

MODE FOR HOT AIR DRYING OF STEAMED BEECH BLANKS WHILE KEEPING THE COLOURS ACQUIRED IN THE STEAMING PROCESS

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ABSTRACT

The analysis of the impact of proposed external conditions for hot air drying of steamed beech wood (*Fagus sylvatica* L.) blanks from the initial moisture content of $w_1 \approx 50\%$ to final moisture content $w_2 = 10\%$ on the maintaining the colour of wood obtained in the process of steaming at the following modes: *mode I* ($t_I = 95 \pm 2.5\text{ }^\circ\text{C}$), *mode II* ($t_{II} = 115 \pm 2.5\text{ }^\circ\text{C}$), *mode III* ($t_{III} = 135 \pm 2.5\text{ }^\circ\text{C}$) is presented in the paper. The drying process is divided into two parts. Evaporation of free water from wet wood at drying medium temperatures $t_s = 35 \div 40\text{ }^\circ\text{C}$ and relative humidity $\varphi = 70 - 60\%$, when there are no chemical changes in the lignin-saccharide complex of beech wood manifested by the decomposition of chromophore structures and the formation of new functional groups manifested by a change in the colour of the wood. Evaporation of bound water from beech wood below the hygroscopicity limit is performed at the temperatures $t_s = 70 \div 80\text{ }^\circ\text{C}$. The colour coordinates in the colour space CIE $L^*a^*b^*$ of beech wood steamed by mode I after drying are: $L^* = 69.6 \pm 1.7$; $a^* = 11.3 \pm 0.9$; $b^* = 19.6 \pm 1.2$, steamed by mode II are: $L^* = 64.6 \pm 1.6$; $a^* = 13.0 \pm 0.7$; $b^* = 22.7 \pm 1.0$ and steamed mode III are: $L^* = 54.5 \pm 1.5$; $a^* = 13.4 \pm 1.1$; $b^* = 25.3 \pm 1.3$. Differences in the colour of dried steamed beech wood according to the proposed drying mode and dried in an air-conditioned space is in the range of values $\Delta E^* = 1.3 - 1.8$.

Key words: beech, blanks, hot-air drying, mode of drying, colour of wood

INTRODUCTION

Wood drying is one of the basic technological operations of wood processing. The mentioned technological operation is a very complicated hydrothermal process and despite the considerable efforts of scientists and technologists, the research of wood drying has not been completed yet.

Drying of hardwood in the form of lumber and blanks is a technological process in which water is removed from the wood. It is usually performed in hot air chamber dryers at drying medium temperatures $t = 50 \div 80\text{ }^\circ\text{C}$. Implementation of the drying process at these temperatures creates conditions not only for the removal of water from wood, but also for the course of chemical reactions such as: extraction of water-soluble accessories, partial hydrolysis of hemicelluloses, degradation of polysaccharides, cleavage of free radicals and phenolic hydroxyl groups in lignin groups of chromophores causing wood colour change.

In thermal processes such as: wood drying, wood steaming, thermo-wood production technologies, the wood changes colour. It darkens and depending on the wood species,

acquires new shades of colour. In the process of wood steaming, depending on the steaming conditions, the beech wood acquires from a pale pink-brown to a dark red-brown colour shade (MOLNAR and TOLVAJ 2002, CIVIDINI *et al.* 2007, TOLVAJ *et al.* 2009, GONZÁLEZ-PEÑA and HALE 2009, TODARO *et al.* 2012, BEKHTA and NIEMZ 2013, DZURENDA 2014, MILIC *et al.* 2015, BARCIK *et al.* 2015, BARANSKI *et al.* 2017, BANSKI and DUDIÁK 2019, DZURENDA 2022). Oak wood, as reported by TOLVAJ and MOLNAR (2006), TODARO *et al.* (2012), DZURENDA (2018a), acquires colour shades from pale brown-yellow to dark brown-grey. The white-yellow colour of maple wood in the process of steaming wood with saturated water steam acquires shades from pale pink-brown to brown-red colour DZURENDA (2018b), DZURENDA and DUDIÁK 2020, DUDIÁK (2021).

