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EXPERIMENTAL RESEARCH OF SOME PARAMETERS OF THE LOGS' FREEZING PROCESS

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ABSTRACT

This paper describes the results from an experimental research according to original methodology of the following parameters of the logs' freezing process: change in the temperature and relative humidity of the air processing medium in the freezer used for the experiments; temperature distribution in the longitudinal section of logs subjected to freezing; distribution of wood moisture content and of basic density of the wood in the separate layers of the logs' cross-section. The methodology is used for research of the mentioned parameters during many hours freezing in a freezer at a temperature of approximately –30 ^{o}C of pine logs with a diameter of 240 mm, length of 480 mm and moisture content above the hygroscopic range. The automatic measurement and record of the temperature and the relative humidity is carried out by means of Data Logger type HygrologNT3 produced by the Swiss firm ROTRONIC.

Key words: logs, freezing, temperature distribution, relative humidity, moisture content, density.

1. INTRODUCTION

The duration of thermal treatment of the frozen logs aimed at their plasticizing in the veneer production, as well as the energy consumption needed for this treatment, depend on the degree of the logs' icing (Shubin 1990, Trebula and Klement 2002, Videlov 2003, Pervan 2009, Deliiski and Dzurenda 2010, Deliiski 2013).

In specialized literature there is a limited number of reports about an experimentally determined or computed temperature distribution in frozen logs subjected to defrosting (Steinhagen 1991, Steinhagen et al. 1987, Khattabi and Steinhagen 1992, 1995, Deliiski 2004, 2009, 2013, Deliiski and Dzurenda 2010), and there is very scarce information about experimentally determined temperature distribution in logs during their freezing (Deliiski and Tumbarkova 2017, 2018).

The aim of this work is to describe a methodology for experimental research of the logs' freezing process and to present the results from applying it for measuring the change in temperature and relative humidity of the processing air medium, and also in non-stationary temperature distribution in 4 characteristic points of the longitudinal section of pine logs with moisture content above the hygroscopic range during their long-lasting freezing in a freezer at a temperature of about –30 ^{o}C. That measurement was preceded by determination of distribution of the wood moisture content and of the basic density of the wood in separate layers of the cross-section of the logs subjected to freezing.

2. MATERIAL AND METODS

The logs subjected to experimental research of temperature distribution in them had a diameter of 240 mm and a length of 480 mm. They were produced from sap-wood of freshly-felled pine trunks (*Pinus Sylvestris* L.) with a diameter not less than 400 mm according to a scheme given in Figure 1 (on the left).

The experiments for research of distribution of wood moisture content and basic density of the wood in separate layers of the logs' cross-section were carried out using 11 samples which were produced according to a scheme given in Figure 1 (on the right). According to the standard ISO 3129, these samples were with the following dimensions: thickness of 35 mm, width of 30 mm, and length of 60 mm. The samples were produced from a disc with a thickness of 35 mm, which was cut off right next to the frontal side of the logs used for the temperature experiments.

Determination of wood moisture content and basic density of the wood of each sample was realized according to the requirements of standard ISO 3130: 1999 and standard ISO 3131: 1999 respectively.

The samples were dried at 103 ± 2 ^{o}C to estimate their initial moisture content u and basic wood density ρ_b, which is equal to the dry mass divided by the green volume. The average values of u and ρ_b, u_{avg} and $\rho_{b.avg}$ respectively, are needed for solution and verification of our 2D mathematical model of the logs' freezing process (Deliiski and Tumbarkova 2017, 2018).

Before the temperature experiments, 4 holes with diameter of 6 mm and of different lengths were drilled into each log (Fig. 2). Sensors with long cylindrical metal casings were positioned in these 4 holes to measure the temperature of the wood during the experiments. The number of characteristic points at which the changes in wood temperature were measured, was limited by the number of available temperature sensors the automatic system used for the experiments had.

The coordinates of the logs' characteristic points are given in Fig. 2. These coordinates allow for the impact of the heat fluxes to be simultaneously covered in radial and longitudinal directions on the temperature distribution of freezing logs. The values of the points' coordinates were chosen to be suitable for computation and visualization of the temperature in these points by means of our 2D model of the logs' freezing process aimed at its verification (Deliiski and Tumbarkova 2017, 2018).

Each log prepared for the experiments was placed in a PVC bag with a view to homogenizing the moisture content in its volume as much as possible. Following this, the experiments began.

