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AN EXPERIMENTAL RESEARCH OF THE DEFROSTING OF POPLAR LOGS WITH DIFFERENT MOISTURE CONTENTS

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Abstract

This paper describes a methodology for experimental research of the change in the temperature and humidity of the air processing medium and also in the temperature in 4 points of the longitudinal section of frozen logs during their defrosting.

The suggested methodology is used for research of the change in the mentioned parameters during 70 h of defrosting at room temperature of poplar logs with diameter of 240 mm, length of 480 mm, initial temperature of –29 °C, and moisture content above the hygroscopic range. The automatic measurement and record of the parameters are carried out with the help of Data Logger type HygrologNT3 produced by the Swiss firm ROTRONIC. The obtained results are graphically presented and analyzed.

Key words: *poplar logs, defrosting, free water, bound water, temperature distribution, automatic measurement*

INTRODUCTION

The duration of the thermal treatment of the frozen logs aimed at their defrosting and plasticizing in the veneer production and also the energy consumption needed for this treatment depends on the degree of the logs‘ icing (Chudinov 1966, Trebula – Klement 2002, Videlov 2003, Deliiski 2004, 2013, Deliiski – Dzurenda 2010).

In the specialized literature there are few limited reports about the experimental determined temperature distribution in subjected to defrosting frozen pine logs (Steinhagen – Lee 1988, Steinhagen 1991, Khattabi – Steinhagen 1995). That is why the experimental research and the multiparameter study of the defrosting process of logs of different wood species are of considerable scientific and practical interest.

The aim of this work is to suggest a methodology for experimental research of the logs' freezing and defrosting process and to present the first results from its usage for measurement of the change in the temperature and humidity of the processing medium, t_m and φ_m, respectively, and also in the non-stationary temperature distribution in 4 characteristic points of the longitudinal section of poplar logs during their many hours defrosting at room temperature of poplar logs with initial temperature of about –30°C.

MATERIAL AND METHODS

The logs subjected to experimenatal research were with a diameter of 240 mm and a length of 480 mm. They were produced from the sap-wood of freshly felled poplar trunk (*Populus nigra* L.) with a diameter of 630 mm according to a scheme given on Fig. 1 (left).

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Before the experiments, 4 holes with diameter of 6 mm and different length were drilled in each log (Fig. 1 – right and Fig. 2). Sensors with long cylindrical metal housings were positioned in these 4 holes for measurment of the wood temperature during the experiments.

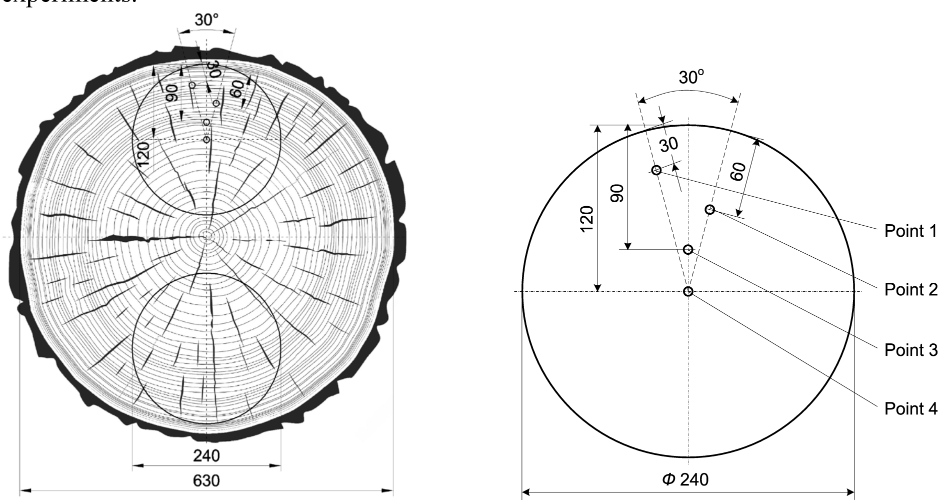

Fig. 1. An approach for the production of logs for the experiments (left) and radial coordinates of 4 characteristic points for measurement of the temperature in the logs (right)

