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IMPACT OF STEAMING AND STORAGE ON THE CHANGES OF THE SURFACE COLOUR OF BEECH WOOD

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Abstract

The aim of this work was to compare the effects of steaming and storage of beech wood on colour changes of its wood surface and simultaneously to characterize these changes as a result of the changes in structure of the main wood components by FTIR spectroscopy.

The results obtained from the measurement of colourity of wood surface showed that steaming under the given conditions had less influence on colourity change of beech wood surface, than its storage. Due to storage change in the total crystallinity index (TCI) and share H_{1730}/H_{1640} on the surface of beech wood was higher. This is probably due to partial degradation of hemicelluloses and amorphous cellulose regions by influence of light and heat, and also by photodegradation and photooxidation reactions of lignin.

Key words: *beech wood, saturated water steam, steaming, storage, colour, total crystallinity index*

INTRODUCTION

In order to obtain certain specific properties of wood in the technology practice, we often use its mating. It is an inseparable part of technological wood processing in sawmills, veneer and plywood factories, in the production of bentwood furniture and for other wood processing (Setnička 1989).

It is a hydrothermal treatment in which the wood is treated with water respectively with water vapor at different modes - temperature, pressure, time and hydro module (Šutý 1982), carrying out a change in external and internal characteristics of wood, which may be permanent or temporary.

The most important transition change is plasticity, which is related to temporary reducing of mechanical strength and flexibility. It is used for forming, bending, cutting, stripping and defibering of plasticized wood. Permanent changes include changes in the chemical composition, structure and colouration. These changes subsequently result in a higher dimensional stability, decrease in sorption properties with respect to water vapor, and sometimes they cause increase in biological stability and also suitable discolouration of wood. An undesired change is a loss of strength, weight loss and in some cases increase in shrinkage (Solar 1997).

Hydrothermal treatment is also used to achieve the desired colour shade of wood, which is closely linked to chemical changes that occur during mating (Kačík 1997). In their works (Solar 1997 Halaj et al., 2001) they showed that the colour changes that occured as a result of hydrothermal treatment were related to chemical changes of lignin and the reactions of degradation products of polysaccharides and extractives. Solar and Kačík

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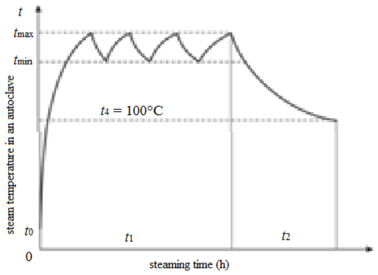
(1995) demonstrated the colour change of lignin alone from pale cream to the cinnamic colour in consequence of time and temperature as a result of new chromophore groups. Laurova et al. (2004) reported discolouration of beech wood as a result of steaming from bright grey - pale yellow to dimly red. Similar colour changes of surface of beech after hydrothermal treatment by steaming, respectively by drying, are presented in the works of many authors (Dzurenda 2014 Dzurenda and Deliiski 2012, Klement and Marko 2008 Babiak et al. 2004).

The aim of this work was to compare the effects of steaming and storage of beech wood on colour changes of its wood surface and simultaneously to characterize the colour changes of the wood surface due to changes in the structure of the main wood components by FTIR spectroscopy.

MATERIAL AND METHODS

To monitor of the colour changes during storage and steaming there were used beech dimension timbers with dimensions 27x75x320 mm.

Beech wood samples were treated by saturated water vapor in a pressure autoclave APDZ 240 under the regime, which is shown in Fig. 1. They were subsequently dried to moisture 12,0±0,5% and loading areas were treated in a horizontal milling machine FS 200.



t_{max} = 115 °C
t_{min} = 110 °C
t_4 = 100 °C
τ_1 = 4,5 h
τ_2 = 1,0 h

Fig. 1 Regime of thermal treatment of beech wood using saturated water steam (Dzurenda 2014)

Wood samples were stored at room temperature 22±2 ° C and relative air humidity 40 ± 10% for 6 months.

