Discolouration of Sawn Birch (*Betula pendula*) Timber from Plantation Forests during Drying: Effect of Growing Site, Felling Season and Storage of Logs on Discolouration

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Discolouration during drying is one of the biggest problems for birch wood in the wood remanufacturing industry. In the future, an increasing proportion of sawn birch timber will be obtained from plantation forests, which in many respects differ from natural forests. In the paper, the appearance of discolouration in sawn birch timber is discussed. Two plantation stands were selected for experiments on conventional and vacuum drying of sawn timber. The lightest colour on the surface layer of the boards was obtained with conventional drying after felling the trees and drying the boards in winter. On the other hand, colour defects, i.e. the difference in colour between inner wood and surface layer, were the greatest in winter. Differences in discolouration between the drying methods were observed. Physiological changes in trees between seasons and during temperatures below freezing were assumed to cause seasonal differences in discolouration.

Key words: Plantation forests, silver birch, wood discolouration, wood drying

Introduction

Discolouration of birch (*Betula pendula, B. pubescens*) wood during drying causes financial losses in the mechanical wood industry, particularly when valuable light-coloured timber assortments such as sawn timber or billets for parquet or furniture are produced. In fact, entrepreneurs who deal with birch wood consider discolouration to be the most important problem in further processing of sawn timber (Kivistö *et al.* 1999). Discolouration occurs irregularly, usually in the middle of the sawn timber while the surface layer remains light (Paukkonen *et al.* 1999, Luostarinen and Luostarinen 2001). The reasons for discolouration are thought to be related to the extractives the wood contains and the schedule used for drying the wood. Research on discolouration of sawn birch timber has so far concentrated on wood coming from older naturally regenerated forests, but lately questions about the properties of wood from birch plantations have also arisen.

Since the 1960's, when birch planting started on a larger scale in Finland, nearly 200 000 hectares of birch have been planted (Peltola 2003). Planting sites have been mostly forest clear-cutting areas of high fertility and abandoned agricultural fields on mineral soil. In comparison with naturally regenerated birch stands, the initial development of birch plantations has been faster and the regeneration result has been more certain (Saksa 1998). In addition, the fertility of the sites selected for plantation may, on average, be higher than the fertility of naturally regenerated birch forests, which emphasises the faster growth of plantations. A marked proportion of naturally regenerated birch is growing in forests dominated by other species; although birch makes up 16.1% of the total volume of the standing crop in southern Finland, only 7.3% of all Finnish forests are birch-dominated (Luostarinen and Verkasalo 2000). The importance of the birch wood from plantations for the mechanical wood industry will increase in the 2010's at the latest, when the older plantations will be mature for harvesting. The properties of wood from planted birches are not known; but they are thought to differ from those of slower growing, naturally regenerated trees.

The objective of this study was to investigate the effect of factors that may contribute to discolouration of birch (*Betula pendula* Roth.) wood from plantation forests during conventional warm-air drying and vacuum drying. The factors included were: growing site, felling season, length of log storage period, and location of wood in the trunk. These factors are thought to influence the occurrence of discolouration, because they are known to affect the chemical composition and the amount of wood extractives. The main reason for chemical discolouration with birch wood, as well as with other hardwood species, is thought to be the oxidation/polymerization of phenolic extractives. The role of proanthocyanidin (condensed tannin) in discolouration will be discussed in detail in the next issue.

Materials and methods

The research material consisted of birch wood from two different plantation forests in North Carelia, eastern Finland: 1) a typical forest regeneration area of high fertility OMT (*Oxalis-Myrtillus*-type) and 2) an afforested abandoned agricultural field, both on mineral soil. The two sites will later be referred to in this paper as forest site and field site, respectively. On both sites the age of the trees at the time of felling in 1999 was 33 years. The basal areas of the trees in the stands were 14.2 m^2 and 19.8 m^2, and the number of trees 380 and 480 per hectare on the forest site and the field site, respectively.

A total of 60 sample trees were felled for the experiment so that ten sample trees from each site were felled during each of three different seasons in 1999: summer, autumn and winter. To ensure an adequate yield of boards during sawing, the largest trees (diameter at breast height at least 19 cm) on both sites were selected. Only healthy trees with sound (according to visual inspection) wood were accepted as sample trees, which had been determined by checking the cross-cut ends of logs after felling. Two logs, of 2.5 m long, were cut from each trunk. The first log was cut beginning at the butt of the tree. The upper log usually started at the upper end of the butt log; but in a few cases, when the diameter of the trunk allowed, the top diameter of the upper log was set at 20 cm. The logs from the first five trees from both sites were sawn within five days after felling. To investigate the effect of storage on discolouration, the remaining 20 logs, ten from each site, were stored eight weeks on the yard of the sawmill before they were sawed and dried. Neither the fresh-sawn logs nor the stored logs were debarked or treated in any other way before sawing or storage.