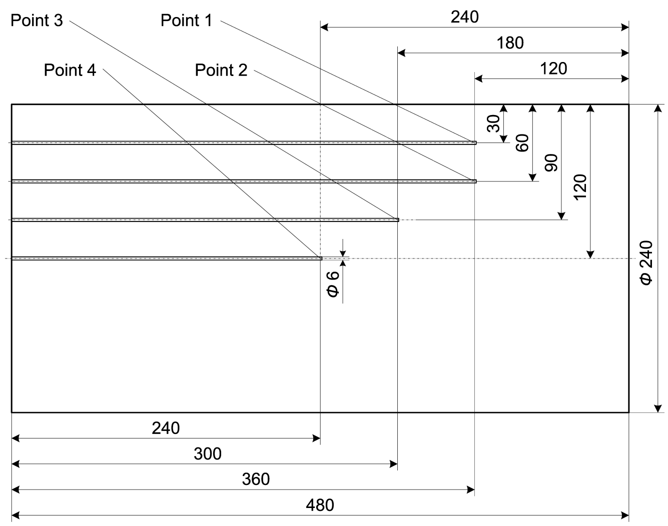

Fig. 2. Longitudinal section of log with drilled holes for positioning of sensors for measurement of the wood temperature during logs' defrosting process

The coorinates of the characteristic points of the logs are, as follows:
Point 1: along the logs' radius $r = 30$ mm and along the log's length $z = 120$ mm;
Point 2: along the logs' radius $r = 60$ mm and along the log's length $z = 120$ mm;
Point 3: along the logs' radius $r = 90$ mm and along the log's length $z = 180$ mm;
Point 4: along the logs' radius $r = 120$ mm and along the log's length $z = 240$ mm.

These coordinates of the characteristic points allow to cover the impact of the heat distribution in the wood simultanously in radial and longitudinal directions during the defrosting of the logs. The values of the points‘ coordinates were choosen to be suitable for the computation and visualization of the temperature in these points with the help of a model of the logs‘ defrosting process aimed at its verification.

Each log prepared for the experiments was placed in a PVC bag aimed as far as possible at homogemization of the moisture content in its volume. After that the experiments were started. For the freezing ot the logs a horizontal freezer was used with length of 1.1 m, width of 0.8 m, depth of 0.6 m and adjustable temperature range from –1 °C to –32 °C. After reaching of the temperature of about –30 °C in all logs' characteristic points, the lid of the freezer has been opened and the logs have been subjected to subsequent defrosting at room temperature being in the freezer with temperature sensors in them.

The automatic measurement and record of the temperature and humidity of the air processing medium and also of the temperature in the 4 characteristic points in logs during the experiments was carried out with the help of Data Logger type HygroLog NT3 produced by the Swiss firm ROTRONIC AG (http:/www.rotronic.com). The measurement of the temperature ot the processing medium, t_m, and of the relative humidity of this medium, φ_m, has been realized by two sensors made by this firm. The sensors are incorporated into one and the same housing, which has been positioned near the logs during the experiments. The measurement of the temperature in the logs‘ characteristic points has been carried out with the help of 4 sensors type Pt100 with suitable length of their housings according to Fig. 2.

After 50 h defrosting of the frozen logs, the sensors have been removed from them and the logs have been subjected to drying at a temperature of 103 ± 2 °C (according to requirements of the standard BDS ISO 3130: 1999) for the estimation of their initial mosture content u and of the wood basic devsity ρ_b, which is equal to the dry mass divided by the green volume. The values of u and ρ_b are needed for the analysis of the experimental results and also for the solving of the mathematical model of the logs‘ defrosting process.

RESULTS AND DISCUSSION

The above described methodology was used for research of the defrosting process of two poplar (*Populus nigra* L.) logs with diameter of D = 0.24 m, length of L = 0.48 m, and moisture content above the fiber saturation point. Such moisture content allows to observe the defrosting of both the free and the bound water in the wood during the experiments.

The first log (named as „Log 1“ below) was with an initial temperature t_0 = –29.0°C, ρ_b = 364 kg·m^{-3}, u = 1.78 kg·kg^{-1} and was subjected to 70 h defrosting at medium temperature t_{m0} = –29.1 °C at the beginning and t_{me}= 23.7 °C at the end of the defrosting process. The second log (named as „Log 2“ below) was with t_0 = –29.6°C, ρ_b = 359 kg·m^{-3}, u = 1.21 kg·kg^{-1} and was subjected to 70 h defrosting at t_{m0} = –29.1 °C and t_{me}= 23.7 °C.

The measured results obtained by the Data Logger during the experiments were additionally processed with the help of a personal computer with an installed licensed software ROTRONIC HW4.