The surface colour of samples of original wood, of steaming wood and of wood after storage was determined by colourimeter Colour Reader CR-10, which is defined by the coordinates of CIELAB colour space (L^*, a^*, b^*). To determine the total colour difference ΔE^* we used this relationship:

$$\Delta E^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \quad (1)$$

where $(L_2^*-L_1^*)$ change in value of black-white coordinate (specific lightness)
$(a_2^*-a_1^*)$ change in value of green-red coordinate
$(b_2^*-b_1^*)$ change in the value of blue-yellow coordinate

The surface of beech dimensional timbers was also analyzed by FTIR on a Nicolet iS 10 using technique ATR-FTIR on the diamond crystal in the range of 4000-400 cm^{-1}. The chemical changes on the wood surface were characterized by evaluating of the spectral records.

RESULTS AND DISCUSSION

Storage and steaming visibly changed the brightness of the surface of the sample and the sample acquired different shade. This change was objectively characterized by determining of the colour space coordinates *L**, *a** and *b** in CIELAB colour space. Their numerical values were measured on the colourimeter Color Reader CR-10 and compared to each other.

Kubovský and Urgela (2004) show the relevance of the colour matching in practice based on the obtained numerical values. In this way it is possible to determine the conformity of the colours or the colour differences in comparison to a standard.

Table 1 shows the average in value of specific lightness of the monitored beech sample surfaces.

Tab. 1 Effect of steaming and storage on specific lightness L*

Beech wood	Original sample	Steamed sample	Storaged sample
Specific lightness L*	66,5 ±0,4	68,6±0,9	64,2±0,7

Specific lightness of the original beech wood under the influence of steaming increased from 66.5 to 68.6, representing increase by 3%. This increase was measured objectively, despite the visual feeling of darkening sample, due to changes in other colour space coordinates. Huráková and Klement (2015) also indicate increase in the specific lightness of the tangential unreacted sample of beech wood in hydrothermal treatment by hot air drying.

Effect of 6-month storage of beech wood in laboratory conditions is manifested as reduction of value of specific lightness from 66.5 to 64.2, representing decrease of this indicator by 3.5%.

According to the authors (Solar 1997, Melcer et al. 1989), mechanism of the origin of the colour changes is complicated and a lot of different reactions of basic wood components and their degradation products participate in it. Change in the colour of wood in hydrothermal treatment is influenced by reactions of degradation products of wood substance and also by chemical changes of extractives and lignin.

Fig. 2 shows the change of the red-green coordinate *a** and yellow-blue coordinate *b** of the colour space CIELAB determined on the surface of beech wood due to steaming and storage.

It can be concluded that due to steaming there was a shift of coordinate *a** more in the red region of the colour space than due to storage and conversely, the shift coordinate *b** due to storage was more yellow in other colour space region, than due to steaming. Clearly these changes were confirmed by visual monitoring too. Surface of the steamed wood had rosier shade and surface wood storage yellower with regard to the original sample.

Based on the measured values it can be concluded that green-red colour space and coordinate *a** moved due to steaming from an average of 6.6 to 9.3 toward the red area and its increase amounted to 41%. Blue-yellow coordinate *b** shifted towards the yellow region of the colour space by 9% compared to the original value.

Storage beech wood caused the shift of the green-red coordinate *a** into the red area from the value 6.6 to 8.9. This shift accounted for about 35% of its original value. For coordinate *b** there was determined the shift into the yellow area from 17.7 to 25.4, representing its increase almost 44%.

An important characteristic for monitoring of the colour changes is total colour difference (ΔE). Kubovský and Urgela (2004) consider the colour difference to be a parameter of major importance in comparing the colours.

Total colour difference ΔE calculated according to equation (1) for the change of surface colour of beech wood due to steaming reached the level 3.8. By Allegretta et al. (2009) range $3<\Delta E<6$ can be characterized as "colour difference visible with medium quality screen."

Due to storage of beech wood total colour difference (ΔE) reached value of 8.4. Such a change in the surface colour ($6<\Delta E>12$) can be characterized by perception of the colour scheme proposed by Allegretto (2009) as "high colour difference".

