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CALCULATION OF THE THERMAL ENERGY AND ITS COMPONENTS REQUIRED FOR THAWING LOGS

Nencho Deliiski – Ladislav Dzurenda – Dimitar Angelski – Pavlin Vitchev – Krasimira Atanasova

ABSTRACT

An approach for calculating the thermal energy and its components required for thawing logs intended for veneer production is proposed. The approach is based on the use of two personal mathematical models. The influence of all combinations between 5 values of the initial wood temperature from −1 °C to −40 °C and 3 values of the wood moisture content above the hygroscopic range (0.4 kg·kg^{-1}, 0.6 kg·kg^{-1}, and 0.8 kg·kg^{-1}) on the thermal energy and its four components required to thaw beech logs with a diameter of 0.4 m at operating temperature of the heating medium of 80 °C was investigated. The obtained results show that this energy changes in the range from 31.66 kWh·m^{-3} (at −1 °C and 0.4 kg·kg^{-1}) to 95.36 kWh·m^{-3} (at −40 °C and 0.8 kg·kg^{-1}). The approach could be applied to determine the energy required to thaw various frozen capillary-porous materials in practice.

Keywords: frozen logs; frozen bound water; frozen free water; thawing; thermal energy.

INTRODUCTION

For the optimization of different thermal treatment processes, it is required that the distribution of the temperature field in the wood materials and the consumed energy for their heating are known. The intensity of heating and the consumption of energy depend on the dimensions and initial temperature of the wood materials, on the content and aggregate condition of the water in them, on the law of change and the values of the temperature of the heating medium, etc. (Chudinov, 1968; Kollmann and Côté, 1984; Shubin, 1990; Sohor and Kadlec, 1990; Lawniczak, 1995; Trebula and Klement, 2002; Videlov, 2003; Câmpean, 2005; Steinhagen, 2005; Pervan, 2009; Deliiski, 2003, 2004, 2011).

The correct and effective control of the heating process is possible only when its physics and the weight of the influence of each mentioned above and many other factors for the specific wood materials are well understood. The summary of the influence of these factors on the thermal treatment processes of the wood materials is a difficult task and its solution is possible only with the assistance of adequate mathematical models, which have increased complexity in cases where the heated wood contains ice.

The development of such temperature-energy models is performed using partial differential equations and requires deep mathematical knowledge. Solving the models without any simplifications, as a rule, is done by developing very complex specialized software packages, using finite difference or finite element methods (Steinhagen, 1986, 1991; Steinhagen *et al.*, 1987; Khattabi and Steinhagen, 1992, 1993, 1995; Deliiski, 2003;

2011, 2013b; Hadjiski, 2005; Deliiski and Dzurenda, 2010; Dzurenda and Deliiski, 2019; Tumbarkova, 2019; Deliiski *et al.*, 2018, 2021; Niemz *et al.*, 2023).

The availability of a simpler and more accessible approach to calculating the energy required for wood thawing would be of particular interest to the development, study, and implementation of science-based energy-saving modes for the thermal treatment of frozen wood materials.

Therefore, the aim of this work is to propose an approach for calculating the thermal energy and its components required for thawing frozen logs intended for the manufacture of veneer. It should offer relatively easy-to-apply (manually or with MS Excel) equations to determine all four types of the individual components of the mentioned energy, namely: for heating the frozen and non-frozen wood itself above the hygroscopic range, for melting the temperature-dependent frozen part of bound water, and for melting all the frozen free water in the wood.

MATERIAL AND METHODS

Material for research

This research was conducted on frozen beech (*Fagus sylvatica* L.) logs, which are commonly used in veneer production. The calculation of the energy required for thawing frozen logs was carried out for the case of steaming or boiling of such logs in equipment operating at atmospheric pressure and at a temperature of the processing medium of 80 °C.

Figure 1 shows the change of the operating temperature t_m in the commonly applied modes for heating of frozen wood materials in order to defrost them in equipment operating at atmospheric pressure (Chudinov, 1968; Shubin, 1990; Dzurenda and Deliiski, 2019). These modes consist of two stages, during which t_m changes as follows:

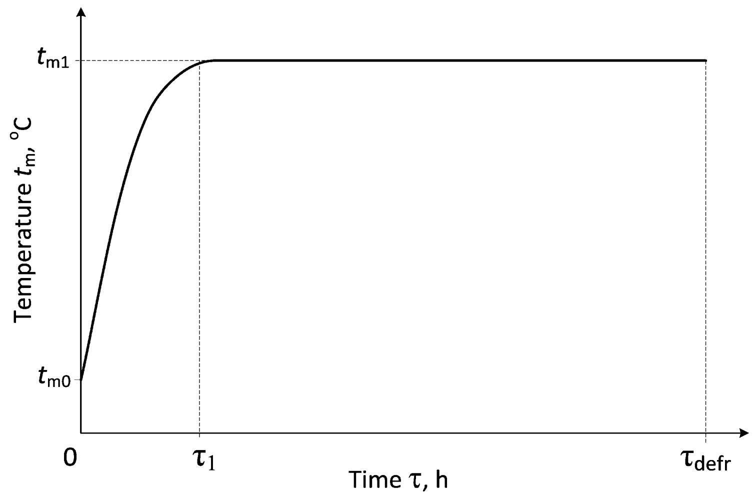

Fig. 1 Change of the operating temperature t_m in modes for thawing of wood at atmospheric pressure.

▪ During the first stage, in the course of time $0 - \tau_1$, an increase in t_m from t_{m0} to t_{m1} takes place by fully or partially opening the valve to introduce heat carrier to the thermal treatment equipment;

▪ During the second stage of the modes, in the course of time $\tau_1 - \tau_{defr}$, dosed introduction of heat carrier into this equipment is carried out in order to maintain a constant technologically permissible value of the operating temperature, equal to t_{m1}. When the temperature at the slowest heating central point of the wood materials reaches 0 °C, this determines the moment of their complete defrosting, τ_{defr}.

The symbols, units, and values of the main parameters of the studied logs, and also of their thawing modes, which were incorporated into the equations of the scientifically validated mathematical models given below, and were used in the computer simulations, are presented in Table 1.

Tab. 1 Main set parameters of frozen beech logs and their thawing modes, which were used during the computer simulations.

Parameter name	Symbol	Unit	Value
1. Diameter of the logs	D	m	0.4
2. Length of the logs	L	m	2.0
3. Basic density of the beech wood	ρ_b	$kg{\cdot}m^{-3}$	560
4. Density of the ice in the frozen wood	ρ_{ice}	$kg{\cdot}m^{-3}$	917
5. Standardized fiber saturation point of the beech wood at 20 °C (i.e. at 293.15 K)	$u_{fsp(293.15K)}$	$kg{\cdot}kg^{-1}$	0.31
6. Moisture content of the logs (a – at u = 0.4 $kg{\cdot}kg^{-1}$, b – at u = 0.6 $kg{\cdot}kg^{-1}$, c – at u = 0.8 $kg{\cdot}kg^{-1}$)	u	$kg{\cdot}kg^{-1}$	0.4a 0.6b 0.8c
7. Initial temperature of the logs in the beginning of their thawing process: (d – at t_{w0} = −1 °C, e – at t_{w0} = −10 °C, f – at t_{w0} = −20 °C, g – at t_{w0} = −30 °C, and h – at t_{w0} = −40 °C)	t_{wo}	°C	−1d −10e −20f −30g −40h
8. Temperature of complete melting of the frozen bound water and start of melting of the frozen free water in the wood	$t_{bw\text{-}end}$	°C	−1
9. Temperature of complete melting of the frozen free water in the wood	$t_{fw\text{-}end}$	°C	0
10. Initial temperature of the modes for logs' thawing	t_{m0}	°C	10
11. Temperature of stage $\tau_1 - \tau_2$ of the thawing modes	t_{m1}	°C	80
12. Time constant for exponential increase of t_m from t_{m0} to t_{m1}	τ_e	s	3600
13. Temperature in the central point of the logs at the end of their complete thawing	$t_{wc\text{-}end}$	°C	0

Modelling of the 1D unsteady temperature change in frozen logs

When the length of the logs, L, is at least four times their diameter, D, the non-stationary temperature distribution along the radius can be determined using the following experimentally verified 1D model (Deliiski, 2011):

$$c_{\text{w-eff.1,2,3}} \cdot \rho_{\text{w}} \frac{\partial T(r,\tau)}{\partial \tau} = \text{div} \ (\lambda_{\text{w-eff.1,2}} \ \text{grad} \ T) \tag{1}$$

at initial condition

$$T(r,0) = T_{\text{w0}} \tag{2}$$

and boundary condition for conductive heat transfer:

$$T(0,\tau) = T_{\text{m}}(\tau) \tag{3}$$

Where: $c_{\text{w-eff.1,2,3}}$ are the effective specific heat capacities of the frozen wood during 1st, 2nd, and 3rd temperature ranges of its thawing process, given below, $J{\cdot}kg^{-1}{\cdot}K^{-1}$; $\lambda_{\text{w-eff.1,2}}$ – effective thermal conductivities in radial direction of the frozen and defrosten wood respectively, $W{\cdot}m^{-1}{\cdot}K^{-1}$; ρ_w – density of the wood, $kg{\cdot}m^{-3}$; r – coordinate along the log radius: $0 \le r \le R$, m; R – radius of the log, m; T – temperature, K; T_{w0} – initial temperature of the log, K; T_m – operating temperature of the defrosting medium, K; τ – time, s.

