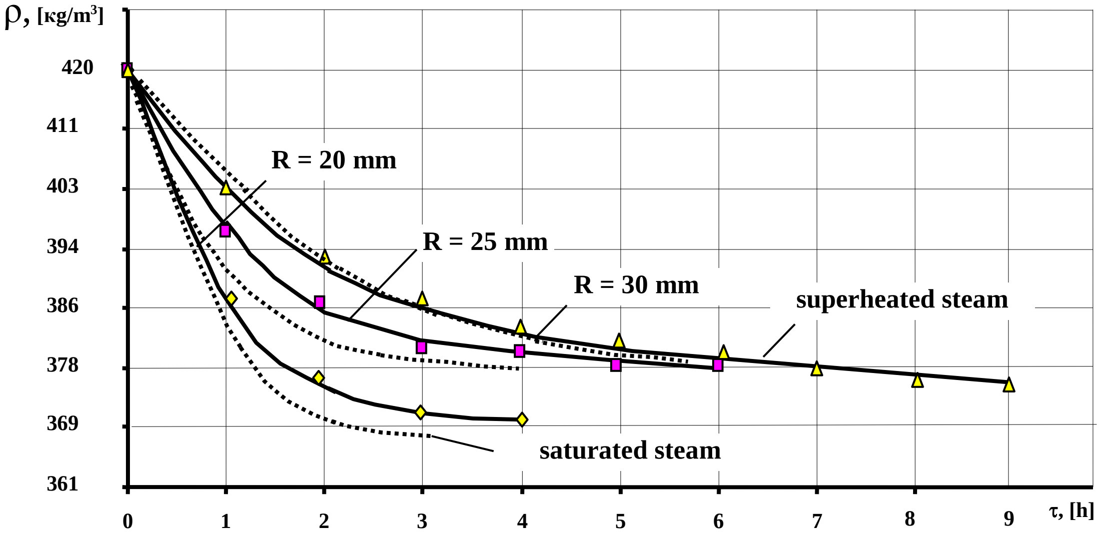

Fig. 5 The change in the density of pine sample depending on the thickness of the material during thermal modification (T = 200^{0}C) in the superheated (____) (SAFIN and SHAIKHTDINOVA 2011) and saturated steam (----). R – thickness in [mm].

Tab. 1 The duration of heating of the material up to 220 °C in saturated and superheated steam depending on the thickness of wood samples.

Wood species	Saturated steam		Superheated steam	
	S, mm	t, min	S, mm	t, min
Pine ρ = 0,52 g/cm^3	10	41	10	120
	20	52	20	132
	30	65	30	139
	40	76	40	150
	50	92	50	162
	60	100	60	180
Birch ρ = 0,65 g/cm^3	10	35	10	100
	20	42	20	112
	30	50	30	120
	40	61	40	128
	50	68	50	135
	60	77	60	155
Oak ρ = 0,69 g/cm^3	10	24	10	90
	20	30	20	105
	30	39	30	110
	40	42	40	118
	50	51	50	122
	60	60	60	130

It can be seen from the data presented in table 1, that the smaller the density of wood and the thicker the sample, the longer is the warming-up stage.

From the research of the duration of the cooling phase after heat treatment in a saturated steam the time of reduction to a predetermined temperature and the value of the final moisture content of thermo wood were determined by experimental study. It should be noted that the duration of the cooling phase in this case is influenced not so much by the required final temperature but by the required final moisture content of the wood. These dependencies are presented in Fig. 6, which shows that the less the required final moisture content of the wood, the greater the duration of this stage.

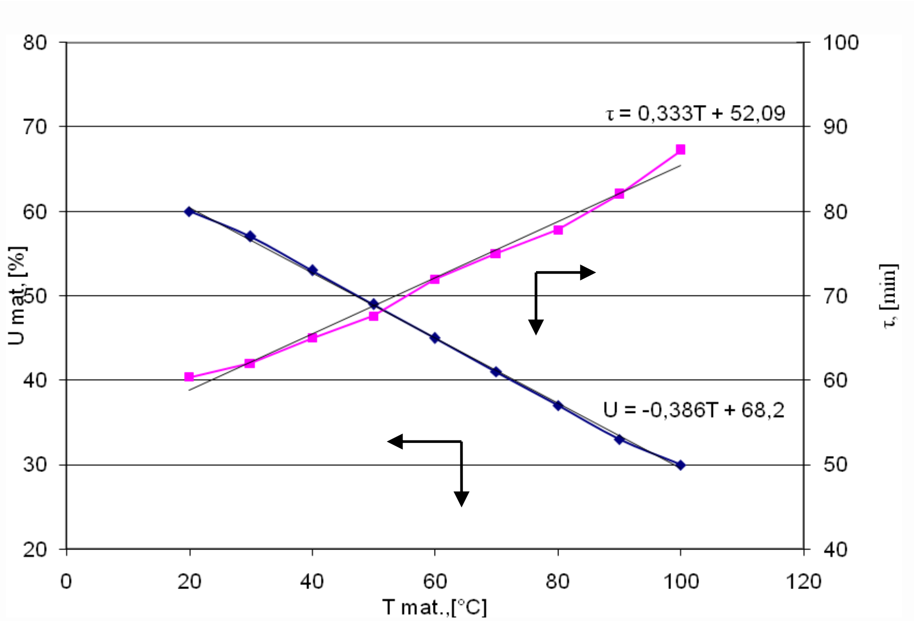

Fig. 6 The dependence of the final moisture content and duration of the cooling phase of the final temperature of the material.

Hence, setting the final moisture content of wood after heat treatment in a saturated steam we must follow the economic expediency: if treated wood will be used outside subsequently, being exposed to natural air-drying, the long-lasting stage of cooling is not particularly appropriate.

From the research of the moisture content of wood samples in the process of thermal modification in saturated steam the data showing the changes in the moisture content of samples of pine, birch, oak at the treatment temperature 200 °C were obtained by experimental study (table. 2).

It can be seen from this table that due to the more porous structure of pine wood, it is much stronger saturated with moisture at the stage of thermal modification than birch and oak. Therefore a further stage of vacuumization can not completely remove absorbed moisture and final moisture content of pine becomes higher than the initial one. During the processing of birch and oak, their final humidity is reduced comparison to their initial moisture content that allows us to make a conclusion about the possibility of simultaneous drying and thermal modification of these wood species as a result of thermal modification in saturated steam and subsequent vacuumization. At the same time, such dependence is not observed for pine, probably due to the more porous structure of the wood.

Tab. 2 Changes in the moisture content of samples of pine, birch, oak when at the treatment temperature 200 °C.

Breed of wood	U [%], initial humidity	U [%], humidity after the filing of saturated steam	U [%], final humidity
pine	80	170	90
birch	80	115	60
oak	80	95	40

CONCLUSIONS

On average of 1.2 GJ is spent on the process of drying of 1 m^3 of wood in modern convective drying chambers. In this regard, the technology of thermal modification of wood in saturated steam without pre-drying stage with the possibility of further drying, if necessary, has been first developed. This technology is relevant from the point of view of reducing the energy consumption and has no analogues in Russian and foreign markets.

The experimental setup for studying the kinetics of thermal modification of wood in an environment of saturated steam has been designed. The parameters influencing the energy consumption during the process of thermal modification and allowing getting recommendations on regime parameters of vacuum-convective thermal modification of wood in the environment of saturated steam have been obtained.

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