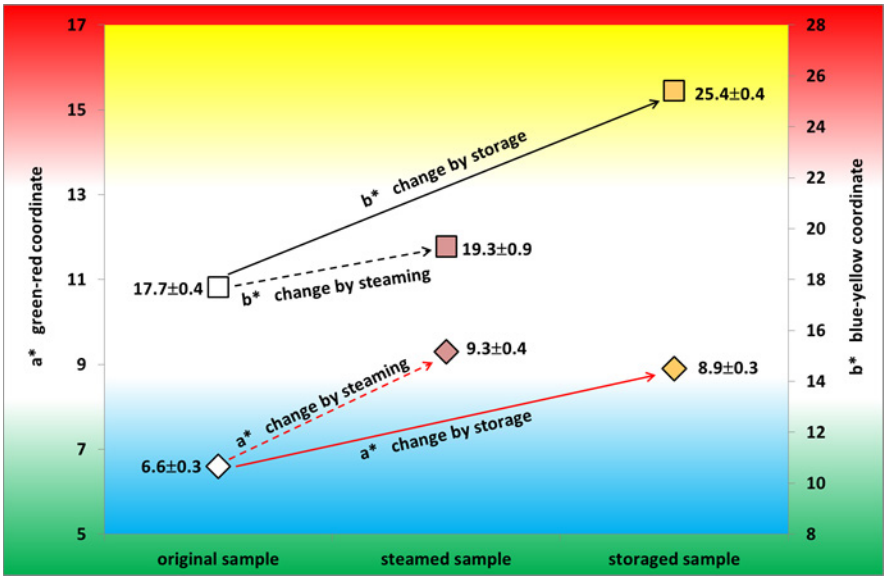


Fig. 2 The effect of steaming and storage on the coordinates of the colour space a, b**

The obtained results show that steaming under the given conditions had less influence on colourity change of beech wood surface, than its storage.

The works of many authors (Solaris 2004, Geffertová and Geffert 2016, Malešič et al. 2005) show that the surface of the lignocellulosic material changes its colour by action of light, and the resulting colour shade is the result of complex chemical changes of extractives, polysaccharides and lignin.

The colour changes of beech wood due to steaming were the result of changes in chemical composition.

The changes on the beech wood surface, which occurred as a result of steaming and storage, were studied by ATR-FTIR spectroscopy. When interpreting FTIR spectra according to the authors Hon et al. (2000), Pandey the Pitman (2003), Colom et al. (2003) were identified the present absorption bands and were associated with pertaining functional groups, respectively fragments of molecules. Comparison of the original spectra, storage and steamed samples is shown in Fig. 3.

The absorption band at 1370 cm^{-1} is an expression of the deformation vibration of C-H in cellulose and hemicelluloses. Band at 2900 cm^{-1} corresponds to valence vibration of -CH in CH_2 and CH_3 groups. The share of their absorbances is the total crystallinity index (O'Connor 1964).

Absorption band at a wave number 1730 cm^{-1} corresponds to valence vibration of non-conjugated C=O carbonyl, carboxyl and ester groups and band at 1640 cm^{-1} corresponds to valence vibration of conjugated C=O carbonyl groups. Increasing the share of their heights H_{1730}/H_{1640} represents increase of unconjugated C=O groups in relation to the conjugated C=O groups. New non-conjugated carbonyl groups are probably products of photodegradation and photooxidation reactions. Decrease in the intensity of the characteristic bands also points to the degradation reactions of lignin during storage. Wang and Ren (2008) found a narrow correlation between the total colour difference ΔE and the above described changes in the intensities of absorption bands due to degradation reactions of lignin and new carbonyl groups.

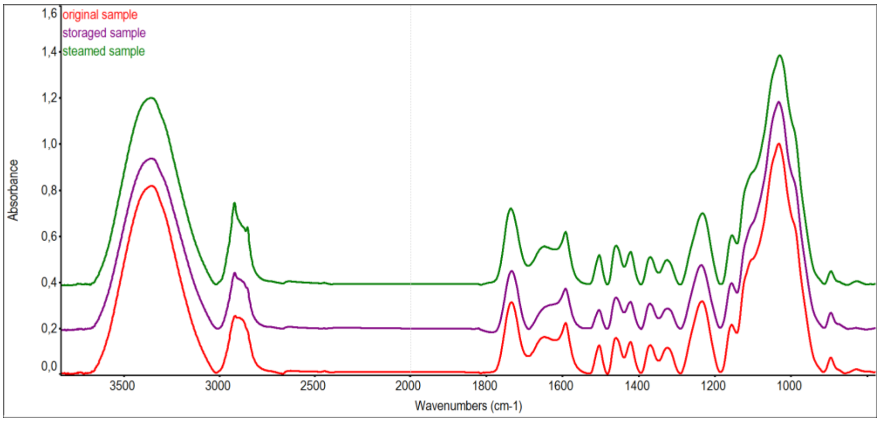


Fig. 3 Effect of steaming and storage on FTIR spectra of the surface of beech wood