On Fig. 3 and Fig. 4 the change in t_m, φ_m, and t in 4 characteristic points of the studied two poplar logs during their 70 h defrosting is presented.

On Fig. 5 to Fig. 8 the zoomed change in t of the separate logs' characteristic points in the temperature range from –1 °C to 0 °C is shown. During the experiments it was discovered that the defrosting of the free water in the wood occurs in this range.

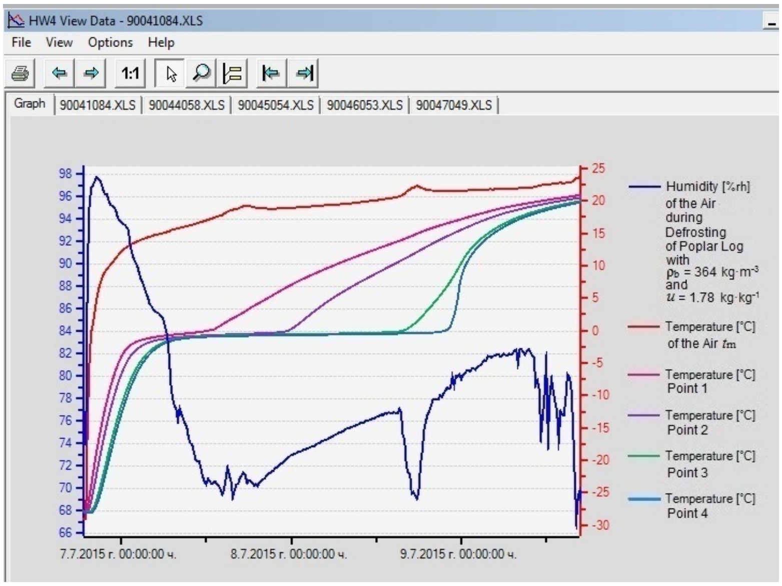

Fig. 3. Change in t_{m}, φ_{m}, and t in 4 characteristic points of poplar Log 1 with $D = 0.24$ m, $L = 0.48$ m, $t_0 = -29.0$ °C, $\rho_{\mathrm{b}} = 364$ kg·m^{-3}, and $u = 1.78$ kg·kg^{-1} during its 70 h defrosting at $t_{\mathrm{m0}} = -29.1$ °C and $t_{\mathrm{me}} = 23.7$ °C

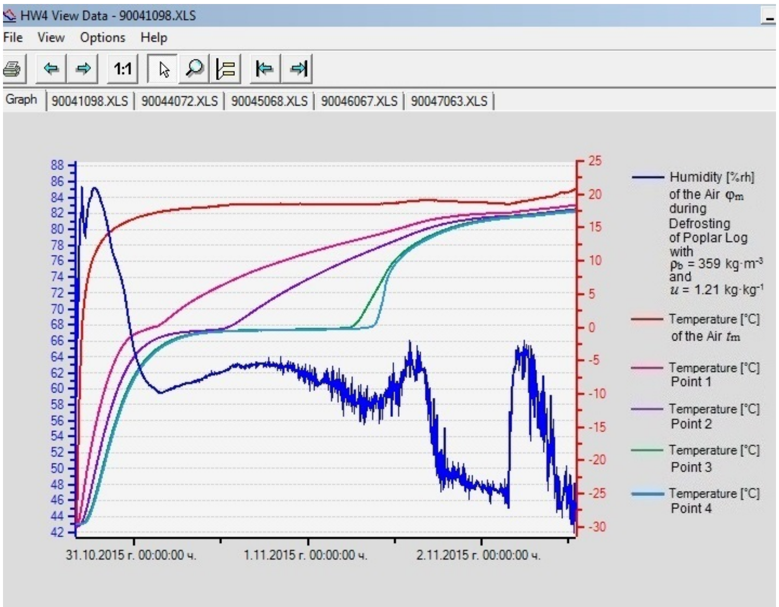

Fig. 4. Change in t_{m}, φ_{m}, and t in 4 characteristic points of poplar Log 2 with $D = 0.24$ m, $L = 0.48$ m, $t_0 = -29.6$ °C, $\rho_{\mathrm{b}} = 359$ kg·m^{-3}, and $u = 1.21$ kg·kg^{-1} during its 70 h defrosting at $t_{\mathrm{m0}} = -30.1$ °C and $t_{\mathrm{me}} = 21.0$ °C