The mathematical descriptions of $c_{\text{w-eff.1,2,3}}$, $\lambda_{\text{w-eff.1,2}}$, and ρ_w given in (Deliiski, 2003; 2009, 2011, 2013a; Deliiski, *et al.*, 2018, 2020) were used in solving model (1) − (3).

During the solving of the model (1) – (3), the current average mass temperature of the log, T^n_{avg}, can be calculated according to the following equation (Deliiski, 2011):

$$T^n_{\text{avg}} = \frac{1}{R}\int_R T(r, n\cdot\Delta\tau)\mathrm{d}R \tag{4}$$

The values of T_{avg} at the moment when the slowest changing temperature in the central point of the logs reaches 0 °C, i.e. values $T_{\text{avg-end}}$, and this is an indicator of the completion of the log thawing process, are needed below to calculate the energy that was consumed by the logs up to that moment.

Mathematical description of the specific heat capacities of wood subjected to thawing

The compresenhive experimental study of the thawing process of logs with an initial temperature of about –30 °C from different wood species and various moisture content above the hygroscopic range, which were carried out in (Tumbarkova, 2019; Deliiski *et al.*, 2020b) show that this process can be separated into three ranges. During the first range, the frozen logs are heated at $T \le 272.15$ K (i.e. $t \le -1$ °C) until they reach the state required for starting and gradually melt the temperature-dependent part of frozen bound water in them. During the second range between –1 °C and 0 °C a further heating of the wood occurs until reaching the state needed for starting and melting all the frozen free water in it. During the third range above 0 °C further heating of the wood layers with already fully liquid water in them occurs.

The effective specific heat capacities of the logs during the pointed three ranges of the thawing process of wood above the hygroscopic range, $c_{\text{w-eff.1,2,3}}$, which participate in equation (1) are equal to the following:

$$\text{First range: } c_{\text{w-eff.1}} = c_{\text{w-fr}} + c_{\text{ice-bw}} \tag{5}$$

$$\text{Second range: } c_{\text{w-eff.2}} = c_{\text{w-nfr}} + c_{\text{ice-fw}} \tag{6}$$

$$\text{Third range: } c_{\text{w-eff.3}} = c_{\text{w-nfr}} \tag{7}$$

Where: $c_{\text{w-fr}}$ and $c_{\text{w-nfr}}$ are the specific heat capacities of frozen and defrosted (non-frozen) wet wood respectively, $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$; $c_{\text{ice-bw}}$ and $c_{\text{ice-fw}}$ – specific heat capacities of the frozen bound and free water in the wood respectively, $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$.

Mathematical descriptions of the specific heat capacities $c_{\text{w-fr}}$, $c_{\text{w-nfr}}$, $c_{\text{ice-bw}}$ and $c_{\text{ice-fw}}$ were given in (Deliiski *et al.*, 2018, 2020a; Tumbarkova, 2019). These descriptions are included below in an appropriate manner in the equations for calculation of the individual components of the energy requred to thaw logs.

Modelling of the energy consumption of frozen logs subjected to thawing

The total specific thermal energy consumption of frozen logs subjected to thawing (in $\text{kWh}\cdot\text{m}^{-3}$), $Q_{\text{w-total}}$, can be expressed by the following model (Deliiski, 2013b):

$$Q_{\text{w-total}} = Q_{\text{w-fr}} + Q_{\text{ice-bw}} + Q_{\text{ice-fw}} + Q_{\text{w-nfr}} \tag{8}$$

Where: $Q_{\text{w-fr}}$ is the thermal energy required for heating of the frozen wood to a condition necessary to melt the frozen bound water in it; $Q_{\text{ice-bw}}$ – energy required to melt the temperature-dependent amount of frozen bound water in the wood; $Q_{\text{ice-fw}}$ – energy required to melt the entire amount of frozen free water in the wood; $Q_{w\text{-}nfr}$ – energy required to heat the allready defrosted layers of the wood until reaching 0 °C in the central point of the materials subjected to thawing.

