Article

IMPACT OF THE DEGREE OF FILLING OF A STEAMING PIT WITH FROZEN VENEER LOGS ON ITS HEAT BALANCE AND EFFICIENCY

Nencho Deliiski[1], Ladislav Dzurenda[2], Pavlin Vitchev[1], Dimitar Angelski[1], Krasimira Atanasova[1]

[1]10 Kliment Ohridski blvd., 1797 Sofia, Bulgaria, University of Forestry, deliiski@netbg.com, p_vitchev@abv.bg, d.angelski@gmail.com, k_atanasova@ltu.bg

[2]Technical University in Zvolen, Zvolen, Slovakia, dzurenda@tuzvo.sk

ABSTRACT

An approach for calculating the heat balance and thermal efficiency of concrete pits during the steaming of frozen logs intended for peeled veneer production is presented. Using our non-stationary model, the temperature field and heating times of beech logs with a diameter of 0.4 m, an initial temperature of −20°C, and moisture contents of 0.4, 0.6, and 0.8 $kg \cdot kg^{-1}$ were determined at a steaming-medium operating temperature of 80°C. Using the calculated heating times and our stationary model of the heat balance of concrete pits during log steaming, the total energy required for the entire steaming process and each of the five individual heat-balance components were calculated. Computations were performed for a concrete pit with overall dimensions of 7.4 × 2.8 × 2.5 m, a working volume of 20 m^3, and filling degrees f of 45%, 60%, and 75%. Reducing the filling degree from 75% to 45% decreased the thermal efficiency from 46.0% to 34.8%, from 52.4% to 41.0%, and from 56.6% to 45.4% at log moisture contents of 0.4, 0.6, and 0.8 $kg \cdot kg^{-1}$, respectively. The proposed approach can be readily adapted to calculate the heat balance and efficiency of concrete steaming pits with different designs and construction parameters.

Keywords: *concrete steaming pits; veneer logs; heat balance; heat efficiency; wood moisture content; energy consumption*

INTRODUCTION

It is well known that logs are thermally treated in steaming pits to plasticize the wood and reduce cutting resistance during the production of high-quality peeled veneer [1–12].

The steaming of wood materials in pits is characterized by high energy consumption and low thermal efficiency [13, 14].

Estimating the combined effects of several dozen factors on the temperature distribution in wood materials subjected to steaming and on the required energy consumption is a difficult task. This problem can be solved only with the aid of adequate mathematical models.

Publications on the energy required to steam or boil logs in pits are scarce. A model of the heat balance of concrete pits was proposed in [15] and used to calculate the heat balance of the pit shown in Figure 1 during the boiling of frozen beech logs.

Citation: Deliiski, N.; Dzurenda, L.; Vitchev, P.; Angelski, D.; Atanasova, K. Impact of the Degree of Filling of a Steaming Pit with Frozen Veneer Logs on Its Heat Balance and Efficiency. INNO 2026, 15 (1). https://doi.org/10.66211/inno.2026.1.394

The aim of this study is to extend the model presented in [15] to the steaming of logs in concrete pits and to investigate the effects of the pit filling degree and log moisture content on the heat balance and thermal efficiency during the steaming of frozen veneer logs.

MATERIALS AND METHODS

This study was conducted on frozen beech (*Fagus sylvatica* L.) logs steamed in the concrete pit shown in Figure 1 to plasticize the wood for peeled veneer production. The main input parameters of the pit and the studied logs used in the mathematical model of the pit heat balance during log steaming are given in Table 1.

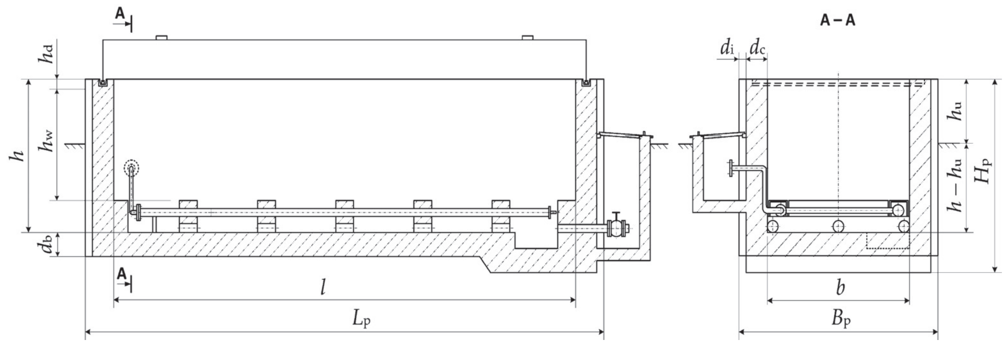

Figure 1. Longitudinal and transverse sections of the pit used for steaming wood materials in the heat-balance and efficiency calculations

