UDC 674.04.047.3

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CHANGE OF THERMAL PROPERTIES OF WOOD IN WARMING UP PERIOD IN THE UNSATURATED ENVIRONMENT

Thermophysical characteristics of pine wood were investigated by the complex method. Dependencies that reflect the temperature changes character on the surface and inside the wood with time were received. Change principles of the thermal conductivity coefficient, of specific heat, temperature conductivity coefficient of wood with time when heated in unsaturated environment.

Introduction. The first technological operation of saw-timber drying process is initial warming up which is done to bring the temperature of the material being dried up to the temperature level of the drying agent.

In the modern drying chambers the warming up operation is carried out with the saturation rate of the processing environment less than 1, i.e. in the unsaturated environment. In such conditions the wood warming up is accompanied by moisture evaporation from its surface and, as consequence, the temperature level of the surface layers is less than the processing environment temperature. It is possible to explain this fact by the following: at warming up in the unsaturated environment there are two simultaneous processes of heat transfer in wood: heat conductivity directed from the assortment surface layers to its internal ones, and hydraulic conductivity in the opposite direction. Thus, at the initial warming up both temperature and wood humidity will change that will cause the change of other physical properties of wood. Thereupon the researches directed at measurement of current values of thermal capacity, heat conductivity and temperature conductivity are of obvious practical interest.

The existing research methods of thermal properties of wood give a chance of their determination only in specific stationary conditions, i.e. in conditions when the thermal current passing through wood remains constant with time. The initial warming up of wood is a non-stationary process because there is changing with time and on section temperature of the assortment itself and temperature of the processing agent. Therefore the authors used the research method based on the method of complex determination of the thermalphysic characteristics at heat exchange of bodies in the environment with linearly changing temperature. One method of complex definition thermalphysic characteristics in the linear heating mode consists in usage of bodies system, one of which has the known thermalphysic properties. This method was used for the first time by E. P. Shurygina [1].

Objective. Determination of change character of wood thermal properties with time in the initial warming up period and also of temperature speed change on the surface and inside wood was the purpose of the present work.

Research technique. Principal circuit of the experimental installation of wood thermal properties during the initial warming up period in the unsaturated environment is given in Fig. 1.

A pine wood plate with the thickness of $2l_1$ touches two steel plates each of which has the thickness of l_2. Thermalphysic properties of outside plates are identical, but are different from the properties of the inside plate.

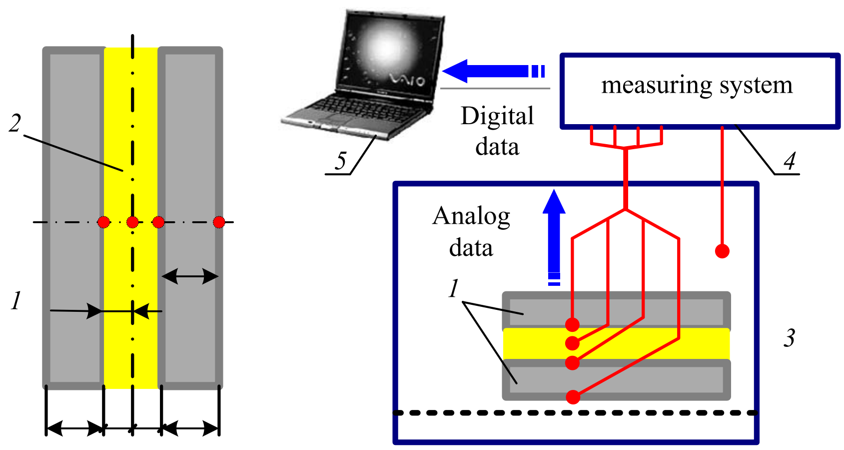
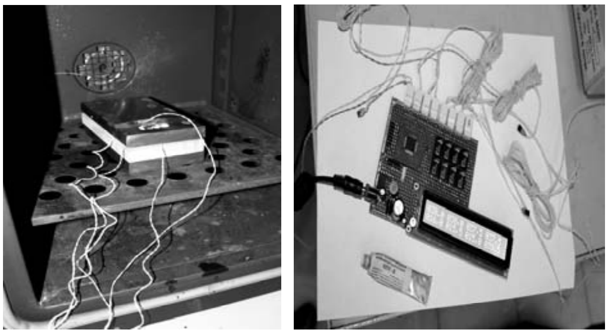


Fig. 1. Principal circuit of the experimental installation:
1 – metal plates (steel 20); *2* – pine wood sample; *3* – oven;
4 – measuring system; *5* – computer

To determine temperature inside and on the surface of wood the measuring system was applied having four temperature sensors DS18S20. On the metal plate, the surface of which contacts the air, temperature detector T_1 is placed and on the surface adjoining the wood – temperature detector T_2. At the depth corresponding to half a thickness of the wood sample there is temperature detector T_3 and on the wood surface adjoining the other metal plate – temperature detector T_4. All detectors were insulated by paste KPT-8 in order to avoid the processing agent influence on the measurements results. The initial temperature of all system elements was identical and equal to ambient temperature t_0 = 15–20°C.



a *b*

Fig. 2. General view of the measuring system:
a – system of plates; *b* – measuring installation

To ensure warming up of the wood sample the described above system of plates was placed into the oven (Fig. 2, *b*). Temperature of the processing air was checked with the help of temperature detector T_5. Indications of all detectors were registered with accuracy of 0.5°C with periodicity of 5 min at the beginning and 20 min at the end of warming up process. Warming up was carried out until the temperatures difference on the surface and inside wood did not make 0.5°C. Samples humidity was found out with the help of a hydrometer GANN HT 85. Conditions of experimental researches carrying out and characteristic of wood samples and metal plates are given in Table 1 and 2 accordingly.