The individual components of the energy required for complete thawing of the frozen logs, $Q_{w\text{-}total}$, can be calculated using the following equations (Deliiski, 2013b):

$$Q_{w-fr} = \frac{\rho_w \cdot c_{w-fr\text{-}avg}}{3.6.10^6} \cdot \left(272.15 - T_{w0}\right) \tag{9}$$

$$Q_{ice\text{-}bw} = \frac{\rho_{ice} \cdot c_{ice\text{-}bw\text{-}avg}}{3.6.10^6} \cdot \left(272.15 - T_{w0}\right) \tag{10}$$

$$Q_{ice\text{-}fw} = \frac{\rho_{ice} \cdot c_{ice\text{-}fw\text{-}avg}}{3.6.10^6} \left(273.15 - 272.15\right) \tag{11}$$

$$Q_{w-nfr} = \frac{\rho_w \cdot c_{w-nfr\text{-}avg}}{3.6.10^6} \cdot \left(T_{avg\text{-}end} - 272.15\right) \tag{12}$$

Where the individual specific capacities $c_{w\text{-}fr\text{-}avg}$, $c_{w\text{-}nfr\text{-}avg}$, $c_{ice\text{-}bw\text{-}avg}$ and $c_{ice\text{-}fw\text{-}avg}$ are calculated as arithmetic mean values for the respective temperature ranges, which are given in parentheses in the right-hand parts of eqs. (6) – (9).

The temperature $T_{avg\text{-}end}$ in eq. (9) is the average mass temperature of the logs at the end of their complet thawing, which is calculated with equation (4) upon reaching 0 °C in the central point of the fully defrosted logs, K.

Solving the models (1) – (3) and (5) – (9)

The numerical solving of the model (1) – (3) in order to determine the duration of the modes for thawing of the studied beech logs, and also of the average wood mass temperature, T_{avg}, during these modes, is carried out with the help of own software packages in the calculation environment of Visual FORTRAN. An explicit finite-difference scheme was used to transform the individual model equations into a FORTRAN-friendly programming form, which excludes any simplifications of the model (Dorn and McCracken, 1972).

Those specified above in Table 1 were used as basic input data relating to the characteristics of the beech logs subjected to thawing and to the operating temperature parameters of the steaming or boiling modes.

From the obtained change of the temperature field along the radius of the logs, and in particular from the moment of reaching 0 °C in their central point, the durations of the log thawing modes, τ_{defr}, were determined for the investigated three values of the wood moisture content u and five values of the initial wood temperature t_{w0}.

The values of the average mass temperature of the logs at $\tau = \tau_{defr}$ (refer to Fig. 1), $T_{avg\text{-}end}$, calculated with equation (4) were used during the solving of eq. (9).

An Excel program was prepared to solve the eqs (5) – (9) jointly. With the help of this program, the change of all four components of the energy $Q_{w\text{-}total}$ required for thawing the investigated logs was calculated.

Table 2 gives some of the data obtained for $T_{avg\text{-}end}$ and some of those for the specific heat capacities of the logs, which were used in the calculation of $Q_{w\text{-}total}$ and its components. In order to facilitate the analysis of the data in this table, three parameters of the logs, which were previously also indicated in Table 1, are included in it.

Tab. 2 Data on the parameters and thermophysical characteristics of the studied beech logs, which were used in the calculations of the energy $Q_{w\text{-}total}$ and its components.

