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STEAMING OF POPLAR, BLACK LOCUST AND BEECH TIMBERS SIMULTANEOUSLY TO INVESTIGATE COLOUR MODIFICATION EFFECT OF EXTRACTIVE TRANSPORT

This paper deals with a colour modification method of poplar (Populus x euramericana cv. Pannonia) without any chemicals or stains. Steaming was found to be a proper modification method to change its natural greyish-white colour to a more attractive brown tint. Black locust and beech timber (as initiators) were steamed together with poplar timber to intensify its colour change. Treatment temperatures were 90 °C; 100 °C; 110 °C and 120 °C. Maximum duration of steaming was 20 days (9 days at 120 °C). The colour change of sapwood and heartwood was monitored separately using the CIE Lab colour system. A wide range of hues was created using this treatment method ranging from the initial colour to brown depending on the steaming time and temperature. The presence of black locust or beech wood facilitated the colour change of poplar only above 100°C. In terms of the colour alteration of different wood parts, these initiator species were more effective in the heartwood part than in sapwood. Chromophore molecules generating the yellowness increase did not prove to be stable at 120 °C. Higher treatment temperature tends to partly degrade these molecules resulting in reduced yellowness values.

Keywords: poplar wood, steaming, colour change, extractives

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Introduction

Wood is a renewable raw material source. Due to the regenerative property, wood belongs to raw materials that can interact with its environment even after becoming a structural element. Various fields of utilization require different wood characteristics, but not all of them correspond to a particular purpose. Unfavourable properties can be improved by modification of the wood material in many cases. One of the possible non-toxic modification processes is steaming. During steaming, the structure and components of natural wood material are affected by heat – released by steam – followed by physical and chemical transformation of hemicelluloses and extractives. It is mostly the extractive content that determines natural wood colour, and the same extractives are the most sensitive chemical components of wood during thermal treatments. Extractive content of different wood species differs considerably. Black locus has got high, beech timber has medium, while poplar has got low extractive content. Colour inhomogeneity and unfavourable colour are the most frequent cause of the application of steaming. Both disadvantages can be improved by steaming. Due to the simultaneous impact of heat and moisture, new chemical components are formulated that contain conjugated double bond systems as a consequence of the thermal degradation of extractives [Németh 1997; Fan et al. 2010; Tolvaj et al. 2012] and hemicelluloses [Tjeerdsma and Militz 2005; Chen et al. 2014; Timar et al. 2016; Xin et al. 2017].

As for industrial scale steam treatments, black locust and beech wood materials are involved in the largest quantities. Through the appropriate combination of steaming parameters, many shades of brown colour can be achieved in the case of black locust [Molnar 1998; Varga and van der Zee 2008; Tolvaj et al. 2010; Dzurenda 2018a]. Extreme colour inhomogeneity of these species also decreases during steaming. The unattractive greyish-white colour of beech wood turns to warmer shades of red during steaming [Hrcka 2008; Milic et al. 2015; Geffert et al. 2017]. Moreover, the colour difference between white and coloured heartwood can also be reduced [Tolvaj et al. 2009]. Turkey oak features similar inhomogeneous colour as black locust does. Huge colour difference can be observed between the light-coloured large size sapwood and the dark-coloured heartwood. This colour inhomogeneity can also be reduced significantly by steaming [Todaro et al. 2012a, 2012b].

There are only a few publications on the steaming properties of species other than beech or black locust. Varga and van der Zee [2008] studied the alteration of some mechanical and physical properties of two European and two tropical hardwood species caused by steaming. The possible colour variations of cherry wood generated by steam treatment were investigated by Straze and Gorisek [2008]. Scots pine and spruce samples were steamed applying a wide range of treatment time (0-22 days) and temperature (70 °C and 100 °C) [Tolvaj et al.

2012]. Various colours were created between the initial and light brown colour that were similar to the hue of aged indoor wooden structures and furniture. The steaming behaviour of oak and maple wood was studied by Dzurenda [2017, 2018b] to obtain an attractive brown colour. Kaygin et al. [2014] studied the surface quality and hardness of eastern red cedar as function of steaming time and temperature.

