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CHANGES IN ACIDITY OF BEECH SAPWOOD AND FALSE HEARTWOOD DURING STEAMING IN SATURATED WATER STEAM

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ABSTRACT

The paper presents the results of experimental monitoring of changes in acidity (pH) of beech sapwood and false heartwood during the steaming process using saturated steam at a temperature of 105°C for 18 hours. The aim of the treatment was to eliminate colour differences between individual zones of the wood. The results show that due to the partial hydrolysis of hemicelluloses and amorphous cellulose, the pH decreases: in the sapwood from pH = 5.4 to pH = 4.7 and in the heartwood from pH = 5.1 to pH = 4.5. The changes in acidity are not uniform - approximately 70% of the total decrease occurs within the first 6 hours of the process. The research also confirmed that the enzymatic processes associated with the formation of the false heartwood, specifically the activity of peroxidase and polyphenol oxidase, do not affect the course of hydrolysis during steaming. This knowledge can contribute to the optimisation of beech wood steaming technologies in order to unify the colour of the material.

Keywords: beech wood, sapwood, false heartwood, steaming, saturated water steam, wood colour, wood acidity.

1. INTRODUCTION

False heartwood is a growth defect of the European beech tree, which is formed during the growth of the tree in the mature wood zone. Among other things, false heartwood differs in colour from the white-grey or pale brown colour of beech wood by a range of shades of red-brown. The representation of false heartwood in sawmill-processed wood mass is up to 35%. Because false heartwood differs in colour from sapwood and mature wood, sawmill assortments are not used in the creation of bending furniture, sports equipment, and partially constructed and joinery goods.

Steaming beech wood is one way to remove colour discrepancies between sapwood and false heartwood while preserving the wood's original mechanical and structural properties. At the Faculty of Wood Sciences and Technology, Technical University in Zvolen, the project APVV 21 0051 is titled "*Research on the false heartwood and sapwood of the wood species Beech (Fagus sylvatica L.) for the purpose of eliminating colour differences by the process of thermal treatment with saturated steam*".

From a chemical point of view, the false heartwood of beech does not fundamentally differ from sapwood in the proportion of cellulose, lignin and hemicelluloses, but more in the proportion of secondary components, such as tannins, organic acids, pectin, etc. *Nečesaný (1956), Albert et al. (2003), Vek et al. (2015), Gülsoy et al. (2021),* and *Dudiak (2023), Dzurenda et al. (2023)*. There is also a certain difference in the acidity of the wood; while the pH of beech sapwood is 5.13 - 5.59, the acidity of beech heartwood, according to the authors *Gäumann (1949), Nečesaný (1956),* and *Dzurenda et al. (2023)*, is 5.06 - 5.32.

The process of steaming wet wood with a moisture content of w ≥ 40% is carried out by extraction of water-soluble substances and partial hydrolysis of hemicelluloses and amorphous

cellulose *(Fengel and Weneger, 1989; Tolvaj and Faix, 1996; Kačík, 2001; Samešová et al., 2018).* Hydrolysis processes initiate polysaccharide degradation in the form of oxidation of carbohydrates and pectin, dehydration of pentose to 2-furaldehyde, and free radicals and phenolic hydroxyl groups begin to form in lignin, which results in the formation of new chromophoric groups causing a change in the colour of wood *(Fengel and Weneger, 1989; Hon, 2001; Sundqvist et al., 2006; Výbohová et al., 2018).*

The aim of the work is to present the knowledge acquired within the framework of the project APVV 21 0051 on the influence of initial pH differences in beech sapwood and false heartwood on hydrolysis processes and the course of pH changes in beech wood in the steaming process when removing colour differences in sapwood and false heartwood.

2. MATERIALS AND WORK METHODS

Three steaming modes were suggested for unifying the colour of beech sapwood and false heartwood with varying degrees of darkening of steamed beech wood based on experimental research aimed at analysing the influence of temperature and steaming duration presented in the work of Dzurenda and Dudiak (2024).