In order to eliminate the colour change of wood of steamed beech blanks in the drying process, a special mode for hot air drying of steamed beech blanks in the chamber dryers was developed based on the heat-moisture wood processing in order to preserve the colour of wood acquired by the steaming process. The aim of this work is to assess the proposed mode for hot air drying of steamed beech blanks with dimensions: $38 \times 100 \times 800$ mm from moisture content $w_1 \approx 50\%$ to moisture content $w_2 = 10\%$ in the chamber dryer, from the aspect of wood colour change and quality of dried wood steamed beech blanks.

MATERIAL AND METHODS

Steaming of beech blanks in order to modify the colour of wood

Beech blanks were steamed before drying. The process of steaming with saturated water steam in order to change the original light white-grey-yellow colour to pale pink-brown, red-brown, or deep brown-red colour was conducted in a pressure autoclave APDZ 240 (Himmasch AD, Haskovo, Bulgaria) in the company Sundermann s.r.o. Banská Štiavnica (Slovakia). The course of the steaming process – thermal modification of the colour of beech blanks presents Fig. 1 and technical-technological parameters of individual steaming regimes are given in Table 1.

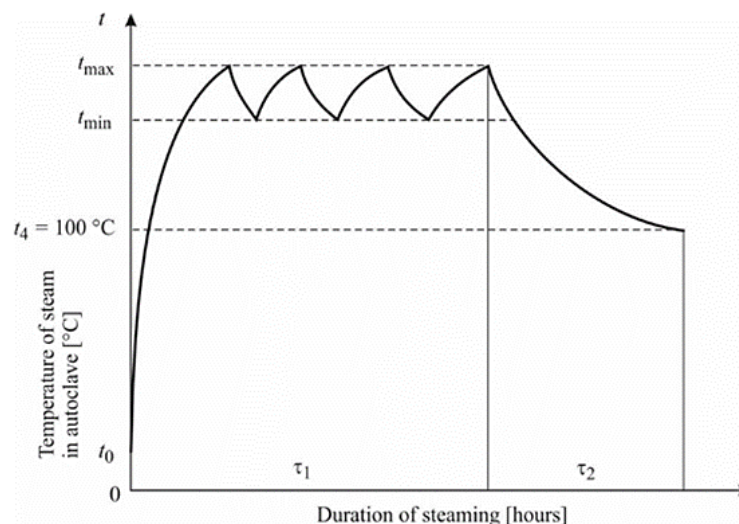


Fig. 1 Mode of colour modification of beech wood with steamed with a saturated steam-air mixture or saturated water steam.

Tab. 1 Mode of colour modification of beech wood with steamed with a saturated steam-air mixture or saturated water steam.

Modes	Colour	Temperature in autoclave [°C]		Time of operation [h]		
		t_{min}	t_{max}	τ_1 -phase I.	τ_2 -phase II.	Total time
Mode I	pale pink-brown	92.5	97.5	8.0	1.0	9.0
Mode II	red-brown	112.5	117.5	7.5	1.5	9.0
Mode III	deep brown-red	132.5	137.5	7.5	1.5	9.0

Drying of steamed beech blanks without affecting the colour change of the wood

The reduction of moisture content of steamed wood to a moisture content of $w_2 \approx 10$ % was performed in two ways:

1. by drying in an air-conditioned room,
2. by drying in a hot air lumber dryer, the proposed mode.

Drying in an air-conditioned space: 20 pieces of steamed beech blanks from each steaming mode were dried in an air-conditioned space at the air temperature of $t = 20$ °C and relative air humidity of $\varphi = 60$ %. After reaching the final moisture content, the values at the coordinates L^* , a^* , b^* in the colour space CIE $L^*a^*b^*$ were measured on both sides of the planed surfaces of the dried blanks.

Drying of steamed beech blanks by the proposed mode was performed in a hot-air chamber dryer KWH-V3. The breakdown of external conditions for drying steamed beech blanks with dimensions: $38 \times 100 \times 800$ mm from moisture content $w_p \approx 50$ % to moisture content $w_k = 10$ % in the chamber lumber dryer is given in Table 2. The drying process is divided into two parts. Drying for adiabatic evaporation of free water from wet wood is designed at humid air temperatures $t = 35 \div 40$ °C and relative air humidity $\varphi = 70 - 60$ %. At the indicated temperatures, no conditions are created for the chemical reactions of lignin in the lignin-saccharide complex manifested by a change in chromophores in the beech wood causing change in the colour of the beech wood. At the end of this phase, conditioning is included in order to partially eliminate the moisture gradient formed in the wood of the blanks during the evaporation of water from the cell lumens. The conditioning is realized by increasing the relative humidity to $\varphi = 84$ % and the air temperature $t = 50$ °C. Drying of beech wood below the hygroscopicity limit is realized at humid air temperatures $t = 70 \div 80$ °C.