Recently, the steam induced colour change of poplar (*Populus x euramericana cv. pannonia*) was investigated to obtain attractive colour suitable for various indoor applications [Banadics and Tolvaj 2019]. Experiments with black locust showed that steam can transport extractable robinetin creating a thin yellow layer on the surface of the specimens. Steaming experiments also demonstrated that steam can penetrate into the dry black locust specimens easily. The fact that poplar has got low extractive content and the above mentioned two experiences resulted in the idea to steam poplar and other wood species with high extractive content simultaneously. No research paper dealing with the extractive transport during steaming was found.

The purpose of this study was to investigate the possible colour modification effect of the extractive transport from black locust and beech samples to poplar samples during steaming. The possibility of extractive transport is based on the experiences that steam can extract specific chemical compounds from black locust above 100 °C. The yellow robinetin appears on the surface of the samples and on the surface of the steaming chamber during the steaming process. Steam is supposed to be able to bring out extractives from black locust crossing the air in the chamber, then the same carrying medium could transport these extractives into the poplar samples located in the same chamber.

Materials and methods

Dried poplar (*Populus x euramericana cv. pannonia*), black locust (*Robinia pseudoacacia*) and beech (*Fagus sylvatica*) timbers were used for sample preparation, with sample dimensions of 30 × 25 × 160 mm^3 (W × H × L). Initial moister content of the samples was between 8-12%. Poplar samples were prepared using both sapwood and heartwood, separately. All samples were cut from the same defect free poplar board. Black locust or beech specimens (as initiators) were steamed together with poplar specimens (sapwood or heartwood) in the same pot in equal volume. Sapwood and heartwood of poplar was steamed alone as well, resulting in a total of 6 types of steam treatment procedure (sapwood and heartwood of poplar, sapwood and heartwood of poplar with black locust, sapwood and heartwood of poplar with beech).

Steaming was carried out in a special pressure pot. 100% relative humidity within the pot was guaranteed by water under the specimens. The chosen steaming temperatures were 90 °C; 100 °C; 110 °C and 120 °C. A heat sensor regulated the temperature automatically within the heating chamber (tolerance rate: 0.5 °C). Each treatment schedule started with a 6-hour warm-up period to reach the specified temperatures followed by 2, 5, 9, 14 and 20 days of steaming (at 90 °C; 100 °C and 110 °C). Duration of the steaming was somewhat shorter, 1, 2, 4, 6 and 9 days at 120 °C due to the exponentially accelerated thermal process. The moister content of the samples was between 18% and 22% after the end of the steaming process. Poplar samples reached this value within 2 hours of steaming and the moister content remained constant afterwards during longer steaming periods as well. After steam treatment, samples were conditioned in laboratory environment for one month. Then, samples were cut longitudinally in the middle and the colour measurements were carried out on the freshly formed surface. Colour coordinates were measured by a KONICA-MINOLTA 2000d colorimeter. The light source was D65 illuminant and 10° standard observer with a test-window diameter of 8 mm was applied. Four samples were prepared for each steaming temperatures and durations. It counts altogether 180 sapwood and 180 heartwood poplar samples. The colour at 10 randomly chosen points was measured on each sample, then the average of the 40 measurements were calculated to obtain colour data. Results were presented in the three-dimensional CIE-Lab colour coordinate system.

Results and discussion

Examining the wood samples with naked eye, the colour of poplar wood clearly turned towards brown more and more intensively with increasing steaming temperature and steaming time. Objective colour measurement reflected the differences more precisely than the visual observation. The presence of an initiator (black locust or beech) amplified the colour change only above 100 °C. Therefore, the data of steaming at 90 °C are not presented here. The lightness change of poplar heartwood (with and without black locust initiator) is presented in Fig. 1. Samples became darker with prolonged steaming time. The change was not sensitive to the temperature below 120 °C. Steaming generated rapid darkening at 120 °C during the first day of steaming.

