

CHANGE IN THE DURATION OF AUTOCLAVE STEAMING REGIMES OF NON-FROZEN PRISMS AT DISPATCHING INTERVENTIONS IN THE PRODUCTION OF VENEER

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ABSTRACT

An approach for computing and research of the duration of regimes for autoclave steaming of non-frozen wooden prisms at limited heat power of the steam generator in cases of dispatching interventions into the regimes in order to obtain a duration that is suitable for the subsequent cutting of the veneer from the heated plasticized wood has been suggested. Using own 2D unsteady model implemented in the approach, calculations of the change of the duration of regimes for plasticizing of beech prisms in an autoclave have been carried out. The variables used during the computer simulation were, as follows: initial wood temperature of 0 °C, wood moisture content of 0.6 kg·kg⁻¹, and cross-section dimensions of the prisms 0.4 × 0.4 m; steaming autoclave with a diameter of 2.4 m, length of 9.0 m, and loading level of 50% for the cases of lowering by the dispatcher the maximal temperature of the basic steaming regime from 130 °C to 120, 110, and 100 °C in the 3rd, 5th, and 7th hour of this regime.

Key words: wooden prisms, autoclave steaming, duration of regimes, dispatching intervention, veneer production.

INTRODUCTION

During the process of veneer cutting, the wood should be in good plasticizing condition. For heating in order to plasticize prismatic wood materials in the production of veneer, the prisms are very often subjected to steaming in pits, chambers or autoclaves (Chudinov 1968, Lawniczak 1995, Trebula – Klement 2003, Pervan 2009).

The plasticizing of wood materials under increased pressure and temperature of the steaming medium in autoclaves is used in many applications due to its greater energy efficiency and shorter duration in comparison with the plasticizing at atmospheric pressure (Shubin 1990, Deliiski 2003, 2011, Videlov 2003, Sokolovski et al. 2007, Deliiski and Dzurenda 2010).

For veneer production companies, steaming regimes for wood materials with

dispatcher intervention are of considerable interest. Organizational or technical problems that sometimes occur in veneer cutting machines disrupt their normal synchronization with the duration of the current steaming regime, which should provide them with well-plasticized prisms. In such cases, it is necessary for the dispatcher to intervene in a timely manner and to change the temperature-time parameters of the regime in an appropriate way.

In the specialized literature sources (Chudinov 1966, Shubin 1990, Hadjiski et al. 2020, 2021) completely lack any information about the temperature and time parameters of steaming regimes in case of dispatcher intervention in them. That is why this article considers a method for using personal mathematical models to compute the duration of regimes for autoclave steaming of non-frozen

wooden prisms for the cases when the dispatcher at a certain moment decides that it is necessary to extend the time for obtaining such a duration of the regime that is suitable for the subsequent cutting of the veneer from the heated plasticized prisms.

COMPUTING THE 2D UNSTEADY TEMPERATURE DISTRIBUTION IN NON-FROZEN WOODEN PRISMS SUBJECTED TO STEAMING

When the length of the prisms, l , is larger than their thickness, d , at least more 4

$$c_w \cdot \rho_w \frac{\partial T}{\partial \tau} = \text{div} (\lambda_{w-cr} \text{grad } T) \quad (1)$$

at

$$T(x, y, 0) = T_{w0} \quad (2)$$

and boundary conditions:

- when the steaming of the prisms takes place:

$$T(x, 0, \tau) = T(0, y, \tau) = T_m(\tau), \quad (3)$$

- when air conditioning of the steamed prisms is realized:

$$\frac{\partial T(x, 0, \tau)}{\partial y} = - \frac{\alpha_{w-cond}(x, 0, \tau)}{\lambda_{w-cr}(x, 0, \tau)} [T(x, 0, \tau) - T_{m-cond}(\tau)], \quad (4)$$

$$\frac{\partial T(0, y, \tau)}{\partial x} = - \frac{\alpha_{w-cond}(0, y, \tau)}{\lambda_{w-cr}(0, y, \tau)} [T(0, y, \tau) - T_{m-cond}(\tau)], \quad (5)$$