Tab. 2 Description of external drying conditions for steamed beech blanks while preserving the colour of the wood obtained by the steaming process.

Phase of drying	Blanks with dimensions: $38 \times 100 \times 800$ mm		
	t_s (°C)	Δt (°C)	τ (h)
Initial heating	35	2	4
Moisture degree 50 – 35 (%)	35	5	55
Moisture degree 35 – 25 (%)	40	8	33
Conditioning	50	3	6
Moisture degree 25 – 20 (%)	70	8	14
Moisture degree 20 – 15 (%)	80	11	18
Moisture degree 15 – 10 (%)	80	16	26
Treatment	80	7	7
Cooling	30	7	4

The degree of hardness of the drying mode process of steamed beech blanks, expressed in terms of the drying gradient ($U = w/w_{\text{equ}}$) in the individual moisture stages presents Fig. 2.

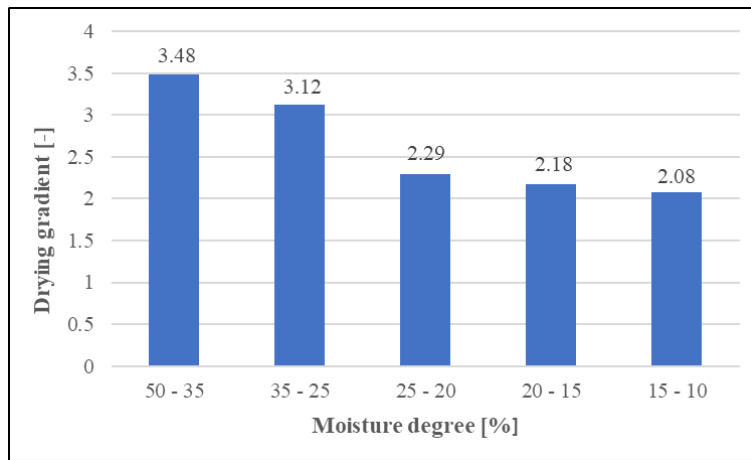


Fig. 2 Drying gradient values for individual moisture stages of steamed beech blanks.

Checking the colour and quality of dried steamed beech blank

The colour on the planed surface of the dried 36 blanks was measured with a Color Reader CR-10 colorimeter. The effect of the drying mode on the colour change of beech wood was evaluated:

- By determining the values of L^* , a^* , b^* of the colour space CIE $L^*a^*b^*$ of steamed beech wood. The values of colour coordinates are given in the form of notation: $x = \bar{x} \pm s_x$ i.e., average measured value and standard deviation.

- By comparing the values on the coordinates L^* , a^* , b^* of the dried wood by the hot air drying mode with the reference values of the coordinates L^* , a^* , b^* of the beech wood dried in the air-conditioned space.

- By determining the total colour difference ΔE^* quantified by:

$$\Delta E^* = \sqrt{(L_1^* - L^*)^2 + (a_1^* - a^*)^2 + (b_1^* - b^*)^2} \quad (1)$$

Where: L_1^* , a_1^* , b_1^* values on the coordinates of the colour space of beech wood dried by the proposed drying mode in the dryer,

L^* , a^* , b^* values on the coordinates of the colour space of beech wood dried in an air-conditioned space.

After the drying process, the quality of the dried blanks was checked by determining the on the 12 blanks deviations of the final moisture from the required moisture w_0 , the fluctuations of the final moisture w_{k0} and the moisture gradient Δw .

The deviation of the final moisture from the required moisture was determined by the relation:

$$w_0 = \frac{\sum_{i=1}^n w_{ik}}{n} - w_k \quad [\%], \quad (2)$$

Where: n – number of control samples,

w_{ik} – final moisture content of the samples [%],

w_k – required final wood moisture content [%].

The fluctuation of the final moisture content was evaluated by the difference of the values of the maximum and minimum moisture content of the samples according to the relation:

$$w_{k0} = w_{\max} - w_{\min} [\%], \quad (3)$$

Where: w_{\max} – maximum moisture content in the drying samples [%],
 w_{\min} – minimum moisture content in the drying samples [%].