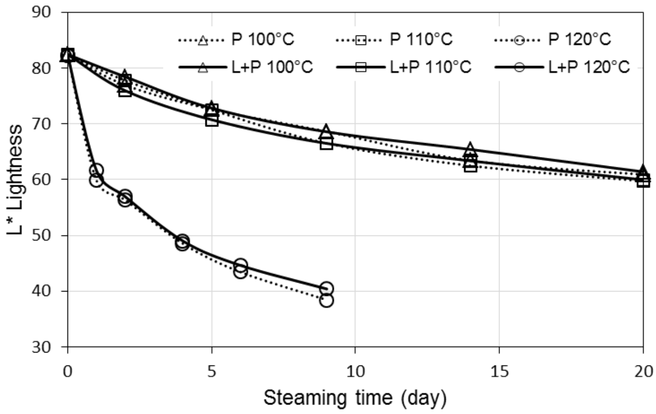

Fig. 1. Lightness change of heartwood of poplar (P) and heartwood of poplar steamed with black locust (L+P) as a function of steaming parameters

The change was moderate but continuous after the first day. Based on the visual observation, there was no significant colour change after 4 days of steaming at 120 °C. Thus, the treatment was terminated after 9 days at 120 °C. Apparently, black locust as initiator did not influence neither the lightness change of poplar heartwood nor that of the sapwood. Beech as initiator did not generate additional lightness change of poplar wood either.

The redness change of poplar is presented in Figs. 2-4. The value of red colour coordinate increased with elapsed steaming time and with rising temperature. Treatment at 120 °C for just only one day generated three times higher redness value compared to the initial value. The effect of initiators was visible only at 120 °C in sapwood (Fig. 2). The presence of both black locust and beech generated slightly greater redness increase in poplar sapwood compared to the poplar sapwood treated separately.

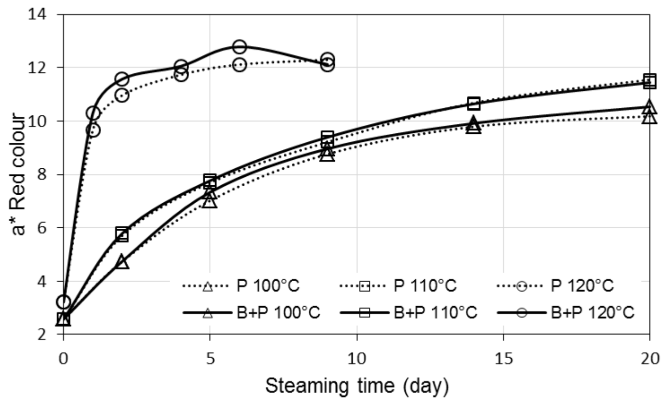

Fig. 2. Redness change of sapwood of poplar (P) and sapwood of poplar steamed with beech (B+P) as a function of steaming parameters

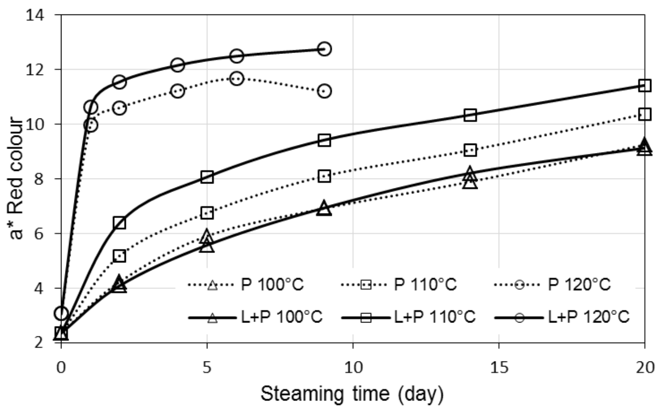

Fig. 3. Redness change of heartwood of poplar (P) and heartwood of poplar steamed with black locust (L+P) as a function of steaming parameters

The effect of initiators in case of redness change of poplar heartwood was visible above 100 °C (Figs. 3-4). The presence of black locust produced greater redness increase than the presence of beech did. However, the difference between the effects of the two initiators is visible only after the fifth day of steaming. This fact could be interpreted by the higher extractive content of black locust.