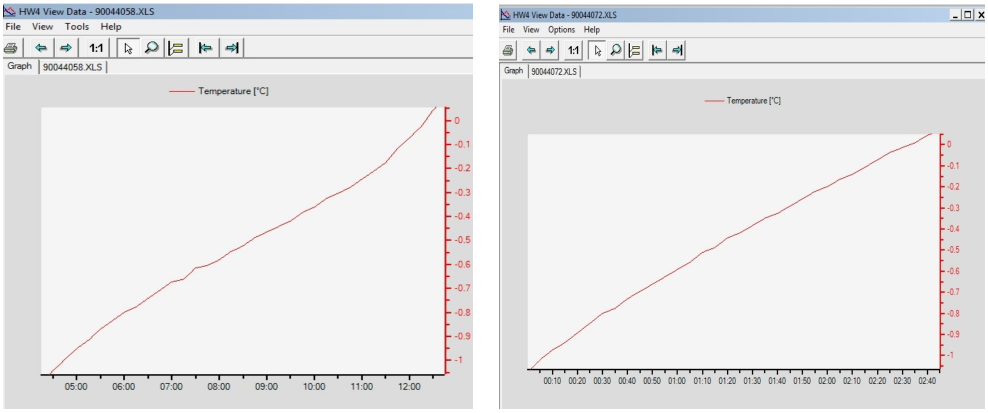

Fig. 5. Change in *t* in the characteristic Point 1 of Log 1 (left) and of Log 2 (right) in the range from –1 ^{o}C to 0 ^{o}C during log's defrosting, depending on time

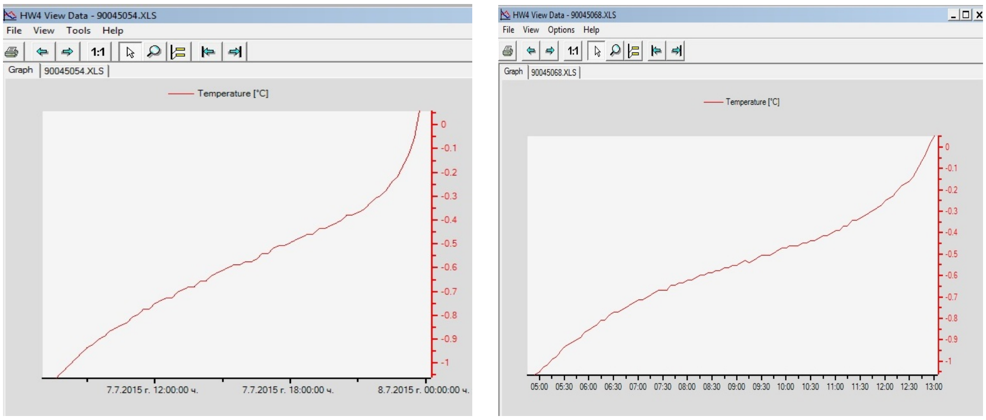

Fig. 6. Change in *t* in the characteristic Point 2 of Log 1 (left) and of Log 2 (right) in the range from –1 ^{o}C to 0 ^{o}C during log's defrosting, depending on time

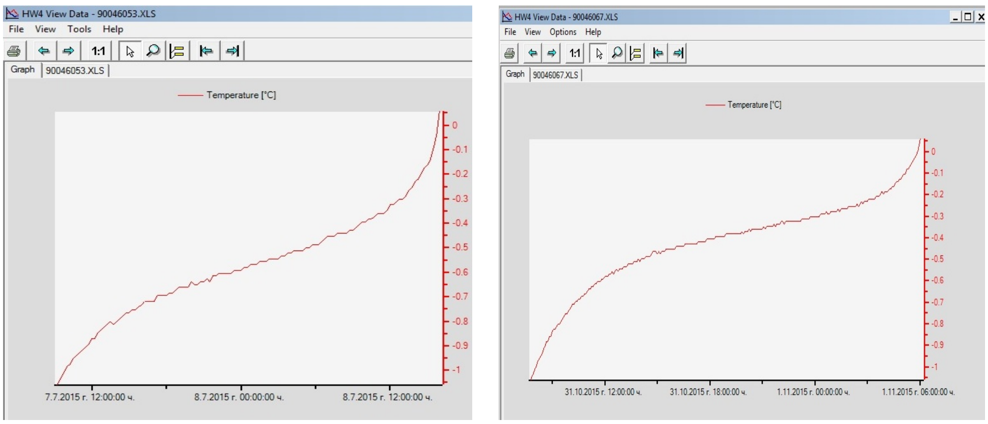

Fig. 7. Change in *t* in the characteristic Point 3 of Log 1 (left) and of Log 2 (right) in the range from –1 ^{o}C to 0 ^{o}C during log's defrosting, depending on time