The pit is a concrete tank with steel-reinforced walls and bottom that are well insulated both thermally and against moisture. A water-filled groove is formed in the pit walls; when the pit is closed, the protruding edge of the lid is immersed in this groove, creating an effective water seal. During steaming, the pit is closed with a removable, well-insulated metal lid.

The required operating temperature during log steaming is maintained by saturated steam introduced into the pit through the heating elements of a tubular radiator. The radiator is located in the lower part of the pit and is supplied with steam from a generator of suitable capacity. The tubular radiator elements are perforated on their underside, and the steam passes through a layer of condensate while heating the pit and the logs. After the steaming cycle is completed, the pit is drained and the condensate is removed.

Commonly used steaming cycles for frozen wood materials were applied in the calculations [15]. During these cycles, the temperature of the steaming medium rises exponentially from an initial value of 10 °C to a constant maximum value of 80°C over 4 h (Table 1).

MODEL OF THE PIT HEAT BALANCE DURING LOG STEAMING

The heat balance of the concrete pit during log steaming can be represented by the following mathematical model:

$$Q_{\text{Pit-steaming}} = Q_{\text{Wood}} + Q_{\text{Constr.}} + Q_{\text{Cond. water}} + Q_{\text{Radiator}} + Q_{\text{Heat losses}} \quad (1)$$

where $Q_{\text{Pit-steaming}}$ is the total specific heat energy (per 1 m^3 of wood) required for the complete plasticization process; Q_{Wood} is the energy required to heat the frozen logs; $Q_{\text{Constr.}}$ is the energy required to heat the pit construction materials; $Q_{\text{Cond. water}}$ is the energy contained in the condensate that accumulates at the bottom of the pit during log steaming and is discharged at the end of the steaming cycle; Q_{Radiator} is the energy required to heat the metal radiator through which steam is introduced into the pit; and $Q_{\text{Heat losses}}$ is the energy required to compensate for heat losses during log steaming. The unit of all specific energies Q in Equation (1) and throughout this paper is $\text{kWh}\cdot\text{m}^{-3}$.

The mathematical descriptions of the heat-balance components Q_{Wood}, $Q_{\text{Constr.}}$, Q_{Radiator}, and $Q_{\text{Heat losses}}$ included in Equation (1) are the same as those given in [15]. Only the mathematical description of $Q_{\text{Cond. water}}$ is absent from that reference. This component can be calculated using the following equation:

$$Q_{\text{Cond.water}} = m_{\text{cw}} \cdot \frac{h_{\text{cw}}^{\tau_2}}{3.6 \cdot 10^6 V_w} \quad (2)$$

where

$$m_{\text{cw}} = 3.6 \cdot 10^6 \cdot V_w \cdot \frac{Q_{\text{Wood}} + Q_{\text{Constr.}} + Q_{\text{Heat losses}}}{r_{\text{steam}}^{\tau_2}} \quad (3)$$

Table 1. Basic input parameters used to solve the mathematical model of the pit's heat balance during log steaming