The weather during the storage of logs in the summer of 1999 was relatively warm (mean temperature between 12.6 and 24.6 °C) (Ilmatieteen laitos 1999). In autumn, the mean temperature at the time of first sawing was about 9 °C, but decreased to below 0 °C in the end of the storage period. During winter felling, the mean temperature during the study was mostly below 0 °C, and the logs did not thaw during storage. At the time of sawing, mean temperatures of –18.6 and –14.0 °C were recorded for unstored logs and for logs stored eight weeks, respectively (Ilmatieteen laitos 2000, 1999).

During sawing, the boards (30 mm × 70 mm × 1200 mm) were encoded according to site, felling season, tree number, and longitudinal and radial location in the trunk. They were dried to 5% target moisture content by using conventional warm-air drying and vacuum drying. The conventional drying, carried out at the University of Joensuu, always started the day after sawing; but the vacuum drying, carried out at the Institute of Environmental Technology in Mikkeli, could not usually be started until seven days after sawing. The kilns used were small computer-controlled laboratory kilns (Brunner Trockentechnik 1992). The drying schedules were similar to those used earlier with sawn timber of naturally regenerated birches (Luostarinen *et al.* 2002). Dry bulb temperatures of 37 – 65 °C and 65 – 82 °C were used during the conventional and vacuum dryings, respectively. Because discolouration was studied, we did not plan the schedules so that discolouration of wood would be avoided; rather, we wanted measurable and visible discolouration to occur.

Spectral measurements of wood were made with a portable spectrophotometer (Minolta CM-2002) using 2° standard observer and D_{65} standard illuminant (Precise color… 1994). The spectrum of reflected light in the visible range (400 – 700 nm) was measured. From each sample board, three measurements, avoiding knots or other extraneous discolourations, were made and averaged to one observation. The fresh colour was measured from planed surfaces of boards immediately after planing. After drying, the original surface of boards was only thinly planed to get rid of the yellowish surface before final colour measurements of the surface layer of the boards. The boards were then spilt-sawn and planed for final colour measurements of the inner wood.

The three-dimensional L*a*b* colour scale (recommended in 1976 by the International Commission on Illumination, CIE), where +a* stands for red, –a* stands for green, +b* stands for yellow, and –b* stands for blue, was used to quantify changes in the tint of the wood (see e.g. Hunt 1998). The L* axis represents nonchromatic changes in lightness from an L* value of 0 (black) to an L* value of 100 (white). The differences in colour between two measurements were determined by $\Delta E_{ab}*$, which was calculated as follows:

$$\Delta E_{ab}* = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$$

where ΔL*, Δa*, and Δb* correspond to differences in lightness, redness and yellowness, respectively, between two measurements.

The L*a*b* colour coordinates were examined separately to determine the differences in the colour of the surface layer and the inner wood of boards between different felling seasons, storage periods and locations of wood in the trunk. The colour difference, ΔE_{ab}*, of the dried wood was calculated as the difference between the inner wood and surface layer of boards in different felling seasons and storage periods. The data were analysed using the analysis of variance procedures of SPSS-statistics (SPSS Inc.) to establish the statistical significance of colour differences between drying lots. The Tukey's test and factor test were used to compare the means of colour coordinates and also the total colour difference.

Results

The measured differences in lightness (L*) of the colour of fresh wood between different felling seasons and between unstored and stored wood were insignificant (Table 1). Fresh wood of unstored planed boards was lightest in summer and darkest in autumn. Storage of logs always increased the lightness of wood but had no effect on redness (a*). In summer the yellowness (b*) of fresh wood decreased during the storage of logs, but in autumn and winter remained about the same. During summer storage, the moisture content of logs decreased, which led to a decrease of 32.2 percent in the moisture content of sawn timber, measured immediately after sawing.

In comparison to the colour of fresh birch wood, with both drying methods the differences in final colour were greater between the different felling seasons and between unstored and stored wood. After conventional drying, the variation in final colour can be summarised as follows (Figure 1a):

1) The colour of the surface layer of boards was always lighter and varied more between different felling seasons and between stored and unstored wood than did the colour of the inner wood of boards.

2) The colour of the surface layer of boards was lightest and the least red and yellow in winter. In the inner wood of boards, the differences in colour between different felling seasons were minor.

3) In autumn the storage period of logs affected colour by increasing the lightness and decreasing the redness and yellowness of both the surface layer and the inner wood of boards. In summer and winter the effects of storage period were opposite to those found in autumn.

Correspondingly, the main results of variation in wood colour after vacuum drying can be summarised as follows (Figure 1b):

1) The colour of the surface layer of boards was always darker than the colour of the inner wood. However, the difference was visible only in wood from unstored logs in autumn and in wood from the eight weeks stored logs in winter.