where c_w is the specific heat capacity of the non-frozen wooden prisms during their steaming and subsequent air conditioning processes, $\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$; ρ_w – wood density, $\text{kg} \cdot \text{m}^{-3}$; λ_{w-cr} – thermal conductivity of the non-frozen wood cross sectional to the fibers, $\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$; x – coordinate along the prism's thickness of the separate points of the calculation mesh for numerical solving of the model: $0 \leq x \leq d$, m; d – thickness of the prism, m; y – coordinate along the prism's width of the separate points of the calculation mesh: $0 \leq y \leq b$, m; b – width of the prism, m; τ – time, s; T – temperature, K; T_{w0} – initial

$\div 5$ times, and simultaneously with this the width, b , does not exceed the thickness more than 3 times, for computing the temperature field in the prism's cross section, which is equally distant from the frontal sides (i.e. along the coordinates x and y of this section) during heating and cooling in steaming or air medium the following 2D mathematical model can be used (Deliiski 2003):

average mass temperature of the prism subjected to steaming, K; T_m – processing medium temperature during the steaming of the prisms, K; T_{m-cond} – temperature of the ambient air environment during the conditioning of the steamed prism, K; α_{w-cond} – convective heat transfer coefficient between the prism's surfaces and ambient air environment during the conditioning process, $\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$.

Mathematical descriptions of the specific heat capacity, c_w , density, ρ_w , and thermal conductivity, λ_{w-cr} , of the non-frozen wood have been suggested in (Deliiski 2003, 2011, 2013) as a function of the temperature, T , and wood moisture content, u .

CHANGE IN T_m IN REGIMES FOR STEAMING OF PRISMS IN AN AUTOCLAVE WITHOUT AND IN THE PRESENCE OF DISPATCHING INTERVENTIONS

The typical temperature time profiles of these regimes include the following 5 stages (Fig. 1):

- Intensive increasing of T_m during the time $0 \div \tau_1$ caused by the opening the valve directing the water steam in the autoclave;

- Constant T_m of the steaming medium during $\tau_1 \div \tau_2$ of the basic (i.e. without dispatching intervention) regime, caused by dosed introduction of steam in the autoclave. In the regimes with dispatcher intervention after a certain time interval $\Delta\tau_a$, $\Delta\tau_b$, or $\Delta\tau_c$ from their beginning the temperature T_{m1} decreases with ΔT_{m1-a} , ΔT_{m1-b} , or ΔT_{m1-c} respectively and remains unchanged until the time $\tau_2 = \tau_{\text{steam}}$ is reached. Upon reaching $\tau_{2-a} = \tau_{\text{steam-a}}$, $\tau_{2-b} = \tau_{\text{steam-b}}$, or $\tau_{2-c} = \tau_{\text{steam-c}}$, the supply of steam to the autoclave is stopped.