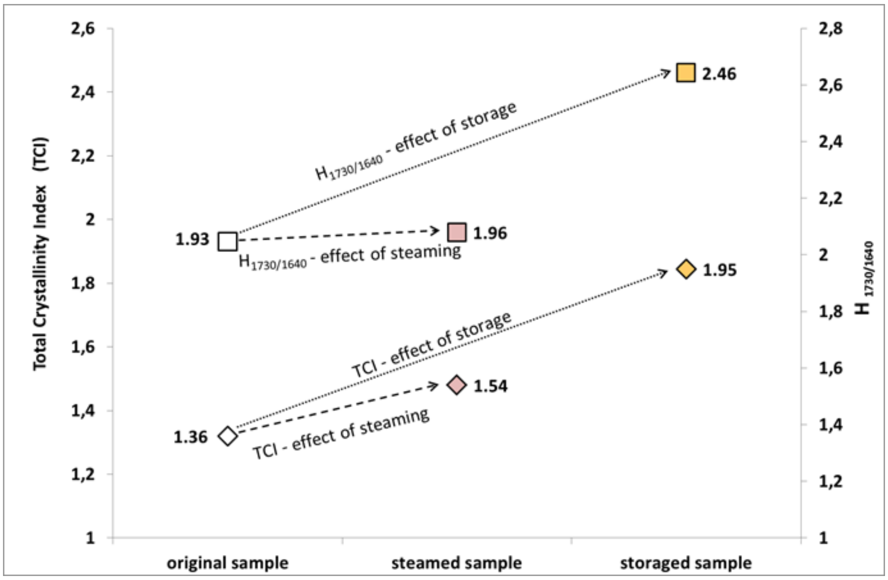


Fig. 4 Effect of steaming and storage on Total Crystallinity Index (TCI) and share H_{1730}/H_{1640}

The values of the total index of crystallinity and of the share H_{1730}/H_{1640} are illustrated in Fig. 4. It can be concluded that a change in the overall index of crystallinity and share H_{1730}/H_{1640} on beech wood surface is greater by effect of storage than by steaming. TCI value increased from 1.36 to 1.95 due to the storage, i.e. increase by 43%. The large increase (27%) was determined at the share H_{1730}/H_{1640} too (from 1.93 to 2.46).

Steaming impact was reflected on the values of TCI and H_{1730}/H_{1640} more moderate. Total crystallinity index increased by steaming by 13.2% and the share H_{1730}/ H_{1640} by 1.6%. This is probably due to partial degradation of hemicelluloses and amorphous cellulose regions by influence of light and heat, and also by photodegradation and photooxidation reactions of lignin.

CONCLUSION

Comparison between the effect of steaming and storage of beech wood on the colour changes of the surface of the test specimens showed that:

- the influence of steaming led to increase of specific lightness by 3% compared to the original sample of beech wood, but the 6-months storage of the original sample under laboratory conditions resulted in decrease of specific lightness by 3.5%,
- a shift coordinate $a*$ due to steaming was more to the red area of the colour space than due to storage and on the other hand, the shift coordinate $b*$ due to steaming was more to the yellow area than due to steaming. Green-red colour space coordinate $a*$ moved by steaming into the red area and its increase amounted to 41%, blue-yellow coordinate $b*$ shifted towards to the yellow region by 9% compared to the original value. Storage of beech wood resulted in the shift of the green-red coordinate $a*$ into the red area by about 35% of its original value, at a coordinate $b*$ represented a shift to the yellow area the increase of almost 44%,
- overall colour difference ΔE due to steaming can be characterized as "colour difference visible with medium quality screen". Overall colour difference ΔE due to storage can be characterized as "high colour difference".
- the obtained results show that steaming under the given conditions had less influence on colourity change of beech wood surface, than its storage,
- change in the total crystallinity index (TCI) and share H_{1730}/H_{1640} on the surface of beech wood was higher due to storage - TCI increased by 43% and the share H_{1730}/H_{1640} increased by 27%. Steaming effect was reflected more moderately - TCI increased by 13.2% and the share H1730 / H1640 by 1.6%.

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