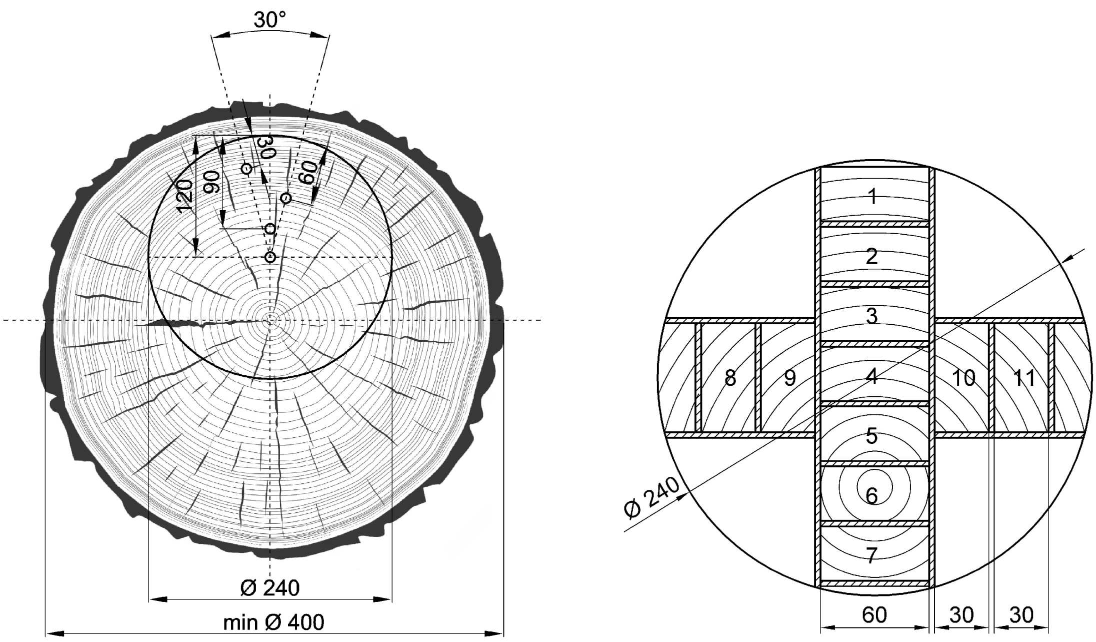

Figure 1. *An approach for the production of logs for the experiments (left) and for measurement of the moisture content and basic density of the wood in the logs' separate layers (right)*

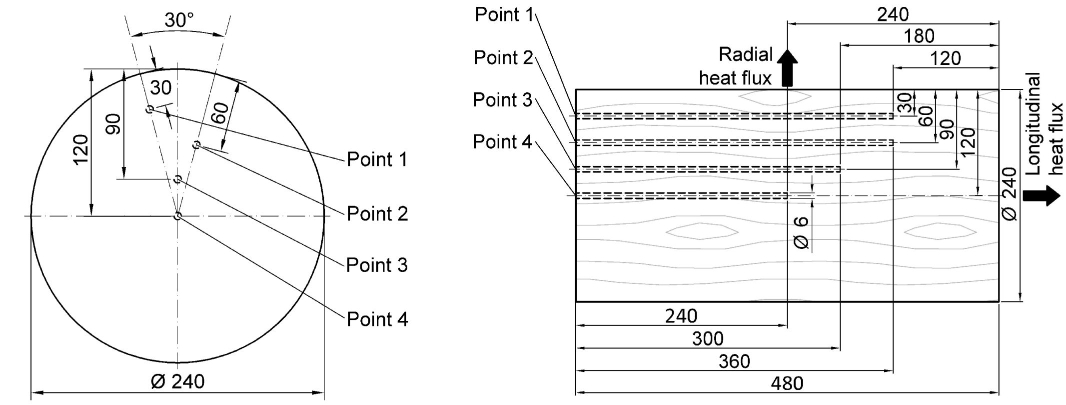

Figure 2. *Radial (left) and longitudinal (right) coordinates of 4 characteristic points for measurement of the temperature in logs subjected to freezing*

To freeze the logs, a horizontal freezer with length of 1.1 m, width of 0.8 m, depth of 0.6 m and adjustable temperature range from –1 °C to –30 °C was used.