Figure 1. *Wood colour of unsteamed beech wood with false heartwood (native) and steamed.*

With steaming mode at a steaming temperature of t ≈ 105°C, beech sapwood and false heartwood acquire a pale brown colour within τ = 18 hours. The values of the colour coordinates of beech sapwood and false heartwood before steaming and the values of the coordinates of steamed colour-homogenised beech wood with mode are shown in Table 1.

Table 1. *Values in the CIE L*a*b* colour space coordinates of beech sapwood and false heartwood before and after steaming.*

Beech wood		Values in colour space coordinates CIE L*a*b*		
		L*	a*	b*
Unsteamed	Sapwood	78.5 ± 2.5	9.2 ± 1.6	19.5 ± 1.8
	False heartwood	63.8 ± 3.6	11.5 ± 1.8	19.9 ± 1.6
Steamed		63.4 ± 2.3	13.0 ± 1.4	19.1 ± 1.6

The acidity of beech sapwood and false heartwood was monitored in a focused experiment to unify the white-grey colour of sapwood and the red-brown colour of false heartwood by steaming with saturated steam at a temperature of t = 105 ± 2.5°C for 18 hours. Steaming was carried out in a pressure autoclave APDZ 240 in Sundermann s.r.o. Banská Štiavnica. Six sets of beech blanks, including blanks from the beech sapwood zone and false heartwood, were placed in the pressure autoclave during the wood steaming process. Each set contained 15 blanks with dimensions of 32 x 50 x 800 mm from sapwood and 15 blanks with dimensions of 32 x 50 x 800 mm from false heartwood.

The diagram in Fig. 2 and Table 2 illustrates the parameters for steaming beech wood in a saturated water steam environment, including the time intervals for gathering individual sets of steamed blanks.

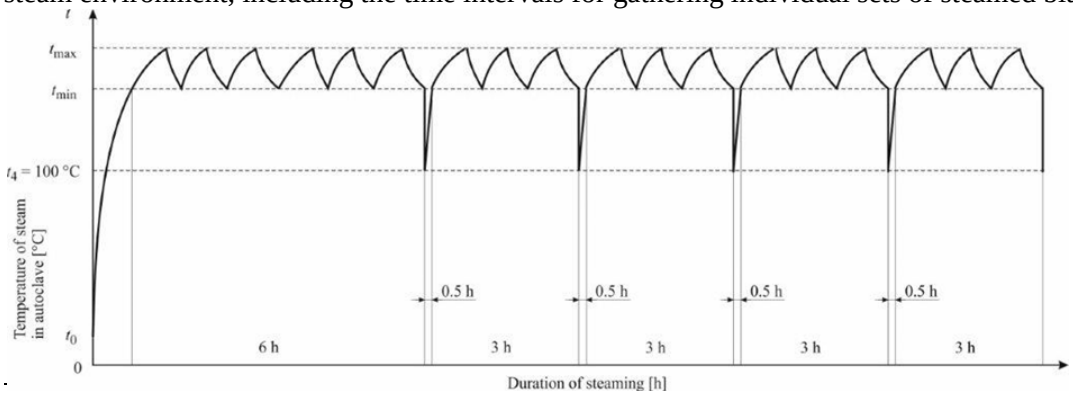

Figure 2. *Diagram of beech wood steaming in the process of removing colour differences between the colour of sapwood and false heartwood with marked intervals for sampling beech wood for determining the pH of the wood.*

Table 2. *Technological conditions for steaming beech wood.*

Temperature of saturated water steam			Length of time wood is exposed to colour modification				
t_{min}	t_{max}	t_4					
102	108	100	τ_1 = 6 h	τ_2 = 9,5* h	τ_3 = 13* h	τ_4 = 16,5* h	τ_5 = 20* h

*Note: * After 6 hours and subsequent 3-hour steaming intervals, there was a break of 0.5 hours during which, in the case of steaming with saturated water steam, the saturated steam pressure in the autoclave was reduced for safe opening of the autoclave, the planned group of steamed beech wood was selected from the autoclave, and after closing and pressurising the autoclave with saturated water steam, the steaming process continued for the purpose of modifying the colour of the wood.*

For direct measurement of the pH of wet unsteamed and steamed wood with saturated water steam, *Geffert et al. (2019)* proposed an original method for measuring the pH of an aqueous solution in the lumens of wet wood cells with $W > W_{BNV}$, using a SENTRON pH meter of the SI 600 series with a LanceFET+H 22704-010 insertion probe (Fig. 3).