№	Parameter name	Symbol	Unit	Value
	Parameters of the steaming pit			
1.	Length of the working volume of the pit	l	m	6.6
2.	Width of the working volume of the pit	b	m	2.0
3.	Distance of the drainage channel from the upper edge of pit	h_d	m	0.13
4.	Depth of the working volume of the pit	h_w	m	1.52
5.	Depth of the upper (above-ground) part of the pit	h_u	m	0.8
6.	Thickness of the walls and bottom of the pit	d_c	m	0.3
7.	Thickness of the insulating layers of the walls and steel lid	d_i, $d_{\text{i-lid}}$	m	0.1
8.	Thickness of the steel sheets of the pit's lid	d_{Fe}	m	0.004
9.	Density of the concrete walls and bottom of the pit	ρ_c	$\text{kg}\cdot\text{m}^{-3}$	2300
10.	Density of the insulating layers of the pit's walls and steel lid	ρ_i, $\rho_{\text{icov.}}$	$\text{kg}\cdot\text{m}^{-3}$	350
11.	Density of the steel sheets of the lid	ρ_{Fe}	$\text{kg}\cdot\text{m}^{-3}$	7850
12.	Initial temperatures of the pit's concrete walls and bottom	t_{cu0}, t_{cg0}, t_{bg0}	ºC	10
13.	Initial temperatures of the pit's insulation layers and soil	t_{iu0}, t_{ig0}, t_{s0}	ºC	10
14.	Temperature of the heat carrier that feeds the pit's radiator	t_{hc}	ºC	130
15.	Temperature of the ambient air, including above the pit's lid	t_{air}	ºC	10
16.	Specific heat capacity of the concrete (average value)	c_c	$\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$	1134
17.	Specific heat capacity of the insul. layers of the walls and lid	c_i, $c_{\text{i-lid}}$	$\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$	850

№	Parameter name	Symbol	Unit	Value
18.	Specific heat capacity of the steel sheets of the pit's lid	c_{Fe}	$J{\cdot}kg^{-1}{\cdot}K^{-1}$	444
19.	Thermal conductivity of the concrete (average value)	λ_c	$W{\cdot}m^{-1}{\cdot}K^{-1}$	1.28
20.	Thermal conductivity of the insulating layers	λ_i	$W{\cdot}m^{-1}{\cdot}K^{-1}$	0.042
21.	Thermal conductivity of the sandy-clay soil around the pit	λ_s	$W{\cdot}m^{-1}{\cdot}K^{-1}$	1.4
22.	Loading level of the pit, i.e. the degree of filling it with logs	f	%	45, 60, 75
23.	Specific mass of the heating elements of the radiator on 1m^2 of the area at the bottom of the pit	m	$kg{\cdot}m^{-2}$	100
	Technological parameters of the steaming modes of frozen beech logs in pit			
1.	Diameter of the logs	D	m	0.4
2.	Lengths of the logs	L	m	3.0
3.	Moisture content of the logs	u	$kg{\cdot}kg^{-1}$	0.4,0.6,0.8
4.	Fiber saturation point of the beech wood	u_{fsp}	$kg{\cdot}kg^{-1}$	0.31
5.	Basic density of the beech wood	ρ_b	$kg{\cdot}m^{-3}$	560
6.	Density of the ice in the wood	ρ_{ice}	$kg{\cdot}m^{-3}$	917
7.	Initial average mass temperature of the logs	t_{w0}	ºC	−20
8.	Initial value of the operating temperature in the pit	t_{m0}	ºC	10
9.	Maximum operating temperature of the steaming modes	t_{m1}	ºC	80
10.	Duration of the increase in t_m from t_{m0} to t_{m1}	τ_1	h	4.0
11.	Duration of the steaming modes of logs, depending on u	τ_2	h	25, 27, 29
12.	Minimum temperature in the center of the steamed logs at $\tau = \tau_2$	$t_{wc\text{-}min}$	ºC	62.0
13.	Average mass temperature of all logs at the end of their modes	$t_{avg\text{-}end}$	ºC	72.9
14.	Condensation heat of steam in the pit at $\tau = \tau_2$ and t_{m1} = 80 ºC	r_{steam}	$kJ{\cdot}kg^{-1}$	2308
15.	Enthalpy of the condensation water in the pit at t_{m1}=80 ºC	h_{cw}	$kJ{\cdot}kg^{-1}$	335

The volume of the wood materials subjected to steaming in the pit, V_w, which participates in Equations (2) and (3), is equal to

$$V_w = f \cdot V_{\text{pit}} \tag{4}$$

where f is the degree of filling (i.e. loading level) of the pit with wood materials subjected to steaming, $m^3{\cdot}m^{-3}$; V_{pit} – working space of the pit equal to (refer to Fig. 1)

$$V_{\text{pit}} = l \cdot b \cdot h_w \tag{5}$$

The mass of condensate accumulated in the pit, m_{cw}, and the corresponding energy, $Q_{\text{Cond. water}}$, are calculated using Equation (3) for the conditions at the end of the steaming cycle, i.e., at $t_m = t_{m1}$ and $\tau = \tau_2$, when the condensate drain valve is fully open. The mass m_{cw} is obtained by dividing the sum of Q_{Wood}, $Q_{\text{Constr.}}$, and $Q_{\text{Heat losses}}$, expressed in $J{\cdot}m^{-3}$, by the latent heat of steam condensation in the pit, r_{steam}, at $\tau = \tau_2$.