Automatic measurement and recording of the temperature and humidity of the air processing medium in the freezer, as well as of the temperature in the 4 characteristic points in the logs during the experiments, was carried out by means of Data Logger type HygroLog NT3 produced by the Swiss firm ROTRONIC AG (http:/www.rotronic. com). The measured results obtained by the Data Logger during the experiments were additionally processed by means of a personal computer with installed licensed software, ROTRONIC HW4.

3. RESULTS AND DISCUSSION

3.1. Distribution of layers' moisture content and basic density of the logs

The experimentally obtained distribution of the layers' wood moisture content and basic density in the cross-section of the studied pine Log 1 and Log 2 is presented in Fig. 3 and Fig. 4 respectively.

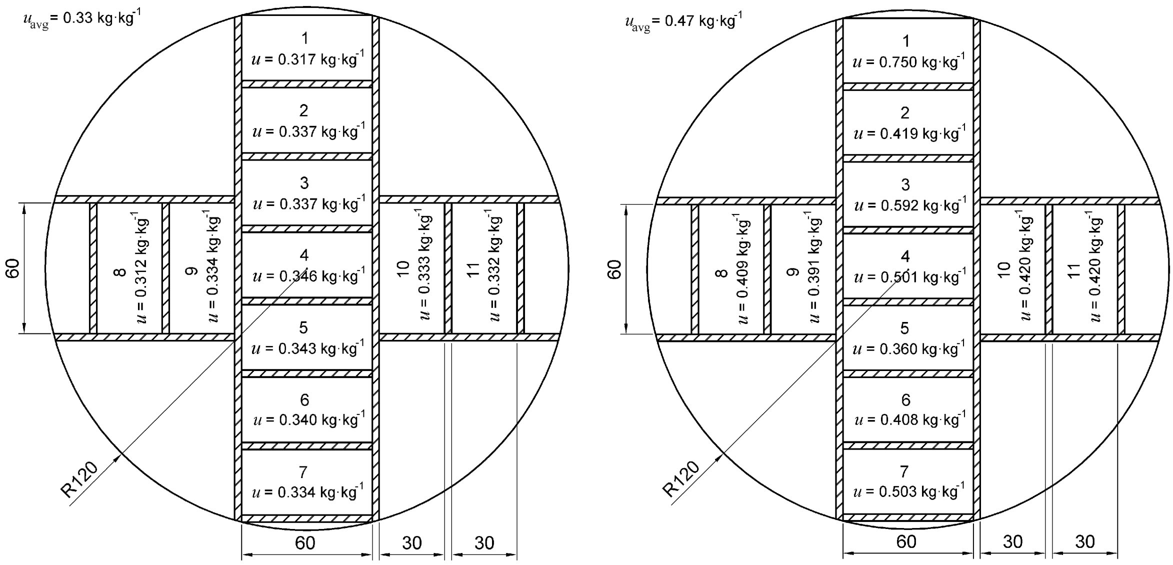

Figure 3. *Distribution of the layers' wood moisture content in pine Log 1 (left) and pine Log 2 (right)*

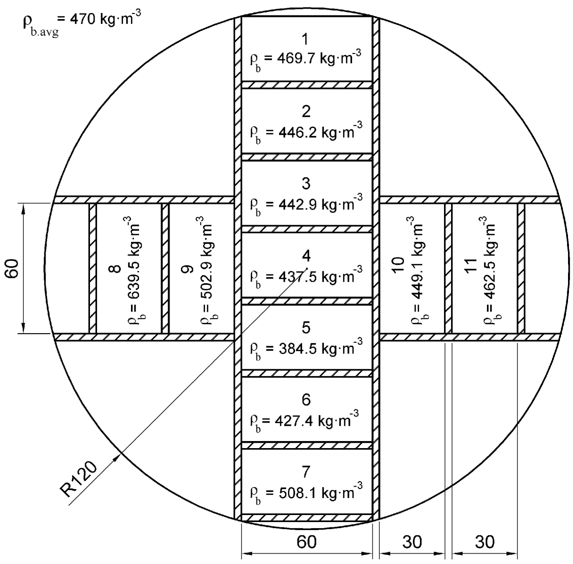

Figure 4. *Distribution of the layers' wood basic density in pine Log 1 (left) and pine Log 2 (right)*

The analysis of the results presented in Fig. 3 and Fig. 4 shows that the wood moisture content and the basic density of the wood are distributed very unequally in the cross-sections of the studied logs, as follows:

- Wood moisture content, u, changes from 0.312 kg·kg^{-1} to 346 kg·kg^{-1} for Log 1 and from 0.360 kg·kg^{-1} to 0.750 kg·kg^{-1} for Log 2;
- Arithmetic average value of u, which is needed for solution and verification of the mathematical model, is equal to u_{avg} = 0.33 kg·kg^{-1} for Log 1 and u_{avg} = 0.47 kg·kg^{-1} for Log 2;
- Basic density of the wood, ρ_b, changes from 384.5 kg·m^{-3} to 639.5 kg·m^{-3} for Log 1 and from 390.1 kg·m^{-3} to 510.0 kg·m^{-3} for Log 2;
- Arithmetic average value of ρ_b, which is needed for solution and verification of our 2D mathematical model, is equal to $\rho_{b\ .avg}$ = 470 kg·m^{-3} for Log 1 and $\rho_{b.avg}$ = 452 kg·m^{-3} for Log 2.

It can be noted that the larger the unevenness of the distribution of u and ρ_b in the logs is, the worse the conformity between the calculated by the model with u_{avg} and $\rho_{b.avg}$ and experimentally determined temperature field in the logs during their freezing is.

3.2. Change in temperature and relative humidity of the processing air medium during logs' freezing and distribution of the temperature in the logs subjected to freezing

In Fig. 5 and Fig. 6 the change in temperature t_m and relative humidity φ_m of the processing air medium, and also in the temperature t in 4 characteristic points of the studied pine logs (Log 1 with u = 0.33 kg·kg^{-1} and initial temperature of 25.2 ^{o}C and Log 2 with u = 0.47 kg·kg^{-1} and initial temperature of 10.8 ^{o}C) during their 30 h and 50 h freezing respectively is shown. The record of all data was made automatically by Data Logger with intervals of 5 min.

On the horizontal and on the left and right vertical axes of Fig. 5 and Fig. 6 the astronomic time during the experiments and the relative humidity in % and the temperature in ^{o}C are presented respectively.

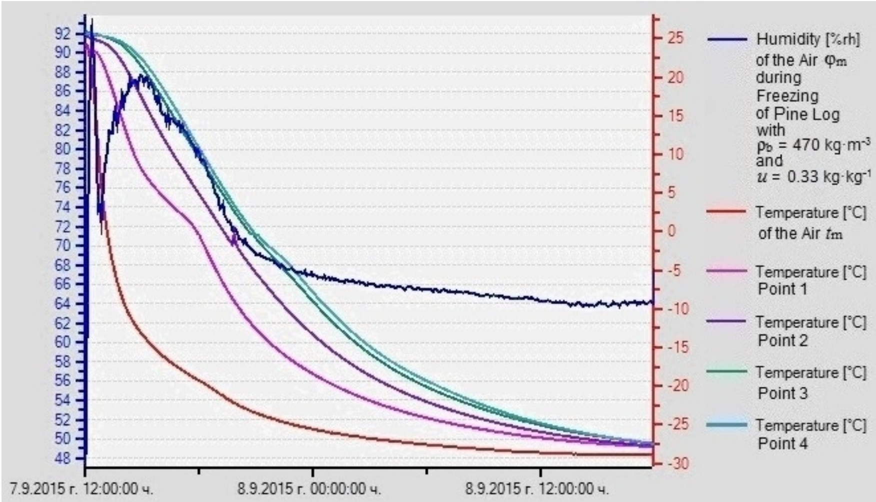

Figure 5. *Change in t_m, φ_m, and t in 4 characteristic points of pine Log 1 with $D = 0.24$ m, $L = 0.48$ m, $t_0 = 25.2\ ^oC$, $\rho_b = 470$ kg·m^{-3}, and $u = 0.33$ kg·kg^{-1}*

The experimental results presented above, and also the results from our research of the freezing process of logs from poplar, beech, and spruce at different moisture contents, show that free water in the wood freezes at temperature range between 0 ^{o}C and –1 ^{o}C. This fact did not prove the points of view of Chudinov (1968) and Topgaard and Söderman (2002). According to the authors, if wood moisture content is slightly higher than fiber saturation point, i.e. a low quantity of free water is present in the wood (such a condition was fulfilled in our experiments presented above), then the centers of crystallization during cooling arise in water at temperatures around –12 ^{o}C ÷ –15 ^{o}C.