The value of yellow colour coordinate of poplar sapwood and heartwood increased with rising temperature (Figs. 5-7). The time dependence of yellowness change was highly temperature dependent as well. The time dependence of yellowness change was almost linear at 100 °C for both sapwood and heartwood. Steaming at 110 °C produced rapid yellowness increase during the first two days of steaming followed by moderate increase, while the treatment at 120 °C generated extremely great yellowness increase during the first day of steaming.

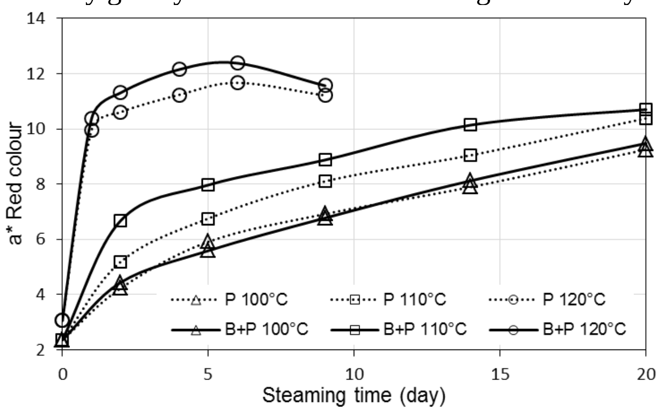

Fig. 4. Redness change of heartwood of poplar (P) and heartwood of poplar steamed with beech (B+P) as a function of steaming parameters

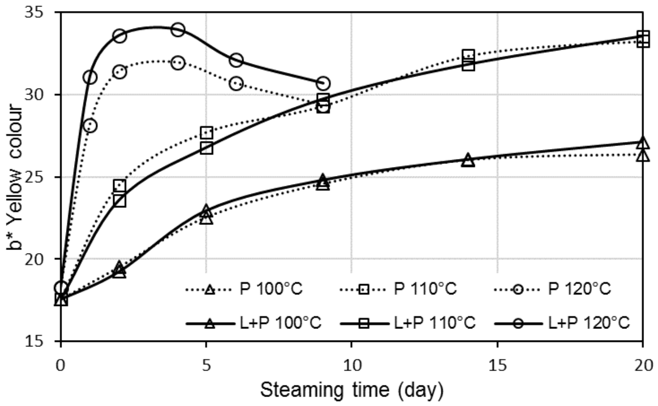

Fig. 5. Yellowness change of sapwood of poplar (P) and sapwood of poplar steamed with black locust (L+P) as a function of steaming parameters

The increase was less intensive from the fourth day in case of sapwood (Fig. 5). The extremely great colour alteration at 120 °C was partly produced by the degradation products of hemicelluloses. This temperature was high enough to modify the chemical structure of hemicelluloses creating acetic acid [Tjeerdsma and Militz 2005]. After the maximum point, the yellow colour coordinate decreased. The yellowness value of heartwood changed similarly at 120 °C as that of the sapwood, but the decrease started earlier, after the second day of steaming already (Figs. 6-7). The presence of initiator generated greater yellowness value increase of sapwood only at 120 °C (Fig. 5). The presence of black locust created a little greater yellowness value increase than the presence of beech (not presented here).

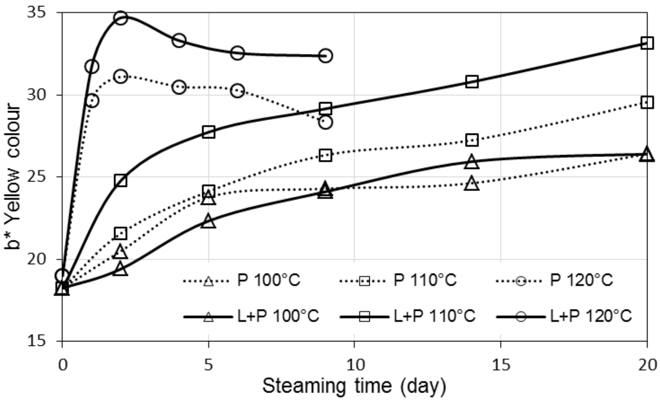

Fig. 6. Yellowness change of poplar heartwood (P) and poplar heartwood steamed with black locust (L+P) as a function of steaming parameters

The yellowness and the redness of poplar heartwood changed in a similar way in the context of initiators. The presence of initiators was effective above 100°C (Figs. 6-7). The presence of black locust (Fig. 6.) initiated considerably greater yellowness change than the presence of beech (Fig. 7.).