The enthalpy of the condensate, hcw, and the value of rsteam are given in the lower part of Table 1. They were taken from reference data on the thermodynamic properties of water and saturated steam at 80 °C [10,16–18].

The thermal efficiency of the concrete pit during the steaming of logs with different moisture contents u and at different pit filling degrees f is calculated (%) using the following equation:

$$\eta_{\text{pit-steaming}} = 100 \frac{Q_{\text{Wood}}}{Q_{\text{steam-total}}} \tag{6}$$

where $Q_{\text{steam-total}}$ and Q_{Wood} are the specific energies calculated using Equation (1) and required to carry out the entire steaming process in the pit and to heat the frozen logs, respectively.

SOLVING THE MODEL (1) – (4)

The mathematical descriptions of tm and the thermophysical properties of wood given in [10, 19–21] were incorporated into our one-dimensional nonlinear model of the radial temperature distribution in frozen logs during heating. The model was solved by the finite-difference method using proprietary software written in Microsoft Visual FORTRAN.

From the calculated temperature-field evolution in the logs, particularly the temperature at their centre, the steaming duration τ_2 was determined at an operating temperature $t_{m1} = 80^{\circ}$C for logs with a diameter of 0.4 m, an initial temperature of -20°C, and moisture contents of 0.4, 0.6, and 0.8 $kg \cdot kg^{-1}$.

An Excel program was developed for the simultaneous solution of all equations in Models (1)–(5). The program was used to investigate the heat balance of the pit shown in Figure 1 during the steaming of the specified frozen beech logs at pit filling degrees of 45%, 60%, and 75%.

The design parameters of the studied pit (Figure 1), the characteristics of the beech logs, and the pit operating temperature listed in Table 1 were used as input data.

RESULTS AND DISCUSSION

Temperature changes in logs during steaming

Figure 2 shows the calculated changes in the temperature at the centre of the studied frozen logs, twc, and in their mean mass temperature, tavg, during steaming at the pit-medium temperature tm. The temperature tm rises exponentially from its initial value tm_0 = 10°C to tm_1 = 80°C = const. over 4 h.

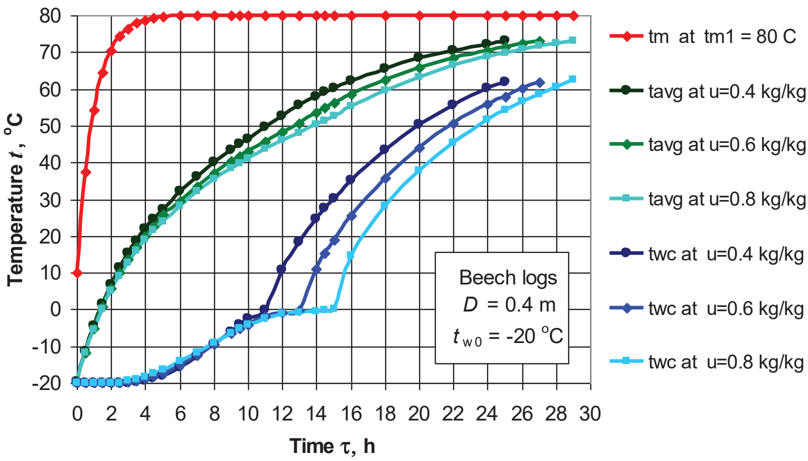

Figure 2. Changes in t_m, t_{wc}, and t_{avg} of the studied logs during steaming as a function *of u*

Figure 2 shows that steaming of the studied beech logs ends after 25.0 h at u = 0.4 kg·kg^{-1}, 27.0 h at u = 0.6 kg·kg^{-1}, and 29.0 h at u = 0.8 kg·kg^{-1}. At these steaming durations, the temperature at the slowest-heating central point of the logs reaches 62°C, which is the minimum temperature required to obtain high-quality veneer from well-plasticized beech logs [10, 22].