2) The colour of both the surface layer and the inner wood of boards was lightest in summer and darkest in winter.

3) The storage period of logs usually decreased the lightness and increased the redness and yellowness of both the surface layer and the inner wood.

Regardless of the felling season or the storage period of logs, boards were clearly darker after vacuum drying than after conventional drying (Figure 1). In addition, the red colouring of boards, in particular, was strong during vacuum drying.

In conventionally dried wood, all colour coordinates differed significantly between felling seasons (Table 2a). Also in vacuum-dried wood, in most cases the differences observed between different felling seasons were significant, although the differences, especially in the surface layer, were not as great as in conventionally dried wood. In conventionally dried wood the colour difference (ΔE_{ab}*) between the inner wood and the surface layer of boards was greatest in winter and smallest in summer, and the differences between different felling seasons were significant. The effect of storage period of logs on the colour coordinates of dried wood was minor (Table 2b). The significant effects observed in conventionally dried wood

Felling season - storage	N	L*	a*	b*	Moisture[1] content, %
S-0	37	87.6 (0.9)	1.1 (0.5)	17.0 (1.2)	100.6 (12.8)
S-8	22	88.7 (1.4)	1.0 (0.4)	15.7 (1.2)	68.4 (12.1)
A-0	40	86.1 (0.9)	1.0 (0.4)	16.2 (0.9)	83.4 (10.9)
A-8	26	88.1 (1.0)	1.1 (0.5)	16.6 (0.9)	83.2 (10.9)
W-0	42	87.0 (1.1)	1.0 (0.4)	16.3 (1.3)	82.6 (7.6)
W-8	36	88.6 (0.6)	1.0 (0.5)	16.4 (0.9)	84.1 (10.7)

[1] moisture content was measured from 20 separate sample boards in each drying lot

Table 1. L*a*b* colour coordinates and moisture content (% of dry weight) of fresh boards in different felling seasons sawn from unstored logs and logs stored for eight weeks. Felling seasons and storage of logs: summer (S), autumn (A), and winter (W); unstored (0) and stored eight weeks (8). Standard deviation in parenthesis

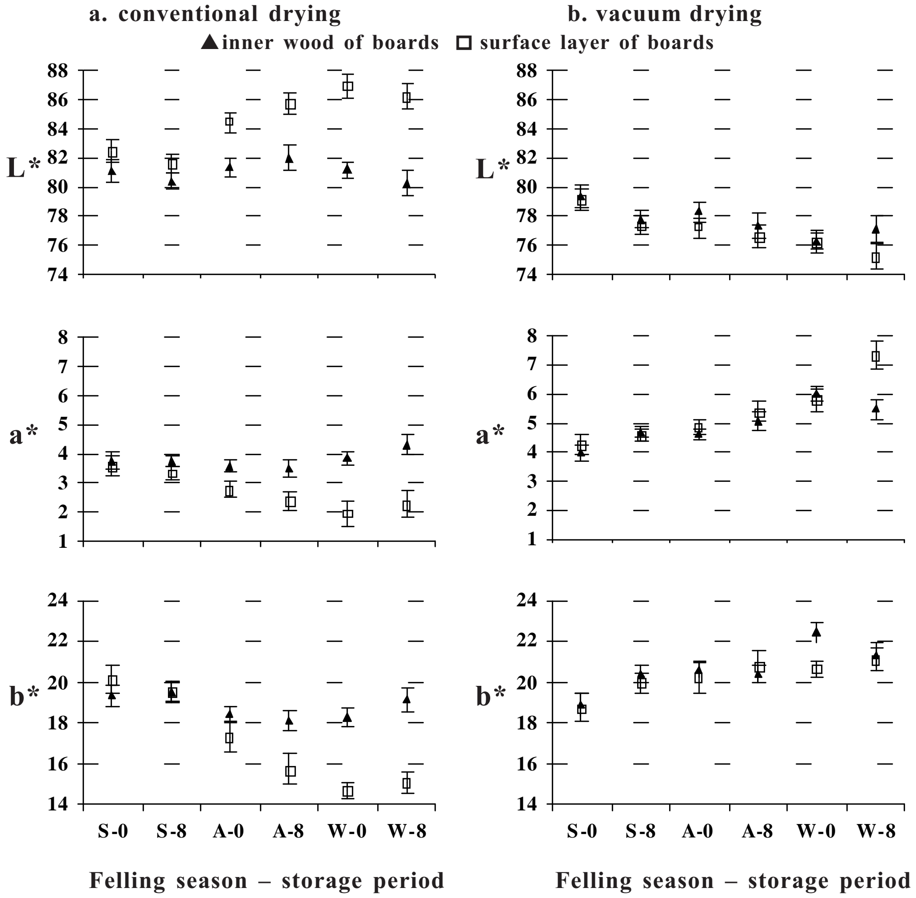

Figure 1. Means and standard deviations of the L*a*b* colour coordinates for final colour in a) conventionally and b) vacuum-dried boards sawn in different felling seasons from unstored logs and logs stored for eight weeks. Felling seasons and storage of logs as in Table 1

were the increase in redness in the inner wood and the decrease in yellowness in the surface layer of boards during storage. In vacuum-dried wood, the storage period of logs significantly affected all colour coordinates of the surface layer of boards. The effect of storage on the colour coordinates of the surface wood of vacuum-dried boards was opposite to that of conventionally dried boards.