The described experimental installation permits to define at any chosen moment of time the temperature differences on thickness of metal plates $\Delta T = T_1(l_1, \tau) - T_2(0, \tau)$ and of the wood sample $\Delta T_0 = T_4(l_1 + l_2, \tau) - T_3(l_1, \tau)$. Using the measurements results it is possible to calculate the thermal characteristics of wood and to determine the character of their changes with time according to the mentioned below formulas:

$$a_1 = \frac{b \cdot l_1^2}{2 \cdot \Delta T_0}; \quad (1)$$

$$c_1 \cdot \gamma_1 = K_{c\lambda} \cdot \frac{\Delta T}{b} - h, \quad (2)$$

where

$$K_{c\lambda} = \frac{\lambda_2 \cdot 10^{-2}}{l_1 \cdot l_2}; \quad (3)$$

$$h = \frac{c_2 \cdot \gamma_2 \cdot l_2}{2 \cdot l_1}; \quad (4)$$

$$\lambda_1 = \frac{l_1^2}{2 \cdot \Delta T_0} \cdot (K_{c\lambda} \cdot \Delta T - b \cdot h), \quad (5)$$

here b – warming up speed of the metal plates surface, ºC/h; λ_1, λ_2 – thermal conductivity coefficient of metal and wood accordingly, W/(m · ºC); a_1 – wood thermal diffusivity, m^2/sec; c_1, c_2 – specific thermal capacity of metal and wood, J / (kg · ºC); λ_1, λ_2 – metal and wood density, kg/m^3 [1].

Table 1

Conditions of the experiment carrying out

Characteristics of experimental samples						Warming up temperature t, ºC
Wood species	Dimensions, mm			Humidity W, %	Grain direction	
	thickness	width	length			
Pine	20	100	200	30	radial	40
	20	100	200		tangential	
	40	100	200		radial	
	40	100	200		tangential	
Pine	20	100	200	53	radial	60
	20	100	200		tangential	
	40	100	200		radial	
	40	100	200		tangential	

Table 2

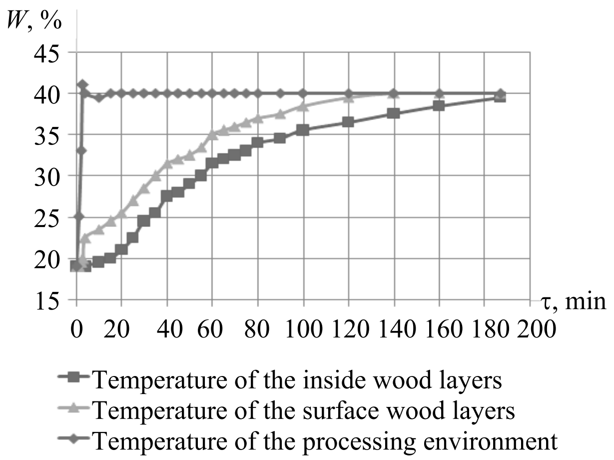
Characteristics of metal plates

Material	Dimensions, mm			density γ, kg/m^3	Thermal conductivity coefficient λ, W/(m·ºC)	Specific heat c, kJ/(kg·ºC)
	thickness	width	length			
Steel 20	20	100	200	7853 at 40ºC, 7847 at 60ºC	51.65 at 40ºC 51.2 at 60ºC	0.486

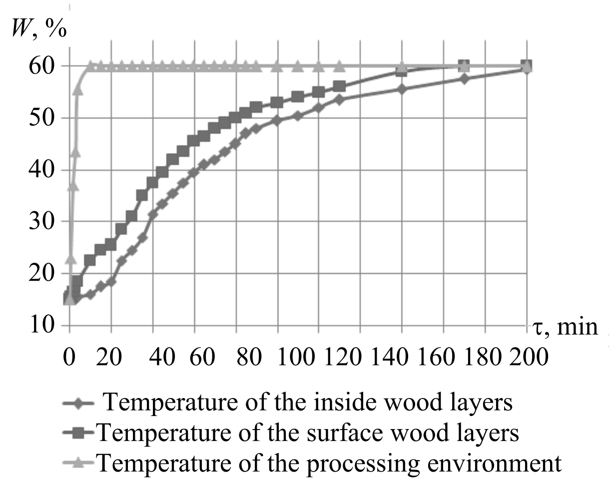
Research results. During the conducted experimental researches the temperature change character of the wood surface and inside layers with time was determined. In Fig. 3 there are graphic dependences received for pine wood samples with thickness of 40 mm, with initial humidity W_n = 30% being warmed up at the environment temperature t_c = 40ºC and 60ºC. Warming up was carried out in the radial direction.