It is also evident that, during steaming, the mean mass temperature of the logs increases from its initial value $t_{w0} = -20$ °C to the same final value $t_{avg\text{-}end} = 72.9$ °C for all studied values of *u*. The equivalent value of $t_{avg\text{-}end}$ in kelvins was used to calculate Q_{Wood} in Equation (1).

Changes in the pit heat balance at the end of steaming

Figure 3 presents the changes in all five components of the heat balance of the studied pit at the maximum filling degree *f* = 75% and an initial log temperature $t_{w0} = -20$ °C, together with the total energy consumption (kWh·m^{-3}) required for the entire steaming process as a function of wood moisture content *u*.

Figure 4 shows the individual heat-balance components Q_i at *f* = 75%, expressed as percentages of the total energy consumption $Q_{steam\text{-}total}$, as a function *of u*.

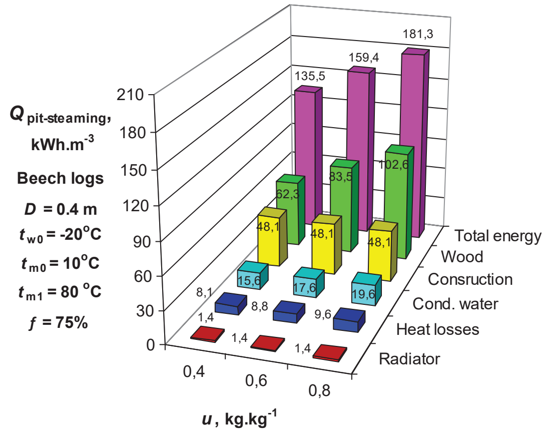

Figure 3. Changes in the heat-balance components (kWh·m^{-3}) of the pit at the end of log steaming as a function *of u*

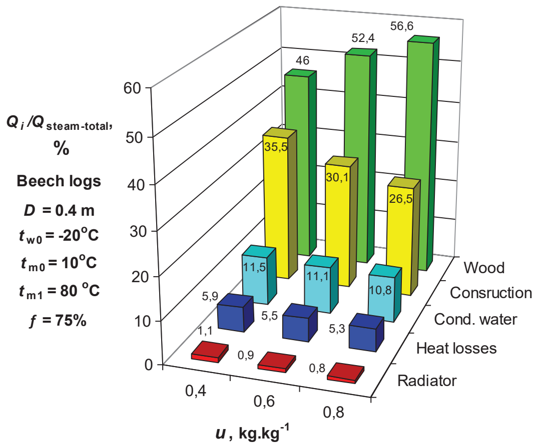

Figure 4. Heat-balance components expressed as percentages of $Q_{\text{steam-total}}$ as a function *of u*

When the pit heat balance is expressed in kWh·m^{-3}, increasing u from 0.4 to 0.8 kg·kg^{-1} increases the total pit energy consumption $Q_{\text{steam-total}}$ from 135.5 to 181.3 kWh·m^{-3}. The individual heat-balance components change as follows (Figure 3): Q_{Wood}, $Q_{\text{Cond. water}}$, and $Q_{\text{Heat losses}}$ increase from 62.3 to 102.6 kWh·m^{-3}, from 15.6 to 19.6 kWh·m^{-3}, and from 8.1 to 9.6 kWh·m^{-3}, respectively, whereas $Q_{\text{Constr.}}$ and Q_{Radiator} remain unchanged at 48.1 and 1.4 kWh·m^{-3}, respectively.

When the individual heat-balance components Q_i are expressed as percentages of the total energy $Q_{\text{steam-total}}$, increasing u from 0.4 to 0.8 kg·kg^{-1} changes the fraction of each component as follows (Figure 4): Q_{Wood} increases from 46.0% to 56.6%, whereas $Q_{\text{Constr.}}$, $Q_{\text{Cond. water}}$, $Q_{\text{Heat losses}}$, and Q_{Radiator} decrease from 35.5% to 26.5%, from 11.5% to 10.8%, from 5.9% to 5.3%, and from 1.1% to 0.8%, respectively.

Changes in the thermal efficiency of the pit

Figure 5 presents the thermal efficiency of the pit ηPit-steaming, calculated using Equation (5), as a function of the studied values of u and pit filling degrees f of 45%, 60%, and 75%.