Parameter name	Symbol	Unit	Value
1. Basic density of the beech wood	ρ_b	$kg \cdot m^{-3}$	560
2. Moisture content of the logs (*a* – at u = 0.4 $kg \cdot kg^{-1}$, *b* – at u = 0.6 $kg \cdot kg^{-1}$, *c* – at u = 0.8 $kg \cdot kg^{-1}$)	u	$kg \cdot kg^{-1}$	0.4*a* 0.6*b* 0.8*c*
3. Fiber saturation point of the beech wood at −1 °C (i.e. at 272.15 K)	$u_{fsp(272.15)}$	$kg \cdot kg^{-1}$	0.331
4. Density of the wet beech wood equal to $\rho_b \cdot (1 + u)$	ρ_w	$kg \cdot m^{-3}$	784*a* 896*b* 1008*c*
5. Initial temperature of the logs in the beginning of their thawing: (*d* – at t_{w0} = −1 °C, *e* – at t_{w0} = −10 °C, *f* – at t_{w0} = −20 °C, *g* – at t_{w0} = −30 °C, and *h* – at t_{w0} = −40 °C)	t_{w0}	°C	−1*d* −10*e* −20*f* −30*g* −40*h*
6. Average mass temperature of the logs with u = 0.6 $kg \cdot kg^{-1}$ at the end of their complete thawing, depending on t_{w0}	$t_{avg\text{-}end}$	°C	48.6*d* 49.7*e* 50.6*f* 51.5*g* 52.4*h*
7. Average specific heat capacity of log layers containing both frozen bound and free water at u = 0.6 $kg \cdot kg^{-1}$, depending on t_{w0}	$c_{w\text{-}fr\text{-}avg}$	$J \cdot kg^{-1} \cdot K^{-1}$	2373*d* 2276*e* 2177*f* 2083*g* 1991*h*
8. Average specific heat capacity of completely defrosted layers of logs with u = 0.6 $kg \cdot kg^{-1}$, depending on t_{w0}	$c_{w\text{-}nfr\text{-}avg}$	$J \cdot kg^{-1} \cdot K^{-1}$	2777*d* 2780*e* 2783*f* 2786*g* 2789*h*
9. Average specific heat capacity of the frozen bound water in logs with u = 0.6 $kg \cdot kg^{-1}$, depending on t_{w0}	$c_{ice\text{-}bw\text{-}avg}$	$J \cdot kg^{-1} \cdot K^{-1}$	2473*d* 1868*e* 1366*f* 996*g* 723*h*
10. Average specific heat capacity of the frozen free water in logs, depending on u	$c_{ice\text{-}fw\text{-}avg}$	$J \cdot kg^{-1} \cdot K^{-1}$	16461*a* 56154*b* 87026*c*

RESULTS AND DISCUSSION

Figure 2 and Figure 3 present, as an example, the change in the operating temperature, t_m, temperature in the central point, t_{wc}, and the average mass temperature, t_{avg}, of frozen logs with an initial temperature of –10 °C and –30 °C respectively, calculated with the equations (1) − (4) during logs' thawing at the three investigated values of the wood moisture content u. Fig.~~s~~ 4, 5, and 6 show the calculated with eqs. (5) – (9) change in the energy $Q_{w\text{-}total}$ and its components for the cases of log moisture content of 0.4 kg.kg^{-1}, 0.6 kg.kg^{-1}, and 0.8 kg.kg^{-1} respectively, depending on t_{w0}.

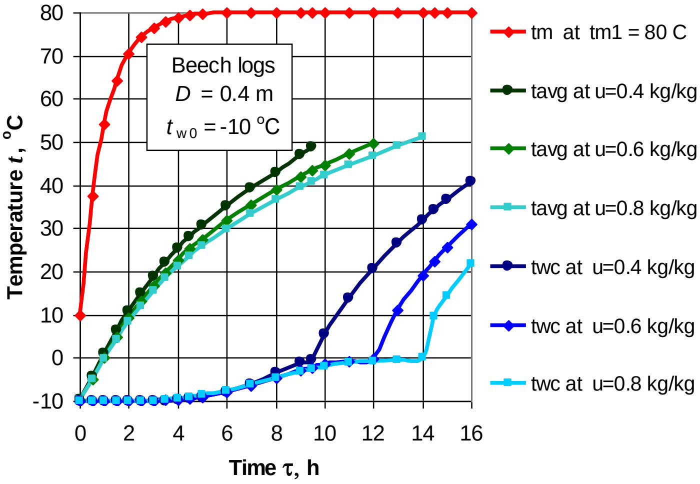

Fig. 2 Change in t_m, t_{wc}, and t_{avg} of logs with t_{w0}= −10 °C during their thawing, depending on *u*.

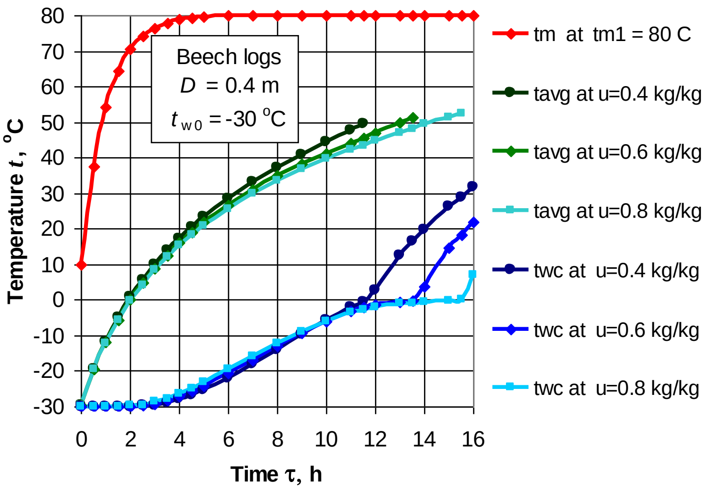

Fig. 3 Change in t_m, t_{wc}, and t_{avg} of logs with t_{w0}= −30 °C during their thawing, depending on *u*.