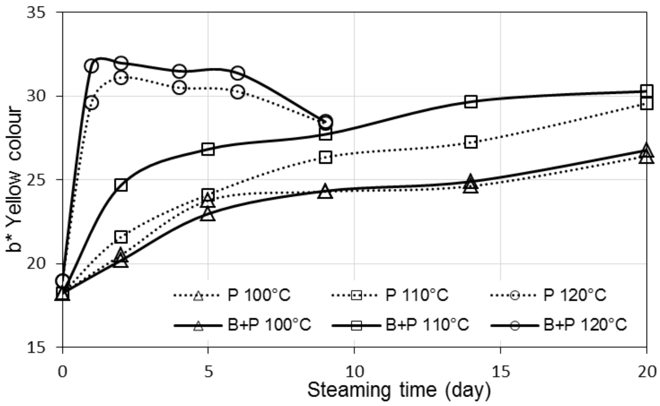

Fig. 7. Yellowness change of poplar heartwood (P) and poplar heartwood steamed with beech (B+P) as a function of steaming parameters

Altogether, the decrease of redness and yellowness values at 120 °C showed that the newly created chromophore molecules were not stable enough. This temperature is high enough to cause secondary degradation reducing the values of both redness and yellowness. Different effectiveness of initiators in terms of colour modification of sapwood and heartwood can be interpreted by the diverse chemical nature of these tissues. Heartwood can bound extractable molecules in a more stable way than sapwood can. Therefore, heartwood is usually darker than sapwood. Due to this nature, poplar heartwood could link the extractives of initiators transported by the steam flow in a stable way. Beech was less effective as an initiator than black locust. It means that steam extractable molecules of black locust were more linkable for poplar wood than the similar molecules of beech.

The yellow colour of poplar heartwood generated by the simultaneous steaming with black locust was more stable to secondary degradation than the yellowness generated by joint treatment with beech. This difference was generated by the presence of the yellow robinetin that cannot be found in beech wood. Colour change results confirmed our hypothesis that steam can remove extractives from the initiator (black locust or beech) samples and as a carrying medium can transport these extractives into the poplar samples in the same chamber above 100°C steaming temperature. The exact chemical nature of extractive transport by steam needs further chemical investigations.

Conclusions

Poplar wood was steamed together with black locust and beech specimens (as initiators) to intensify the colour modification effect of steaming. Black locust and beech were chosen as initiators since these two hardwood species have much higher extractive content compared to that of poplar. Our basic hypothesis was that steam as a carrying medium could transport extractives from the initiator samples into poplar wood resulting in a significant colour change. The applied treatment temperature range was 90-120 °C, while the maximum duration of the steaming was 20 days (at 120 °C only 9 days). Based on the objective colour measurements, it can be concluded that:

- the presence of initiators intensified the colour change of poplar only above 100 °C;
- as for the colour change of different wood parts, the presence of black locust or beech wood in the steaming chamber proved to be much more effective for heartwood than for sapwood;
- chromophore molecules generating the yellow hue increase at 120 °C were not stable. Such high temperature partly degrades these molecules reducing yellow hue values.