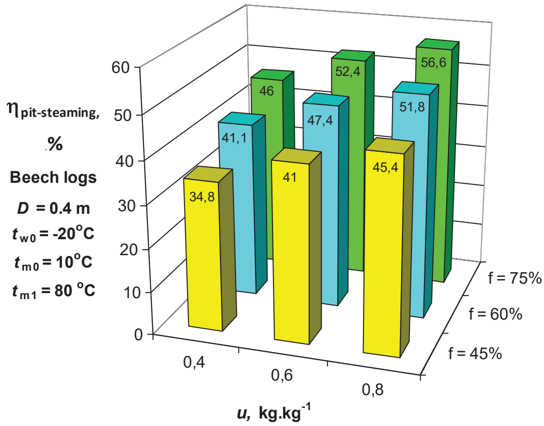

Figure 5. Thermal efficiency of the pit as a function of *u* and *f*

Figure 5 shows that increasing the log moisture content from 0.4 to 0.8 kg·kg^{-1} produces the following increases in pit thermal efficiency $\eta_{pit\text{-}steaming}$ at each filling degree:

- at f = 45%: from 34.8 to 45.4%;
- at f = 60%: from 41.1 to 51.8%;
- at f = 75%: from 46.0 to 56.6%.

Figure 5 also shows that reducing the pit filling degree from 75% to 45% decreases $\eta_{pit\text{-}steaming}$ at each wood moisture content as follows:

- at u = 0.4 kg·kg^{-1}: from 46.0 to 34.8%;
- at u = 0.6 kg·kg^{-1}: from 52.4 to 41.0%;
- at u = 0.8 kg·kg^{-1}: from 56.6 to 45.4%.

These results demonstrate that maintaining a high pit filling degree is important for achieving good thermal efficiency.

CONCLUSIONS

At the commonly used operating temperature t_{m1} = 80 °C, the total energy consumption $Q_{steam\text{-}total}$ of the studied pit was 163.7 kWh·m^{-3} when steaming beech logs with a diameter D = 0.4 m, an initial temperature t_{w0} = −20 °C, and a moisture content u = 0.6 kg·kg^{-1} at the maximum pit filling degree f = 75% for plasticization prior to peeled veneer production.

Increasing u from 0.4 to 0.8 kg·kg^{-1} at f = 75% increases $Q_{steam\text{-}total}$ from 135.5 to 181.3 kWh·m^{-3}, i.e., by 33.8%. The fractions of the individual components of $Q_{steam\text{-}total}$ change as follows: Q_{Wood} increases from 46.0% to 56.6%, whereas $Q_{\text{Constr.}}$, $Q_{\text{Cond. water}}$, $Q_{\text{Heat losses}}$, and Q_{Radiator} decrease from 35.5% to 26.5%, from 11.5% to 10.8%, from 5.9% to 5.3%, and from 1.1% to 0.8%, respectively.

Reducing the pit filling degree from 75% to 45% decreases its thermal efficiency from 46.0% to 34.8%, from 52.4% to 41.0%, and from 56.6% to 45.4% at log moisture contents of 0.4, 0.6, and 0.8 $\text{kg}\cdot\text{kg}^{-1,}$ respectively.

The proposed approach can be applied to calculate the heat balance and efficiency during the steaming of frozen logs from various wood species with different geometrical and thermophysical properties. It can be readily adapted to concrete pits with a wide range of design and construction parameters.

REFERENCES

[1] Vorreiter, L. *Holztechnologisches Handbuch*, Vol. II; Verlag Georg Fromme & Co.: Vienna–Munich, **1958**; 656 pp.

[2] Chudinov, B. S. *Theory of the Thermal Treatment of Wood*; Nauka: Moscow, USSR, **1968**; 255 pp. (in Russian).

[3] [Kollmann, F. F. P.; Côté, W. A., Jr. *Principles of Wood Science and Technology. Vol. I: Solid Wood*; Springer-Verlag: New York, NY, USA, **1984**; 592 pp.

[4] Shubin, G. S. *Drying and Thermal Treatment of Wood*; Lesnaya Promyshlennost: Moscow, USSR, **1990**; 337 pp. (in Russian).

[5] Trebula, P.; Klement, I. *Drying and Hydrothermal Treatment of Wood*; Technical University in Zvolen: Zvolen, Slovakia, **2002**; 449 pp. (in Slovak).