In Figures 2 and 3 it is seen that complete thawing of the logs occurs as follows:
• for t_{wo} = –10 °C: after 9.5 h, 12.0 h, and 14.0 h at u = 0.4, 0.6, and 0.8 kg·kg^{-1} respectively;
• for t_{wo} = –30 °C: after 11.5 h, 13.5 h, and 15.5 h at u = 0.4, 0.6, and 0.8 kg·kg^{-1} respectively.
At these values of defrosting duration, τ_{defr}, the temperature of the central point of the logs reaches 0 °C, at which the melting of the entire amount of frozen water in the logs was completed. Then, at the end of thawing, the average mass temperature of the relatively most frequently subjected to thermal treatment logs with u = 0.6 kg·kg^{-1} are equal as follows: $t_{avg\text{-}end}$ = 49.7 °C at t_{wo} = –10 °C and $t_{avg\text{-}end}$ = 51.5 °C at t_{wo} = –30 °C. These and the other values of $t_{avg\text{-}end}$ calculated with eq. (4) for all studied combinations between t_{wo} and u were used to calculate the energy $Q_{w\text{-}nfr}$ according to eq. (9).

It can be noted, that a specific almost horizontal sections of retention of the temperature t_{wc} for a long period of time in the range from –1 °C to 0 °C in the center of the frozen logs (and also in all calculation points not shown in Fig. 2 and Fig. 3 in the inner layers of the studied logs) was observed. These sections are caused by the extremely small temperature conductivity of these points during the too long melting of the frozen free water in the wood (Deliiski, 2009; Tumbarkova, 2019; Niemz *et al.*, 2023).

Figures 4, 5, and 6 show the change in the energy $Q_{\text{w-total}}$ and its components for the cases of log moisture content of 0.4 kg.kg^{-1}, 0.6 kg.kg^{-1}, and 0.8 kg.kg^{-1} respectively calculated with eq. (5) – (9), depending on t_{w0}.

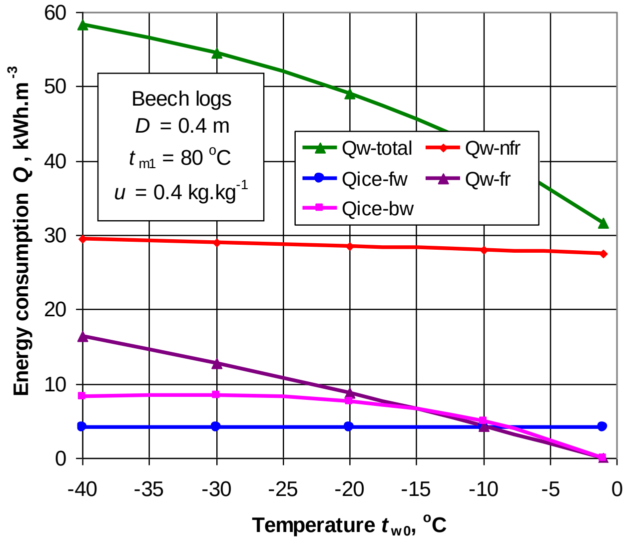

Fig. 4 Changes in the energy $Q_{\text{w-total}}$ and its components required for thawing of logs with u = 0.4 kg·kg^{-1}, depending on t_{w0}.

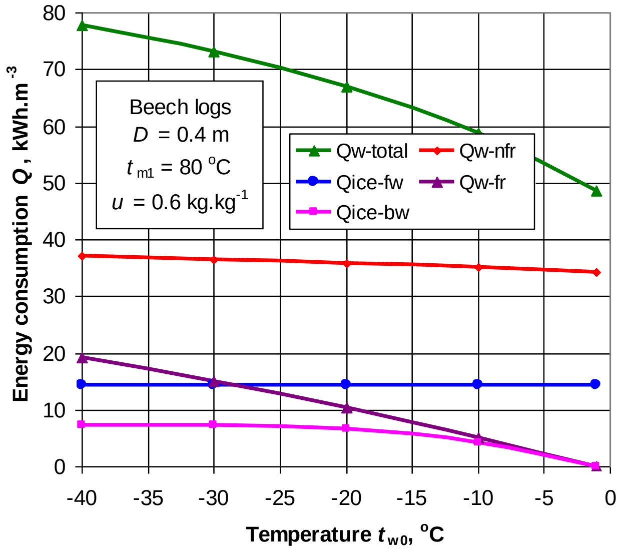

Fig. 5. Changes in the energy $Q_{\text{w-total}}$ and its components required for thawing of logs with u = 0.6 kg·kg^{-1}, depending on t_{w0}.