Figure 3. *SENTRON pH meter SI 600 series with LanceFET+H probe 22704-010.*

Since the pH measuring probe has a diameter of d = 10 mm and cannot be immersed (pressed) into a solid material, according to the proposed methodology for measuring the pH of wood, a hole with a diameter of 12 mm was created at the measurement location with a cordless drill, the chips created by drilling were poured into the drilled hole, and the LanceFET+H 22704-010 probe of the SENTRON SI 600 pH meter was inserted into the wet chips in the drilled hole. After a while of stabilisation ($\tau \approx 30 - 60$ s.), the pH value of the measured wood was read. The actual measurement of the pH of wood is shown in Fig. 4.

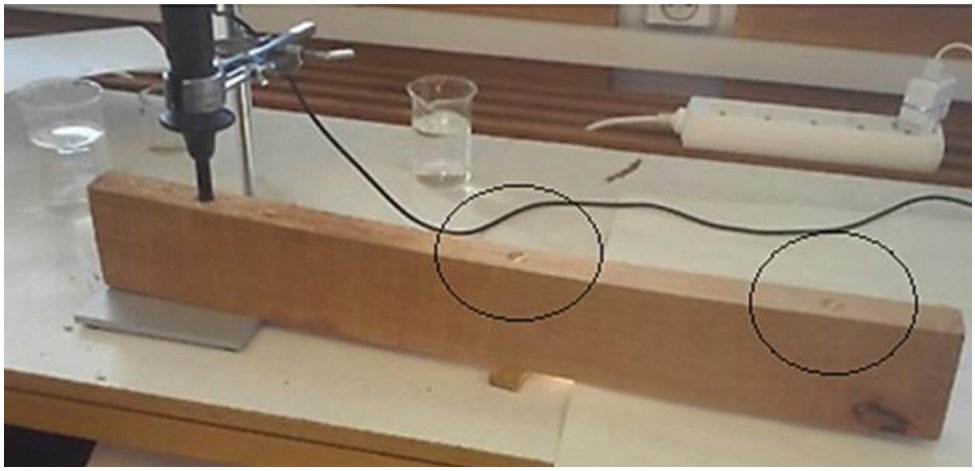

Figure 4. *View of direct measurement of the pH of steamed beech wood.*

3. RESULTS

The measured pH values of wet beech sapwood and false heartwood before steaming, as well as during the steaming process at 6 h, 9 h, 12 h, 15 h and 18 h of the technological steaming process, are shown in Fig. 5.