[6] Videlov, H. *Drying and Thermal Treatment of Wood*; University of Forestry: Sofia, Bulgaria, **2003**; 335 pp. (in Bulgarian).

[7] Câmpean, M. *Heat Treatments of Wood*; Transilvania University of Brașov: Brașov, Romania, **2005**; 199 pp.

[8] Steinhagen, H. P. Veneer block conditioning manual for veneer and plywood production. *Maderas: Ciencia y Tecnología* **2005**, *7*(1), 49–56.

[9] Pervan, S. *Technology for Treatment of Wood with Water Steam*; University of Zagreb: Zagreb, Croatia, 2009. (in Croatian).

[10] Deliiski, N.; Dzurenda, L. *Modelling of the Thermal Processes in the Technologies for Wood Processing*; Technical University in Zvolen: Zvolen, Slovakia, **2010**; 224 pp. (in Russian).

[11] Hadjiski, M.; Deliiski, N.; Angelski, D. Computing the processing medium temperature and heat fluxes at the beginning of regimes for autoclave steaming of frozen wood materials. In *Proceedings of the International Conference Automatics and Informatics (ICAI 2021)*, Varna, Bulgaria, 30 September–3 October **2021**; 6 pp.

[12] Niemz, P.; Teischinger, A.; Sandberg, D., Eds. *Springer Handbook of Wood Science and Technology*; Springer Nature Switzerland AG: Cham, Switzerland, **2023**; 2069 pp.

[13] Sohor, M.; Kadlec, P. Hydrothermal treatment of wood for veneer production. *Drevo* **1990**, No. 2. (in Slovak).

[14] Lawniczak, M. *Hydrothermal and Plasticizing Treatment of Wood. Part I: Boiling and Steaming of Wood*; Agricultural Academy: Poznań, Poland, **1995**; 149 pp. (in Polish).

[15] Deliiski, N.; Niemz, P.; Dzurenda, L.; Vitchev, P.; Angelski, D. An approach for computing the thermal balance and energy consumption of concrete pits during boiling of frozen logs for veneer production. *Wood Material Science & Engineering* **2023**, *18*(6), 2153–2163.
[16] Rivkin, S.; Aleksandrov, A. *Thermodynamic Properties of Water and Water Vapor*; Tehnika: Sofia, Bulgaria, **1978**; 84 pp. (in Bulgarian).
[17] Telegin, A. S.; Shvidkiy, V. S.; Yaroshenko, Y. G. *Heat and Mass Transfer*; Akademkniga: Moscow, Russia, **2002**; 455 pp. (in Russian).
[18] Dzurenda, L.; Deliiski, N. *Thermal Processes in Woodworking Technologies*; Technical University in Zvolen: Zvolen, Slovakia, **2019**; 283 pp. (in Slovak).
[19] Deliiski, N. *Modelling and Technologies for Steaming Wood Materials in Autoclaves*. DSc Dissertation, University of Forestry, Sofia, Bulgaria, **2003**; 358 pp. (in Bulgarian).
[20] Deliiski, N. Transient heat conduction in capillary porous bodies. In *Convection and Conduction Heat Transfer*; Ahsan, A., Ed.; InTech: Rijeka, Croatia, **2011**; pp. 149–176.
[21] Tumbarkova, N. *Modelling of the Freezing and Defrosting Processes of Logs and Their Energy Consumption*. PhD Thesis, University of Forestry, Sofia, Bulgaria, **2019**; 198 pp. (in Bulgarian).
[22] Mörath, E. Das Dämpfen und Kochen in der Furnier- und Sperrholzindustrie. *Holztechnik* **1949**, No. 7.

CONTENTS

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2026

INNO vol. XV

ISSN 1314-6149

e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN
Science Journal
Vol. 15/ p. 1–158
Sofia 1/2026
ISSN 1314-6149/e-ISSN 2367-6663

FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA
The Scientific Journal is indexed with and included in CABI.

Cover Design: Desislava Angelova

Printed by: INTEL ENTRANCE

Contact address: 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
University of Forestry, Faculty of Forest Industry
Scientific journal Innovations in Woodworking Industry and Engineering Design
E-mail: inno_scientific_journal@ltu.bg
https://innojs.ltu.bg/