The analysis of the results shown in Fig. 5 and Fig. 6 leads to the following statements:

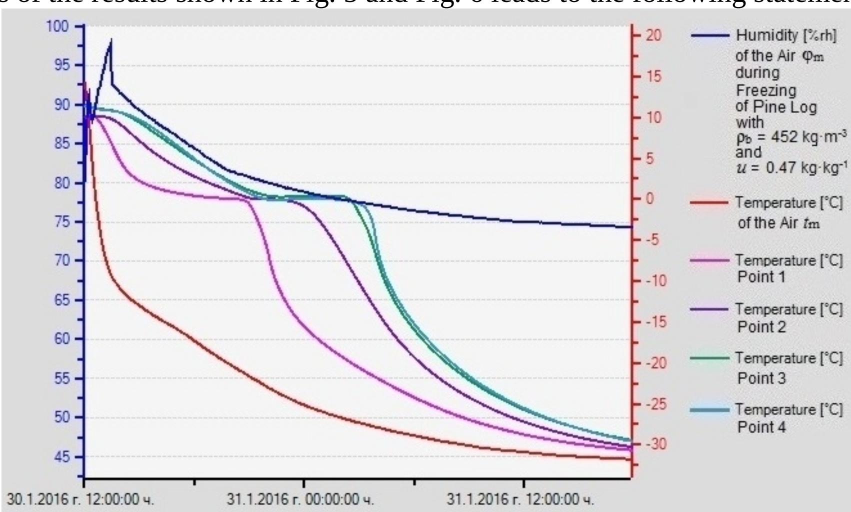

Figure 6. *Change in t_m, φ_m, and t in 4 characteristic points of pine Log 2 with $D = 0.24$ m, $L = 0.48$ m, $t_0 = 10.8\ ^oC$, $\rho_b = 452$ kg·m^{-3}, and $u = 0.47$ kg·kg^{-1}*

- The decrease in temperature t_m and in relative humidity φ_m in the freezer goes on according to complex curves. At the beginning of the freezing process φ_m rockets up to 93% at Log 1 and up to 96% at Log 2, but after that it gradually drops smoothly and reaches a value of 64% (Log 1) and of 75% (Log 2) at the end of the logs' freezing. At the same time φ_m reaches the following values: –28.8 ^{o}C for Log 1 and –30.1 ^{o}C for Log 2;
- The non-stationary decreasing of the temperature in the logs' characteristic points goes on according to very complex curves during the freezing process. While water in the log is fully in a liquid state, the decreasing of t_m causes a smooth decreasing of t in the characteristic points. Specific, almost horizontal sections of temperature retention for a long period of time in the range from 0 ^{o}C to –1 ^{o}C

can be seen, whereas at the points a complete freezing of free water in the wood occurs. The further the point from the logs' surfaces is distanced and the higher the amount of free water in the wood is, the more these sections with temperature retention get extended. The reason for such a long retention of wood temperature is the very low temperature conductivity of wood during freezing of free water in it (Deliiski and Tumbarkova 2017).

- After the whole amount of free water in the separate characteristic point freezes, the water bound in the wood starts to freeze. When the freezing process ends, the temperature of all characteristic points of Log 1 and Log 2 reaches a value equal to –27.6 ± 0.2 ^{o}C and –30.2 ± 0.5 ^{o}C respectively.

4. CONCLUSIONS

This paper describes a methodology for experimental research of some parameters of the logs' freezing process. It presents results from applying the methodology for measurement of the change in the temperature and relative humidity of the processing air medium and also in the non-stationary temperature distribution in 4 characteristic points of the longitudinal section of pine logs with moisture content above the hygroscopic range during their 30-to-50-hour freezing in a freezer at a temperature of approximately –30 ^{o}C. The results from experimental determination of distribution of wood moisture content and of basic density of the wood in the separate layers of the cross-section of the logs subjected to freezing are also presented.

The experimental results show that free water in wood freezes at temperature range between 0 ^{o}C and –1 ^{o}C. This fact did not prove the points of view of some authors that free water in wood freezes at much lower temperatures. Our results prove the popular belief that after freezing of the whole amount of free water, freezing of bound water in wood begins and it happens gradually during the remaining time of the experiments.

The obtained experimental results are used for solution and verification of our 2D mathematical models of logs' freezing process (Deliiski and Tumbarkova 2017, 2018). They could be very useful for creation, solution, and verification of analogous models by other researchers.

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