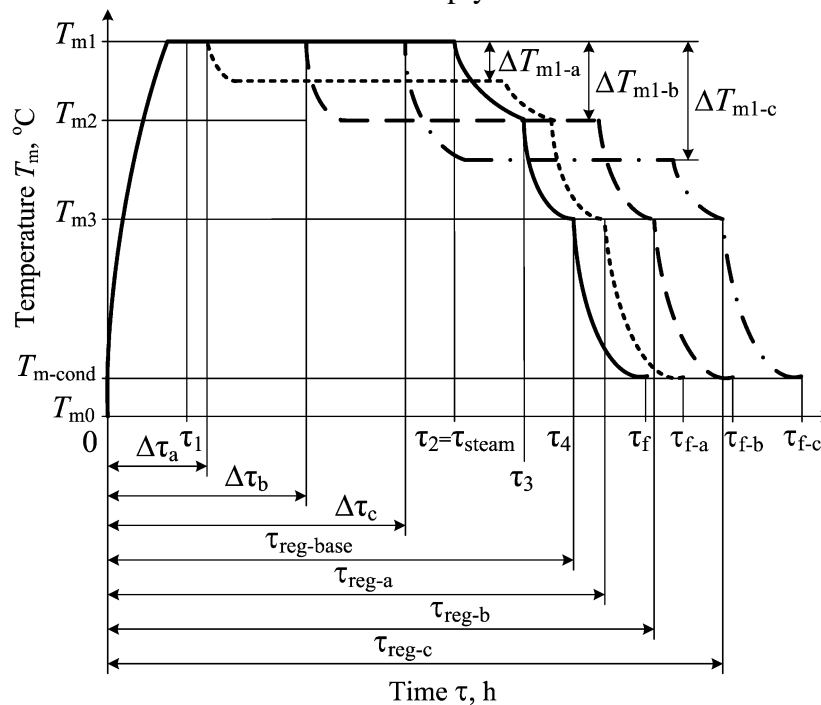


Figure 1: Typical time profile for change in T_m during steaming of prisms in an autoclave and their subsequent conditioning in an air environment

- Decreasing T_m of the steaming medium during $\tau_2 \div \tau_3$ caused by using the already accumulated heat in the autoclave;
- Decreasing T_m of the steaming medium during $\tau_3 \div \tau_4$, which is caused by the opening the valves directing the steam and condensed water out of the autoclave;
- Decreasing T_m of the temperature near the steamed prisms out of the autoclave during $\tau_4 \div \tau_f$.

RESULTS AND DISCUSSION

Using own software package for solving of the model (1) \div (5) in the calculation environment of Visual FORTRAN, simulations were made to compute the T_m and also the 2D non-stationary change in the temperature field in the square cross section of the studied non-frozen beech prisms during their steaming in an autoclave.

The coordinates of the representative points of the prisms, in which the change in T was recorded, were equal, as follows: Point

1 with $T_1: d/8, b/8$ and Point 2 with $T_2: d/2, b/2$ (center of the prisms).

During simulations the following values of the parameters of T_m , which influence the temperature distribution in the prism's cross section of autoclave steaming regimes both without and in the presence of dispatching intervention were set:

1. Initial value of T_m : $T_{m0} = 273.15$ K (i.e. $t_{m0} = 0^\circ\text{C}$).
2. Maximal value of the temperature of the basic steaming regime without dispatcher's intervention: $T_{m1} = 403.15$ K (i.e. $t_{m1} = 130^\circ\text{C}$).
3. Steps of change in the basic value of $T_{m1} = 403.15$ K at dispatcher's interventions: $\Delta T_{m1-a} = 10$ K = 10°C , $\Delta T_{m1-b} = 20$ K = 20°C , and $\Delta T_{m1-c} = 30$ K = 30°C .
4. Temperature of the second stage of the basic steaming regime with constant value of $T_{m1} = 403.15$ K: $T_{m2} = 383.15$ K (i.e. $t_{m2} = 110^\circ\text{C}$).
5. Temperature of the third stage of the basic steaming regime with constant value of $T_{m1} = 403.15$ K: $T_{m3} = 353.15$ K (i.e. $t_{m3} = 80^\circ\text{C}$).
6. Temperature of the air near the steamed prisms during their conditioning: $T_{m\text{-cond}} = 293.15$ K (i.e. $t_{m\text{-cond}} = 20^\circ\text{C}$).