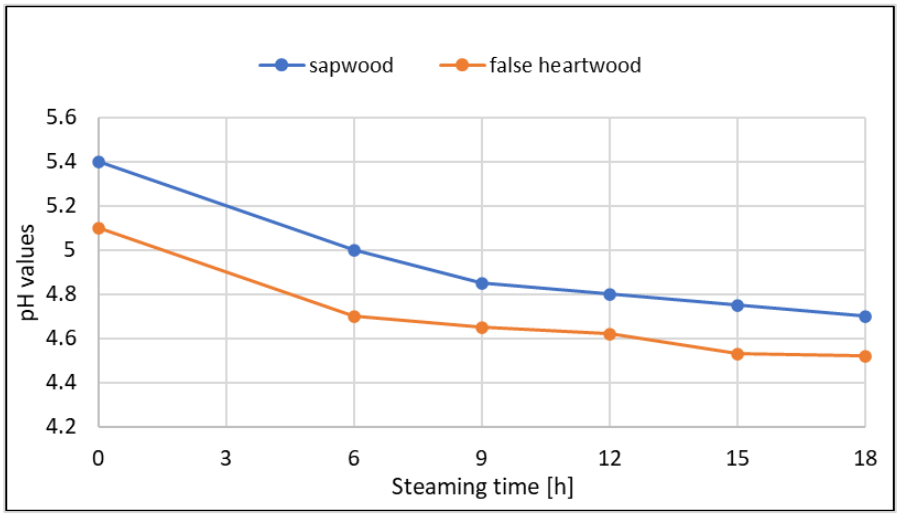

Figure 5*. Changes in acidity of beech sapwood and false heartwood during 18 h of steaming at a steaming temperature of t = 105°C.*

The average acidity readings and standard deviations of the examined beech sapwood and false heartwood samples before and after 18 hours of steaming are shown in Table 3. Changes in the acidity of beech sapwood and false heartwood caused by the steaming process are determined in the form of the difference in ΔpH values of unsteamed beech wood and steamed beech wood at a given temperature after 18 h of steaming:

$$\Delta pH = pH_0 - pH_{18} \quad (1)$$

Where: pH_0 – acidity of beech wood before steaming;

pH_{18} – acidity of beech wood after 18 h of steaming.

Table 3. *Acidity of beech wood before steaming and after 18 hours of steaming*.

Beech wood	Unsteamed	Steamed t = 105 °C, τ =18 h	
	pH [-]	*pH* [-]	Δ *pH* [-]
Sapwood	5.4 ± 0.1	4.7 ± 0.2	0.7
False heartwood	5.1 ± 0.2	4.5 ± 0.2	0.6

The steaming method for τ = 18 hours causes nearly identical variations in the acidity of beech sapwood and false heartwood. The lower acidity value of unsteamed beech false heartwood compared to beech sapwood by ΔpH = 0.3% in the course of wood hydrolysis was not demonstrated.

The analysis of the course of pH changes in the steaming process in Fig. 5 shows the unevenness of changes in wood acidity during 18 hours of steaming. The approximately 60% decrease in wood acidity during the first 6 hours of the steaming process is more pronounced than in the last 12 hours of steaming. This is also demonstrated statistically by the average hourly drop in ΔpH, while the decrease in acidity of beech sapwood and false heartwood in the first 6 hours is ΔpH = 0.066 $pH.h^{-1}$, so the average hourly decrease in acidity in the last 12 hours is ΔpH = 0.025 $pH.h^{-1}$, which is 2.7 times less. The aforementioned claim is consistent with research by *Dzurenda et al. (2020)* that examined the pH change during the steaming of maple wood and by *Dzurenda and Dudiak (2021)* that analysed the pH shift during the steaming of birch wood.

Based on the aforementioned facts, it can also be concluded that the chemical changes in beech false heartwood created by the enzymatic processes of peroxidase and polyphenol oxidase, which are responsible for the oxidation of phenolic compounds and the characteristic colouration of false heartwood *Hofmann et al., (2004), Albert et al., (2003), Tolvaj et al., (2009)* during tree growth and the formation of heartwood, do not affect the hydrolysis process.

4. CONCLUSION

The paper presents the results of experimental work monitoring the change in acidity of beech sapwood and false heartwood in the process of steaming wood with saturated steam in order to remove colour differences at t = 105°C for τ = 18 hours.

The partial hydrolysis of hemicelluloses and amorphous cellulose in wet beech wood under the aforementioned thermal treatment settings causes the sapwood's pH to change from 5.4 to 4.7 and the false heartwood's pH to change from 5.1 to 4.5.

The course of pH changes in the steaming process indicates the uneven decrease in wood acidity during 18 hours of steaming. Compared to the final 18 hours of steaming, there is a more noticeable 70% reduction in wood acidity within the first 6 hours.

Based on presented facts, it can also be said that the hydrolysis process is unaffected by the lower acidity of beech false heartwood produced by the enzymatic processes of peroxidase and polyphenol oxidase, which are responsible for both the oxidation of phenolic compounds and the distinctive colouration of false heartwood during tree growth and false heartwood formation.

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