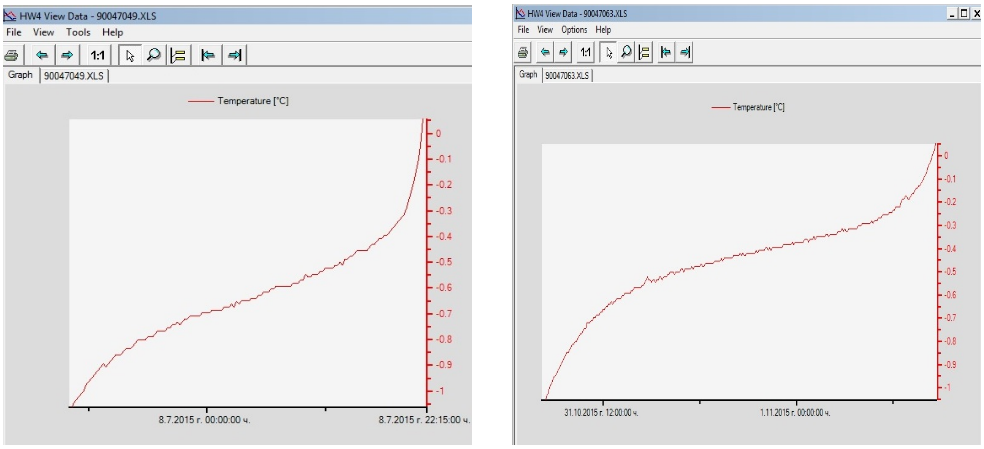

Fig. 8. Change in t in the characteristic Point 4 of Log 1 (left) and of Log 2 (right) in the range from -1 ^{o}C to 0 ^{o}C during log's defrosting, depending on time

In Table 1 the durations of the decreasing of the temperature in the logs' characteristic points in the range from -1 ^{o}C ^{o}C to 0 ^{o}C according to Fig. 3 and Fig. 4 is given. Those durations are needed for their further comparison to the durations of the freezing process of the same logs' points in the temperature range from 0 ^{o}C to -1 ^{o}C.

Table 1. Duration of the increasing of the temperature t from -1 ^{o}C to 0 ^{o}C in characteristic points of the studied frozen poplar logs during their defrosting

№	Time of reaching of temperature equal to:				Duration of the increasing of t from -1 ^{o}C to 0 ^{o}C, h
	-1 ^{o}C		0 ^{o}C		
	Hour	Data	Hour	Data	
Poplar log with $t_0 = -29.0$ ^{o}C, $\rho_b = 364$ kg·m^{-3}, and $u = 1.78$ kg·kg^{-1} subjected to 70 h defrosting at $t_{m0} = -29.1$ ^{o}C and $t_{me} = 23.7$ ^{o}C (Fig. 3)					
Point 1	4:46	07.07.2015	12:21	07.07.2015	7:58
Point 2	8:17	07.07.2015	23:36	07.07.2015	15.32
Point 3	9:45	07.07.2015	15:50	08.07.2015	30.08
Point 4	11:30	07.07.2015	21:46	08.07.2015	34.27
Poplar log with $t_0 = -29.6$ ^{o}C, $\rho_b = 359$ kg·m^{-3}, and $u = 1.21$ kg·kg^{-1}, subjected to 70 h defrosting at $t_{m0} = -30.1$ ^{o}C and $t_{me} = 21.0$ ^{o}C (Fig. 4)					
Point 1	0:07	31.10.2015	2:33	31.10.2015	3.43
Point 2	5:13	31.10.2015	12:53	31.10.2015	7.70
Point 3	8:04	31.10.2015	5:53	01.11.2015	21.82
Point 4	8:40	31.10.2015	8:25	01.11.2015	23.75

The obtained results lead to the following conclusions:

1. The increasing of the temperature of the processing air medium t_m in the opened freezer goes on exponentially at the beginning of the defrosting process of the logs and after that gradually passes into an almost straight line (Fig. 3 and Fig. 4). The logs' defrosting process begins from $t_{m0} = -29.1$ ^{o}C for Log 1 and from $t_{m0} = -30.1$ ^{o}C for Log 2 and it ends at $t_{me} = 23.7$ ^{o}C for Log 1 and at $t_{me} = 21.0$ ^{o}C.