The meaning and the set values of the other variables shown on Fig. 1 are, as follows: $\Delta\tau_a = 3$ h, $\Delta\tau_b = 5$ h, and $\Delta\tau_c = 7$ h – time intervals between the beginning of the steaming regimes and the occurrence of the dispatching intervention; τ_1 – duration of the intensive temperature rise of T_m from $T_{m0} = 273.15$ K to $T_{m1} = 403.15$ K; τ_2 – duration of steam introduction into the autoclave in the basic steaming regime; $\tau_2 - \tau_3$ – time interval of use the already accumulated heat in the autoclave; $\tau_3 - \tau_4$ – time interval of removal of residual steam and condensate water from the

autoclave; $\tau_4 - \tau_f$ – time interval of the air conditioning process of the steamed prisms; $\tau_{\text{reg-base}}$ – duration of the basic steaming regime; $\tau_{\text{reg-a}}$ – duration of the steaming regime with $\Delta\tau_a = 3$ h; $\tau_{\text{reg-b}}$ – duration of the steaming regime with $\Delta\tau_b = 5$ h; $\tau_{\text{reg-c}}$ – duration of the steaming regime with $\Delta\tau_c = 7$ h.

During the simulation the following in total of 9 combinations between ΔT_{m1} and $\Delta\tau$ have been applied: ΔT_{m1-a} with $\Delta\tau_a, \Delta\tau_b$, and $\Delta\tau_c$; ΔT_{m1-b} with $\Delta\tau_a, \Delta\tau_b$, and $\Delta\tau_c$; ΔT_{m1-c} with $\Delta\tau_a, \Delta\tau_b$, and $\Delta\tau_c$.

During simulations the following values of the factors influencing the duration τ_{reg} of the prisms' steaming regimes were set:

1. Dimensions of the square cross section of beech prisms with thickness d and width b : 0.4×0.4 m.
2. Initial temperature t_{w0} of the non-frozen prisms subjected to autoclave steaming: 0°C .
3. Moisture content u of the prisms: $0.6 \text{ kg}\cdot\text{kg}^{-1}$.
4. Basic density of $560 \text{ kg}\cdot\text{m}^{-3}$ for the beech wood.
5. Inner diameter of 2.4 m, length of the cylindrical part of 9.0 m of the well insulated steaming autoclave.
6. Loading level γ of the autoclave with filled in wooden prisms for steaming: $\gamma = 50\%$.
7. Limited heat power $q_{\text{source}} = 500$ kW of the generator, which feeds the autoclave with saturated water steam.

On Fig. 2, as an example, the calculated change in the surface temperature, t_s , average mass temperature, $t_{w\text{-avg}}$, and t of 2 representative points t_1 and t_2 of the studied beech prisms during their autoclave steaming at dispatcher's intervention at 3rd hour from $t_{m1} = 130^\circ\text{C}$ to $t_{m1} = 110^\circ\text{C}$ and to $t_{m1} = 100^\circ\text{C}$ and subsequent air conditioning is presented. In addition, this figure shows the change of the

same variables in the basic regime, in which there is no dispatcher intervention.

On this figure the minimal and maximal values of the temperature, $t_{opt-min} = 62^{\circ}C$ and $t_{opt-max} = 90^{\circ}C$, respectively, are also shown. For the obtaining of quality veneer from plas-

ticized beech wood it is needed that the temperature of all points of the prisms during the veneer cutting process stays between these optimal values of the temperature (Deliiski 2003, Deliiski and Dzurenda 2010, Deliiski et al. 2019, 2021).