The moisture gradient in the lumber was determined from the difference between the moisture of the middle layer and the diameter of both surface layers:

$$\Delta w = w_s - w_{\text{pov}} [\%], \quad (4)$$

Where: w_s – moisture of the middle layer [%],
 w_{pov} – moisture of surface layers [%].

The wood moisture content of steamed blanks was measured with an FMD6 resistance hygrometer from Brookhuis Micro-Eletronics BV.

RESULTS AND DISCUSSION

The values of colour coordinates: L^* , a^* , b^* of dried beech blanks measured on the planed surface of both loading areas are given in Table 3.

Tab. 3 Values of colour coordinates of steamed beech wood dried in the chamber lumber kiln KWH-V3, the proposed drying mode.

Steamed beech blanks dried in a lumber chamber dryer	Coordinates of colour space CIE $L^*a^*b^*$		
	L^*	a^*	b^*
<i>Steaming mode at the temperature of the steaming medium $t_{II} = 95 \pm 2.5$ °C</i>			
number of measurements	72	72	72
coordinate value	69.6 ± 1.7	11.3 ± 0.9	19.6 ± 1.2
<i>Steaming mode at the temperature of the steaming medium $t_{II} = 115 \pm 2.5$ °C</i>			
number of measurements	72	72	72
coordinate value	64.6 ± 1.6	13.0 ± 0.7	22.7 ± 1.0
<i>Steaming mode at the temperature of the steaming medium $t_{III} = 135 \pm 2.5$ °C</i>			
number of measurements	72	72	72
coordinate value	54.5 ± 1.5	13.4 ± 1.1	25.3 ± 1.3

The values of colour space coordinates CIE $L^*a^*b^*$, steamed beech blanks dried to moisture content $w \approx 10$ % in an air-conditioned space at air temperature $t = 20$ °C and relative air humidity $\varphi = 60$ %, on the planed surface are given in Table 4.

Tab. 4 Values of colour coordinates of steamed beech wood dried in an air-conditioned space.

Steamed beech blanks dried in an air-conditioned space	Coordinates of colour space CIE $L^*a^*b^*$		
	L^*	a^*	b^*
<i>Steaming mode at the temperature of the steaming medium $t_I = 95 \pm 2.5$ °C</i>			
number of measurements	40	40	40
coordinate value	70.7 ± 1.4	11.7 ± 0.7	20.6 ± 1.2

<i>Steaming mode at the temperature of the steaming medium $t_{II} = 115 \pm 2.5 \text{ }^\circ\text{C}$</i>			
number of measurements	40	40	40
coordinate value	64.6 ± 1.5	12.1 ± 0.9	22.7 ± 1.1
<i>Steaming mode at the temperature of the steaming medium $t_{III} = 135 \pm 2.5 \text{ }^\circ\text{C}$</i>			
number of measurements	40	40	40
coordinate value	54.5 ± 1.3	13.4 ± 1.0	24.7 ± 1.2

The differences between the colour of dried wood of steamed beech blanks in the dryer and the colour of dried wood of steamed beech blanks in the air-conditioned space are shown in Table 5.

Tab. 5 Values on the coordinates of the colour space CIE $L^*a^*b^*$ of beech wood dried in the dryer with the values of beech wood dried in the air-conditioned space and the total colour difference ΔE^* .

Coordinates of colour space CIE $L^*a^*b^*$	L^*	a^*	b^*	ΔE^*
<i>Steaming mode at the temperature of the steaming medium $t_I = 95 \pm 2.5 \text{ }^\circ\text{C}$</i>				
Wood dried in the dryer	69.6	11.3	19.6	-
Wood dried in an air-conditioned space	70.7	11.7	20.6	-
Differences on coordinates $\Delta L^*, \Delta a^*, \Delta b^*$ a ΔE^*	- 1.1	- 0.4	- 1.0	1.6
<i>Steaming mode at the temperature of the steaming medium $t_{II} = 115 \pm 2.5 \text{ }^\circ\text{C}$</i>				
Wood dried in the dryer	63.2	13.0	22.7	-
Wood dried in an air-conditioned space	64.6	12.1	23.4	-
Differences on coordinates $\Delta L^*, \Delta a^*, \Delta b^*$ a ΔE^*	- 1.4	+ 0.9	- 0.7	1.8
<i>Steaming mode at the temperature of the steaming medium $t_{III} = 135 \pm 2.5 \text{ }^\circ\text{C}$</i>				
Wood dried in the dryer	53.5	12.9	25.3	-
Wood dried in an air-conditioned space	54.5	13.4	24.7	-
Differences on coordinates $\Delta L^*, \Delta a^*, \Delta b^*$ a ΔE^*	- 1.0	- 0.5	+ 0.6	1.3