The analysis of the results presented in Fig. 4 to Fig. 6 allows the following statements to be made about the influence of t_{w0} and u on the energy $Q_{\text{w-total}}$ and each of its components:

• The total energy required for thawing the frozen logs increases with a decrease in the initial temperature of the wood t_{w0} according to a convex slightly curvilinear dependence $Q_{\text{w-total}} = f(t_{w0})$, as follows:

▪ at u = 0.4 kg·kg^{-1}: from 31.66 kWh·m^{-3} at t_{w0} = −1 °C to 58.40 kWh·m^{-3} at t_{w0} = −40 °C;
▪ at u = 0.6 kg·kg^{-1}: from 48.58 kWh·m^{-3} at t_{w0} = −1 °C to 77.87 kWh·m^{-3} at t_{w0} = −40 °C;
▪ at u = 0.8 kg·kg^{-1}: from 63.39 kWh·m^{-3} at t_{w0} = −1 °C to 95.36 kWh·m^{-3} at t_{w0} = −40 °C.

If the dependences $Q_{\text{w-total}} = f(t_{w0})$ calculated according to Equation (5), are approximated with straight lines, which connect their initial and final points it turns out that each decrease in t_{w0} with 1 °C causes an increase in $Q_{w\text{-}total}$ with approx. 0.686 kWh·m^{-3} at u = 0.4 kg·kg^{-1}, 0.751 kWh·m^{-3} at u = 0.6 kg·kg^{-1}, and 0.820 kWh·m^{-3} at u =0.8 kg·kg^{-1}.

• The energy required to heat frozen wood to a state necessary to start melting the temperature-dependent fraction of bound water in the wood, $Q_{w\text{-}fr}$, increases slightly with an increase in the moisture content u and almost linearly with a decrease in t_{w0}, from 0 kWh·m^{-3} at t_{w0} = −1 °C for all u to the following values at t_{w0} = −40 °C: 16.43 kWh·m^{-3} at u = 0.4 kg·kg^{-1}, 19.33 kWh·m^{-3} at u = 0.6 kg·kg^{-1}, and 22.27 kWh·m^{-3} at u = 0.8 kg·kg^{-1}.

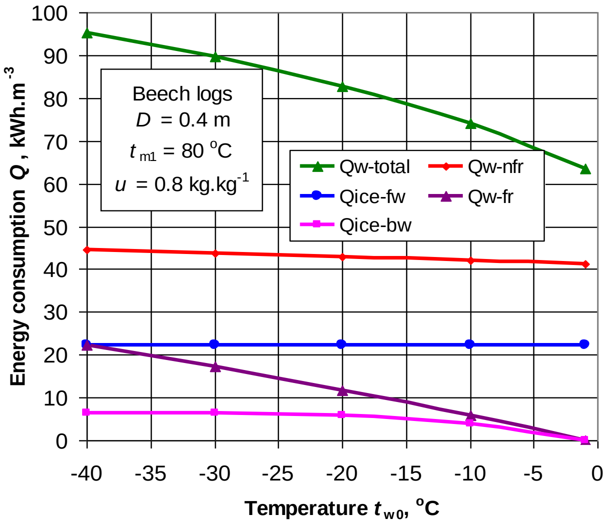

Fig. 6 Changes in the energy $Q_{w\text{-}total}$ and its components required for thawing of logs with u = 0.8 kg· kg^{-1}, depending on t_{w0}.

• The energy required to melt the temperature-dependent amount of frozen bound water in the wood, $Q_{ice\text{-}bw}$, decreases slightly with an increase in u, and increases according to a convex curved line with a decrease in t_{w0}, from 0 kWh·m^{-3} at t_{w0} = −1 °C for all u to the following values at t_{w0} = −40 °C: 8.21 kWh·m^{-3} at u = 0.4 kg·kg^{-1}, 7.19 kWh·m^{-3} at u = 0.6 kg·kg^{-1}, and 6.39 kWh·m^{-3} at u = 0.8 kg·kg^{-1}.