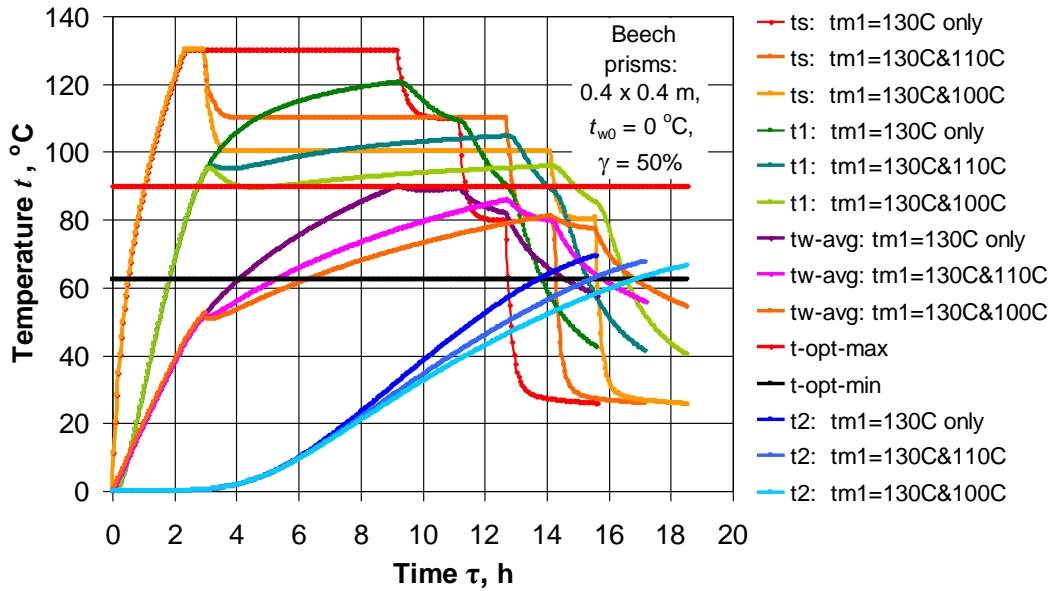


Figure 2: Changes in t_s , t_{w-avg} , t_1 , and t_2 of the prisms during their steaming in an autoclave at dispatching interventions in 3rd h and subsequent air conditioning, depending on Δt_{m1} and τ

On Fig. 3 the duration of the studied steaming regimes, depending on the influencing factors is presented.

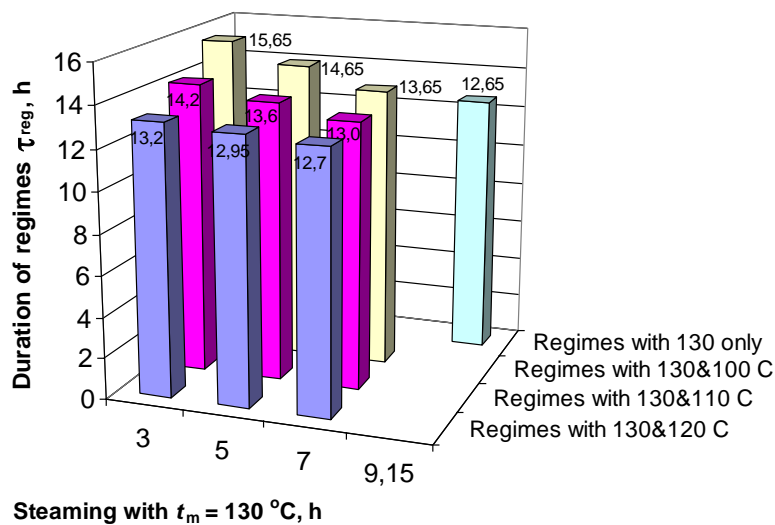


Figure 3: Duration of the studied steaming regimes depending on t_m , Δt_{m1} , and $\Delta \tau$

In Table 1 the change in the duration of the stages τ_2 , τ_3 and τ_4 (see Fig. 1), the temperatures t_1 and t_2 at τ_2 and τ_4 of all of the studied steaming regimes, and also after 1 h

air conditioning (at τ_4+1h) and after 1.5 h conditioning (at $\tau_4+1.5h$) of the plasticized prisms is given.

Table 1: Change in the duration of regimes for steaming of non-frozen beech prisms with $t_{w0} = 0$ °C in an autoclave, τ_{reg} , at $t_{m1} = 130$ °C, 130° & 100° C, 130° & 110° C, and 130° & 120° C, depending on dispatching interventions $\Delta\tau$ in 3rd h, 5th, and 7th h of the regimes