2. The change of the humidity of the processing air medium φ_m in the opened freezer goes on according to a very complex curve during the logs' defrosting process (Fig. 3 and

Fig. 4). At the beginning of the freezing process it jumps up to 98 % for Log 1 and up to 85% for Log 2. After that it gradually decreases smoothly and reaches a value of 70 % for Log 1 and of 59 % for Log 2 at the end of exponentially increasing of t_m. When the further increase of t_m becomes almost linear, the change in φ_m follows the physical law of the dependence of φ_m on t_m: during the afternoon t_m increases and then φ_m decreases; during the late-night hours t_m decreases and then φ_m increases.

3. The non-stationary increasing of the temperature in the logs' characteristic points goes on according to very complex curves during the whole defrosting process (Fig. 3 and Fig. 4).

4. While at the beginning of the defrosting process a melting only of the frozen bound water in the logs occurs, the increasing of t_m causes a smooth increasing of t in the characteristic points. The smoothness of the increasing of t depends proportionally on the distance of the points from both logs' surfaces.

5. Specific almost horizontal sections of retention of the temperature for a long period of time in the temperature range from –1 °C to 0 °C can be seen, while in the points a complete melting of the frozen free water in the wood occurs (Fig. 3 ÷ Fig. 8). In this range the heat introduced in the wood from the surrounding air is transformed into work needed only for destruction of the bonds between molecules of the frozen free water without increasing of the wood temperature. As the characteristic points are further distanced from the logs' surfaces and also as large the wood moisture content is that much these sections with temperature retention are more extended, as follows (Table 1):

- at Point 1: 7.58 h for Log 1 with u = 1.78 kg·kg^{-1}) and 3.43 h for Log 2 with u = 1.21 kg·kg^{-1};
- at Point 2: 15.32 h for Log 1 and 7.70 h for Log 2;
- at Point 3: 30.08 h for Log 1 and 21.82 h for Log 2;
- at Point 4: 34.27 h for Log 1 and 23.75 h for Log 2.

6. After the melting of the whole amount of the free water in the separate characteristic points a heating of the wood with fully liquid water in it starts. The increasing of t in the all points during this heating of the wood is smoother than the increasing of t during the melting of the frozen bound water in the logs. At the end of the 50 h defrosting process, the temperature in the characteristic points of the logs reaches the following values:

- for Log 1: 20.9 °C in Point 1, 20.5 °C in Point 2, 20.0 °C in Point 3, 19.7 °C in Point 4 and then the t_m is equal to t_{me} = 23.7 °C (Fig. 4);
- for Log 2: 18.5 °C in Point 1, 17.9 °C in Point 2, 17.7 °C in Point 3, 17.6 °C in Point 4 and then the t_m is equal to t_{me} = 21.0 °C (Fig. 4);

CONCLUSIONS

This paper describes a methodology for experimental research of the logs‘ freezing and defrosting processes. It presents also the first results from the usage of the suggested methodology for measurement of the change in the temperature and humidity of the processing medium, t_m and φ_m, respectively, and also in the non-stationary temperature distribution in 4 characteristic points of the longitudinal section of frozen up to –30 °C wet poplar logs during their 70 hours subsequent defrosting at room temperature.

The automatic measurement and record of t_m and φ_m and also of the temperature in the characteristic points in logs during the experiments was carried out with the help of Data Logger type HygroLog NT3 produced by the Swiss firm ROTRONIC AG.

The experimental results from our research of the defrosting process of wet poplar logs proved the fact established earlier by Steinhagen – Lee (1988), Steinhagen (1991), and Khattabi – Steinhagen (1995) for pine logs that specific retention of the temperature in the separate logs' points for a long period of time in the range from –1 ^{o}C to 0 ^{o}C occurs, while in those points a complete melting of the frozen free water in the wood is carried out. As far the points are distanced from the logs' surfaces and also as larger the wood moisture content is, that much these sections with temperature retention are more extended.

Our experimental results did not prove the opinion of Chudinov (1966), according to whom the frozen free water in the wood melts between –2 ^{o}C and –1 ^{o}C.

The obtained experimental results will be very useful for the creation, solution, and verification of mathematical models of the logs' defrosting process.

The suggested in this work methodology could be used for experimental research of the freezing and/or defrosting processes of different capillary-porous bodies.

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