• The energy required to melt the entire amount of frozen free water in the wood, $Q_{ice\text{-}fw}$, does not depend on t_{w0}, but increases strongly with an increase in u, reaching the following values: 4.19 kWh·m^{-3} at u = 0.4 kg·kg^{-1}, 14.30 kWh·m^{-3} at u = 0.6 kg·kg^{-1}, and 22.27 kWh·m^{-3} at u = 0.8 kg·kg^{-1}.

• The energy $Q_{w\text{-}nfr}$ required to heat the completely defrosted layers of logs at the moment of reaching 0 °C in the log central point, when the average mass temperature, $t_{avg\text{-}end}$, reaches values around 50±2 °C (see item 6 in Table 2), increases with an increase in u and when t_{w0} is lowered, as follows:

▪ at u = 0.4 kg·kg^{-1}: from 27.47 kWh·m^{-3} at t_{w0} = −1 °C to 29.57 kWh·m^{-3} at t_{w0} = −40 °C;
▪ at u = 0.6 kg·kg^{-1}: from 34.28 kWh·m^{-3} at t_{w0} = −1 °C to 37.05 kWh·m^{-3} at t_{w0} = −40 °C;
▪ at u = 0.8 kg.kg^{-1}: from 41.22 kWh·m^{-3} at t_{w0} = −1 °C to 44.53 kWh·m^{-3} at t_{w0} = −40 °C.

CONCLUSION

The present paper describes an approach for calculating the energy and its components required for thawing logs intended for veneer production. The approach is based on the use of two personal models: a 1D unsteady model of the temperature distribution along the radius of frozen logs during their thawing, and a stationary model of the energy consumption of the logs subjected to thawing as a sum of its four multifactorial components.

The numerical solving of the 1D model in order to determine the duration of the modes for thawing of the logs, and also their average mass temperature during these modes is carried out with the help of own software packages in the calculation environment of Visual FORTRAN Professional. Using this program together with the own Excel program for solving the stationary model, the influence of all combinations between 5 values of the initial temperature of frozen beech logs (−1 °C, −10 °C, −20 °C, −30 °C, and −40 °C) and 3 values of their moisture content (0.4 kg·kg^{-1}, 0.6 kg·kg^{-1}, and 0.8 kg·kg^{-1}) on the total energy and its components required to thaw logs with a diameter of 0.4 m at operating temperature of the heating medium of 80 °C was investigated.

It was found that the total energy changes in the range from 31.66 kWh·m^{-3} (at −1 °C and 0.4 kg·kg^{-1}) to 95.36 kWh·m^{-3} (at −40 °C and 0.8 kg·kg^{-1}).

When expressing the individual components of the total energy as a % of it, a decrease in the initial temperature from −1 °C to −40 °C causes the following change in these components at log moisture content of 0.6 kg·kg^{-1}:

▪ the relative share of the energy required to heat the logs to a condition necessary to melt the frozen bound water in them increases from 0% to 24.8%;

▪ the relative share of the energy required to melt the temperature-dependent amount of frozen bound water in the logs increases from 0% to 9.2%;

▪ the relative share of the energy required to melt the entire amount of frozen free water in the logs decreases from 29.4% to 18.4%;

▪ the relative share of energy required to heat the already defrosted layers of the logs at the moment of reaching 0 °C in their central point decreases from 70.6% to 47.6%.

It can be noted that the approach presented in this work could be applied to determine the energy and its components required for thawing of various frozen capillary-porous materials in practice.

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AUTHORS' ADDRESSES

Prof. Nencho Deliiski, DSc.
University of Forestry,
Faculty of Forest Industry
Kliment Ohridski Blvd. 10
1797 Sofia, Bulgaria
deliiski@netbg.com

Prof. Ing. Ladislav Dzurenda, PhD.
Technical University in Zvolen
Faculty of Wood Science and Technology
Department of Woodworking
T. G. Masaryka 24
960 01 Zvolen, Slovakia
dzurenda@tuzvo.sk

Prof. Dimitar Angelski, PhD.
University of Forestry,
Faculty of Forest Industry
Kliment Ohridski Blvd. 10
1797 Sofia, Bulgaria
d.angelski@gmail.com

Assoc. Prof. Pavlin Vitchev, PhD.
University of Forestry,
Faculty of Forest Industry
Kliment Ohridski Blvd. 10
1797 Sofia, Bulgaria
p_vitchev@abv.bg

Assist. Prof. Krasimira Atanasova, PhD.
University of Forestry,
Faculty of Forest Industry
Kliment Ohridski Blvd. 10
1797 Sofia, Bulgaria
k_atanasova@ltu.bg