t_{m1} , °C	$\Delta\tau$, h	$\tau_2 = \tau_{steam}$, h	$\tau_4 = \tau_{reg}$, h	t_1 at τ_2 , °C	t_2 at τ_2 , °C	t_1 at τ_4 , °C	t_2 at τ_4 , °C	t_1 at τ_4+1h , °C	t_2 at τ_4+1h , °C	t_1 at $\tau_4+1.5h$, °C	t_2 at $\tau_4+1.5h$, °C
130 only	0	9.15	12.65	120.4	31.7	90.7	56.2	67.1	61.7	57.1	64.1
130&120	3	9.90	13.20	112.0	35.4	89.6	55.9	66.3	60.9	56.4	63.1
130&120	5	9.65	12.95	112.2	34.8	89.7	55.8	66.3	60.9	56.4	63.1
130&120	7	9.40	12.70	113.1	33.5	89.9	55.6	66.5	60.8	56.5	63.1
130&110	3	12.70	14.20	104.5	49.5	88.5	56.9	65.5	62.1	55.6	63.2
130&110	5	12.10	13.60	104.6	49.0	88.6	56.6	65.5	61.1	55.7	63.0
130&110	7	11.50	13.00	105.3	48.1	88.6	56.2	64.6	60.9	55.2	63.0
130&100	3	14.15	15.65	95.7	52.4	84.8	58.2	60.9	61.6	52.3	63.1
130&100	5	13.15	14.65	95.8	51.9	85.2	58.0	62.1	61.5	53.1	63.2
130&100	7	12.15	13.65	96.7	50.8	85.7	57.8	62.5	61.7	53.4	63.4

The obtained results allow for making the following statements about the change in the duration of the regimes for autoclave steaming of frozen beech prisms, τ_{reg} , depending on the studied influencing factors:

1. The non-stationary change of the temperature in the prisms' representative points goes on according to very complex curves during the steaming and consequent air conditioning processes.

2. In the beginning of the steaming process, the temperature of the processing medium t_m increases curvilinearly until reaching its largest value $t_{m1} = 130$ °C after time interval, equal to $\tau_1 = 2.35$ h, which is the same for all studied regimes.

3. The basic steaming regime that is without dispatching intervention has a duration $\tau_{reg} = 12.65$ h, while its duration of the introduction of steam into the autoclave is $\tau_2 = \tau_{steam} = 9.15$ h.

4. Each dispatching intervention causes an increase in the durations τ_2 and τ_{reg} in comparison with the values of τ_2 and τ_{reg} of the

basic steaming regime without dispatching intervention.

5. The increase of the time interval $\Delta\tau$ between the beginning of the steaming process and the moment when the dispatcher decides to intervene with given value of ΔT_{m1} (refer to Fig. 1) causes linear decrease of τ_2 and τ_{reg} . The longer the interval $\Delta\tau$, the shorter the durations τ_2 and τ_{reg} . For example, when $\Delta T_{m1} = 20$ K (i.e. when $t_{m1} = 130$ & 110° C) the durations τ_2 and τ_{reg} obtain the following values: 12.7 h and 14.2 h for $\Delta\tau = 3$ h, 12.1 h and 13.6 h for $\Delta\tau = 5$ h, and 11.5 h and 13.0 h for $\Delta\tau = 7$ h.

6. The increase of the temperature range Δt_{m1} between the basic value of $t_{m1} = 130$ °C and the second value of t_{m1} , which can be equal to 120, 110, 100° C, causes non-linear increase of τ_2 and τ_{reg} . The larger the range Δt_{m1} , the longer the durations τ_2 and τ_{reg} . For example, when $\Delta\tau = 7$ h, the durations τ_2 and τ_{reg} obtain the following values: 9.40 h and 12.70 h for $t_{m1} = 130$ & 120° C, 11.50 h and 13.00 h for $t_{m1} = 130$ & 110° C, 12.15 h and 13.65 h for $t_{m1} = 130$ & 100° C.