The values on the colour coordinates of the dried beech wood in the dryer differ slightly from the values of the beech wood dried in the air-conditioned space. The stated changes of dried steamed wood samples according to individual steaming modes, expressed in the form of the total colour difference, are within the tolerance $\Delta E^* = 1.3 - 1.8$. According to the categorization of wood colour changes in thermal processes reported by the authors CIVIDINI *et al.* (2007), the total colour difference classifies the colour change of steamed beech wood in the category $\Delta E^* = 0.2 - 2.0$, i.e., small (insignificant) colour changes. The results of analysis evaluating the quality of dried steamed beech blanks are shown in Table 6.

Tab. 6 Evaluation of the quality of dried beech blanks.

Qualitative sign		The measured values
<i>Steaming mode at the temperature of the steaming medium $t_I = 95 \pm 2.5 \text{ }^\circ\text{C}$</i>		
Deviation of the final moisture from the required moisture	w_0	0.4 %
Fluctuation of the final moisture content of the wood	w_{k0}	0.9 %
Moisture gradient in the wood of the blanks	Δw	0.5 %
<i>Steaming mode at the temperature of the steaming medium $t_{II} = 115 \pm 2.5 \text{ }^\circ\text{C}$</i>		
Deviation of the final moisture from the required moisture	w_0	0.5 %
Fluctuation of the final moisture content of the wood	w_{k0}	1.2 %
Moisture gradient in the wood of the blanks	Δw	0.7 %
<i>Steaming mode at the temperature of the steaming medium $t_{III} = 135 \pm 2.5 \text{ }^\circ\text{C}$</i>		
Deviation of the final moisture from the required moisture	w_0	0.4 %
Fluctuation of the final moisture content of the wood	w_{k0}	0.8 %
Moisture gradient in the wood of the blanks	Δw	0.4 %

A comparison of the measured values of dried wood quality of steamed beech blanks with the values for determining the quality of dried lumber presented in TREBULA and KLEMENT (2002) shows that dried steamed beech blanks meet the requirements of quality parameters of individual classes as follows:

- final deviation from the required moisture content, quality class I ($w_0 \leq 0.5$ %),
- final change in moisture content, quality class I ($w_{k0} \leq 2.0$ %),
- moisture gradient, quality class I ($\leq w \leq 1.5$ %).

CONCLUSIONS

The paper presents a mode for drying wood of steamed beech blanks with dimensions: $38 \times 100 \times 800$ mm from moisture content $w_p \approx 50$ % to the final moisture content $w_k = 10$ %, without affecting the colour change of steamed beech wood.

Pale pink-brown colour of dried beech wood steamed mode I in the colour space CIE $L^*a^*b^*$ is identified by the values on the coordinates: $L^* = 69.6 \pm 1.7$; $a^* = 11.3 \pm 0.9$; $b^* = 19.6 \pm 1.2$. Red-brown colour of steamed beech wood mode II after drying is: $L^* = 64.6 \pm 1.6$; $a^* = 13.0 \pm 0.7$; $b^* = 22.7 \pm 1.0$ and deep brown-red colour of steamed beech wood mode III is: $L^* = 54.5 \pm 1.5$; $a^* = 13.4 \pm 1.1$; $b^* = 25.3 \pm 1.3$. Changes in the colour of steamed beech wood caused by the drying process, expressed in terms of the total colour difference ΔE^* compared to the colour of steamed beech wood dried in an air-conditioned space, is in the range of values $\Delta E^* = 1.3 - 1.8$. The mentioned colour changes, according to the categorization of wood colour changes in thermal processes reported by the authors (CIVIDINI *et al.* 2007) classifies the colour changes of steamed beech wood due to drying into the category $\Delta E^* = 0.2 - 2.0$, i.e., small (insignificant) colour changes.

According to the quality assessment of dried wood of steamed beech blanks, steamed dried blanks meet the quality parameters of I. class.

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