References

Banadics E.A., Tolvaj L. [2019]: Colour modification of poplar wood by steaming for brown colour. European Journal of Wood and Wood Products 77: 717–719

Chen Y., Tshabalala M.A., Gao J., Stark N.M., Fan Y. [2014]: Color and surface chemistry changes of extracted wood flour after heating at 120 °C. Wood Science and Technology 48:137–150. doi: https://doi.org/10.1007/s00226-022-01401-1

Dzurenda L. [2013]: Modification of wood colour of *Fagus sylvatica* L to a brown-pink shade caused by thermal treatment. Wood Research 58 [3]: 475-482

Dzurenda L. [2017]: Modification of wood colour of *Acer platanoides* L. to a brown-red shade caused by thermal treatment. Forestry and Wood Technology 98: 26–32

Dzurenda L. [2018a]: Colour modification of robinia pseudoacacia l. during the processes of heat treatment with saturated water steam. Acta Facultatis Xylologiae Zvolen 60 [1]: 61−70

Dzurenda L. [2018b]: The Shades of Color of *Quercus robur* L. Wood Obtained through the Processes of Thermal Treatment with Saturated Water Vapour. BioResources 13 [1]: 1525–1533

Fan Y., Gao J., Chen Y. [2010]: Colour responses of black locust (*Robinia pseudoacacia* L.) to solvent extraction and heat treatment. Wood Science and Technology 44: 667–678. doi: https://doi.org/10.1007/s00226-009-0289-7

Geffert A., Vybohová E., Geffertová J. [2017]: Characterization of the changes of colour and some wood components on the surface of steamed beech wood. Acta Facultatis Xylologiae Zvolen 59 [1]: 49−57

Hrcka R. [2008]: Identification of discoloration of beech wood in CIElab space. Wood Research 53 [1]: 119–124

Kaygin B., Koc K.H., Hiziroglu S. [2014]: Surface quality and hardness of eastern redcedar as function of steaming. Journal of Wood Science 60 [4]: 243–248

Milić G., Todorović N., Popadić R. [2015]: Influence of steaming on drying quality and colour of beech timber, Glasnik Šumarskog Fakulteta 83–96

Molnar S., [1998]: Die technischen Eigenschaften und hydrothermische Behandlung des Robinienholzes, In: Molnar S (ed.), Die Robinie Rohstoff für die Zukunft, Stiftung für die Holzwissenschaft, Budapest, pp 50–63

Németh K., [1997]: Wood chemistry. Mezőgazdasági Szaktudás Kiadó, Budapest, pp. 72-73

Straze A., Gorisek Z. [2008]: Research on colour variation of steamed Cherry wood (*Prunus avium* L.). Wood Research 52 [2]:77–90

Timar M.C., Varodi A., Hacibektsoglu M., Campean M. [2016]: Color and FTIR analysis of chemical changes in beech wood (*Fagus silvatica* L.) after light steaming and heat treatment in two different environments. BioResources 11: 8325–8343

Tjeerdsma B.F., Militz H. [2005]: Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dry heat-treated wood. Holz als Roh- und Werkstof 63: 102–111

Todaro L., Zuccaro L., Marra M., Basso B., Scopa A. [2012a]: Steaming effects on selected wood properties of Turkey oak by spectral analysis. Wood Science and Technology 46 [1–3]: 89–100

Todaro L., Zanuttini R., Scopa A., Moretti N. [2012b]: Influence of combined hydro-thermal treatments on selected properties of Turkey oak (*Quercus cerris* L.) wood. Wood Science and Technology 46 [1–3]: 563–578

Tolvaj L., Molnár S., Németh R., Varga D. [2010]: Colour modification of black locust depending on the steaming parameters. Wood Research 55 [2]: 81–88

Tolvaj L., Németh R., Varga D., Molnár S. [2009]: Colour homogenisation of beech wood by steam treatment. Drewno 52 [181]: 5–17

Tolvaj L., Papp G., Varga D., Lang E. [2012]: Effect of steaming on the colour change of softwoods. BioResources 7 [3]: 2799–2808

Varga D., Van der Zee M.E. [2008]: Influence of steaming on selected wood properties of four hardwood species. Holz als Roh- und Werkstoff 66 [1]: 11–18

Xin Y.L., Timar M.C., Varodi A.M., Sawyer G. [2017]: An investigation of accelerated temperature-induced ageing of four wood species: colour and FTIR. Wood Science and Technology 51: 357–378

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