7. It can be seen on Fig. 2 and Table 1 that the temperatures of the studied representative points near the prisms surfaces (t_1) and in the prisms center (t_2) enter between the limits required for obtaining quality veneer $t_{\text{opt-min}} = 62^\circ\text{C}$ and $t_{\text{opt-max}} = 90^\circ\text{C}$ after conditioning of the heated steamed prisms at $t_{\text{m-cond}}$ (refer to Fig. 1) in an air environment equal to approximately 60 min (i.e. $\tau_4 + 1\text{h}$).

CONCLUSIONS

The present paper describes a method for computing the duration of regimes for autoclave steaming of non-frozen wooden prisms intended for production of veneer, τ_{reg} , at limited heat power of the steam generator in cases of dispatching intervention in the regimes in order to increase and obtain their desired duration. The method is based on the use of two personal mathematical models: 2D non-linear model of the unsteady distribution of the temperature in non-frozen prismatic wood materials subjected to heating at conductive boundary conditions and consequent conditioning in an air environment, and model of the non-stationary thermal balance of autoclaves for steaming wood materials.

It was determined that the duration of the basic steaming regime at $t_{\text{m1}} = 130^\circ\text{C}$ of beech prisms with cross section dimensions 0.4×0.4 m, moisture content of $0.6 \text{ kg}\cdot\text{kg}^{-1}$, and loading level of the autoclave of 50%, that is without dispatching intervention is equal to 12.65 h.

Each dispatching intervention causes an increase in τ_{reg} in comparison with the duration of the basic regime. It was also found that the increase in the time intervals between the beginning of the steaming regimes and the occurrence of the dispatching intervention, $\Delta\tau$, at given value of the decrease in the maximal steaming temperature after dis-

patcher's intervention, Δt_{m1} , causes linear decrease of τ_{reg} . The increase of Δt_{m1} at given value of $\Delta\tau$ causes non-linear increase of τ_{reg} . The regime at $\Delta\tau = 3$ h and $\Delta t_{\text{m1}} = 30^\circ\text{C}$ has the longest duration $\tau_{\text{reg}} = 13.65$ h.

The suggested method can be applied for various calculations with ANSYS and to create the software for systems used for computing and model-based automatic realization of optimal energy-efficient regimes for autoclave steaming of non-frozen wood materials with desired duration set by the dispatcher.

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CONTENTS

BUILDING EXPERT MAPS FOR ERGONOMETRIC, COMPOSITIONAL AND COLORS SCHEME EVALUATION OF MACHINE CONTROL PANELS	5
Aleksandrina Bankova, Zoya Tsoneva	
THE TRIPOD: A RARELY MENTIONED FURNITURE TYPE.....	13
Regina Raycheva, Desislava Angelova	
CHANGE IN THE DURATION OF AUTOCLAVE STEAMING REGIMES OF NON-FROZEN PRISMS AT DISPATCHING INTERVENTIONS IN THE PRODUCTION OF VENEER	25
Nencho Deliiski, Dimitar Angelski, Pavlin Vitchev, Natalia Tumbarkova	
IDENTIFICATION OF THE COLOR FALSE HEARDWOOD OF <i>FAGUS SYLVATICA</i> L. IN THE COLOR SPACE CIE L*A*B*	33
Ladislav Dzurenda, Michal Dudiak	
RECYCLING OF MEDIUM DENSITY FIBREBOARDS – A REVIEW	39
Christian Panchev, Viktor Savov	
PROPERTIES OF PARTICLEBOARDS WITH THE PARTICIPATION OF HEMP AND VINE PARTICLES IN THE CORE LAYER – PART I: EFFECT OF THE COMPOSITION.....	47
Rosen Grigorov, Viktor Savov, Slavcho Alexandrov	
ABSTRACT METHODS TO CLASSIFY THE STRUCTURE OF WOOD	57
Nikolai Bardarov, Vladislav Todorov, Tanya Pancheva	
STUDY ON DURABILITY OF TUNGSTEN CARBIDE CUTTER HEADS	65
Zhivko Gochev, Pavlin Vitchev, Georgi Vukov	
SCIENTIFIC JOURNAL „INNOVATIONS IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN“	72