The analysis of graphs given in Fig. 3 shows that the air temperature in the oven is set at the required level (40ºC and 60ºC) already in 3-10 minutes after the warming up beginning. After that it remains invariable throughout all the experiment. Thus, it is possible to consider, that wood warming up advances at constant temperature of the processing environment.

Warming up of wood samples surface layers begins at once and internal layers – with some delay. 20 minutes after the process beginning the difference of temperatures on the surface and inside samples reaches the maximum value and makes 4ºC and 7ºC at the environment temperature of 40ºC and 60ºC accordingly.



a



b

Fig. 3. Pine wood temperature change during the warming up at temperature of the processing environment: *a* – 40ºC; *b* – 60ºC

At the further warming up the temperatures difference of the surface and inside wood layers remains practically constant up to the moment of achievement by the sample surface of the processing environment temperature. In the first case it happened 140 minutes after the warming up process beginning, in the second – in 190 minutes. After that at a constant temperature of the surface layers the temperature inside the sample increases only that leads to their full alignment. As a result the duration of the complete warming up of pine wood samples with thickness of 40 mm and initial humidity of 30% has made: 187 minutes at the processing environment temperature of 40ºC, 220 minutes – at temperature of 60ºC.

The fact that during the wood warming up process there arises and is maintained for a long time considerable temperatures difference of environment and surface of the wood sample attracts attention. It definitely testifies that warming up is accompanied by moisture evaporation from the wood surface, i.e. about simultaneous heat and moisture transfer.

Graphic dependences similar to the presented ones in Fig. 3 were also received for other conditions of experiment specified in Table 1. In all cases the temperature change character of the surface and inside layers during the warming up was identical. Comparison of the received graphs among themselves permitted to note the following.

1. With the temperature rise the warming up process duration increases and the temperature change speed on the surface and inside wood also increases.

2. With the wood humidity rise the wood temperature change speed decreases and, as a result, the warming up duration increases.

3. With the sample thickness increase the warming up duration increases, and the wood temperature change speed remains practically identical.

To determine the change character of thermal physical wood characteristics with time during the warming up the value calculations of specific thermal capacity, of thermal conductivity coefficients and thermal diffusivity were done according to the above-stated formulas.

As the change regularities of wood thermal physical characteristics for all warming up conditions are similar, the calculations results for pine wood with thickness of 40 mm, with initial humidity W_i = 30% are given as an example in Table 3, and in Table 4 – for samples with thickness of 40 mm, initial humidity W_i = 53%. Warming up was carried out in the radial direction.

Analyzing the data given in Tables 3 and 4 we shall note first of all that the received values of all thermal physical wood characteristics do not contradict the data known in the literature [2].

Table 3

Thermal physical properties of pine wood with humidity W_i = 30%

τ, min	T = 40ºC			T = 60ºC		
	$a \cdot 10^{-6}$	c	λ	$a \cdot 10^{-6}$	c	λ
20	0.31	2.10	0.28	0.31	2.26	0.42
40	0.17	2.22	0.21	0.22	2.38	0.26
60	0.14	2.55	0.18	0.12	2.48	0.21
80	0.12	2.70	0.16	0.11	2.6	0.18
100	–	–	–	0.10	3.0	0.15
average	0.19	2.39	0.21	0.18	2.54	0.24

Table 4

Thermal physical properties of pine wood with humidity W_i = 53%

τ, min	T = 40ºC			T = 60ºC		
	$a \cdot 10^{-6}$	c	λ	$a \cdot 10^{-6}$	c	λ
20	0.35	2.60	0.55	0.40	2.47	0.54
40	0.23	2.66	0.36	0.28	2.50	0.41
60	0.17	2.74	0.28	0.23	2.54	0.35
80	0.15	2.84	0.25	0.22	2.64	0.34
100	0.11	3.16	0.20	0.22	2.74	0.37
120	–	–	–	0.19	2.85	0.32
average	0.20	2.80	0.33	0.26	2.62	0.39

Thus specific thermal capacity and thermal conductivity coefficient measured at wood with initial humidity W_i = of 53% are more than at more seasoned wood (W_i = 30%), it also agrees with modern conceptions about wood properties: wood warming up is accompanied by increase of specific thermal capacity and by decrease of thermal conductivity coefficient. Thermal diffusivity coefficient also decreases.

Conclusion. Complex method is applied to research thermal physical characteristics of pine wood permitting to determine thermal capacity, thermal conductivity and thermal diffusivity in non-stationary conditions. The dependences reflecting the temperature change character on the surface and inside warmed up wood are received. It is found that wood warming up is accompanied by specific thermal capacity increase and also by coefficients of thermal conductivity and thermal diffusivity.

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Received 14.03.2012