The differences in colour coordinates between the two growing sites were not significant in either conventionally or vacuum-dried wood (Table 2c). The colour difference between the surface layer and the inner wood of boards did not differ significantly between the two growing sites.

The effect of location of wood in the trunk on the colour of dried birch wood was greater in radial than in longitudinal direction (Table 3). In the radial direction, the lightness of the inner wood of boards increased, and the redness and yellowness decreased from wood near the pith towards that near the trunk surface. The lightness of the surface layer was greatest in boards sawn midway between the trunk surface and the pith. An interaction between the longitudinal and radial locations in the trunk was observed in the lightness and the redness of the inner wood of the boards. This interaction resulted from the fact that the difference in lightness and redness of the inner wood of boards taken from near the pith and the inner wood of boards taken from near the trunk surface was greater in the upper log than in the butt log.

Discussion and conclusions

Differences in the fresh colour of planted birch wood between different felling seasons were slight. The observed differences in yellowness seemed to be related to the moisture content of the wood, the yellowness decreasing with decreasing moisture content, although the dependence of colour on the moisture content could not be tested statistically due to separation of sample boards for measurements of fresh colour and the moisture content. On the other hand, regardless of changes in the moisture content, during the eight-week storage period of the logs the lightness of fresh wood increased in all seasons. With regard to lightness, the results obtained here are similar to those reported by Luostarinen *et al.* (2002) for naturally regenerated birches. In general, due to the

Table 2. L*a*b* colour coordinates of inner wood (i) and surface layer (s) of boards in the two drying processes by a) felling season, b) length of the log storage period and c) growing site. Within drying process, means followed by the same lowercase letter do not differ significantly (į=0.05). Standard deviation in parenthesis

a)

Drying process	Felling season	N	L_i*	L_s*	a_i*	a_s*	b_i*	b_s*	ΔE_{ab}*
Conventional	Summer	89	80.8 a (1.3)	82.1 a (1.4)	3.8 a (0.5)	3.5 a (0.6)	19.4 a (1.0)	19.9 a (1.3)	1.9 a (0.9)
	Autumn	96	81.7 b (1.6)	85.2 b (1.6)	3.5 b (0.5)	2.6 b (0.6)	18.3 b (0.9)	16.5 b (1.7)	4.2 b (1.9)
	Winter	105	80.7 a (1.6)	86.6 c (1.7)	4.1 c (0.6)	2.1 c (0.9)	18.7 c (1.1)	14.9 c (1.0)	7.3 c (1.8)
Vacuum	Summer	40	78.6 a (1.6)	78.3 a (2.1)	4.3 a (0.6)	4.4 a (0.6)	19.7 a (1.3)	19.4 a (1.2)	2.0 a (1.0)
	Autumn	40	77.9 a (1.7)	76.9 b (2.0)	4.8 b (0.7)	5.1 b (0.9)	20.5 b (1.6)	20.5 b (1.5)	1.9 a (1.0)
	Winter	40	76.7 b (1.7)	75.7 c (2.3)	5.7 c (0.8)	6.6 c (1.3)	21.9 c (1.6)	20.9 b (1.6)	3.2 b (1.0)

b)

Drying process	Length of log storage period	N	L_i*	L_s*	a_i*	a_s*	b_i*	b_s*	ΔE_{ab}*
Conventional	0 weeks	145	81.2 a (1.3)	84.7 a (2.3)	3.7 a (0.5)	2.7 a (1.0)	18.7 a (1.1)	17.4 a (2.6)	4.4 a (2.6)
	8 weeks	145	80.9 a (1.8)	84.8 a (2.5)	3.9 b (0.7)	2.6 a (0.9)	18.9 a (1.1)	16.6 b (2.3)	5.0 a (2.9)
Vacuum	0 weeks	60	78.0 a (2.1)	77.5 a (2.3)	4.9 a (1.0)	5.0 a (1.0)	20.7 a (2.0)	19.9 a (1.6)	2.2 a (1.2)
	8 weeks	60	77.4 a (1.5)	76.4 b (2.3)	5.1 a (0.7)	5.8 b (1.5)	20.7 a (1.4)	20.6 b (1.6)	2.5 a (1.5)

c)

Drying process	Growing site	N	L_i*	L_s*	a_i*	a_s*	b_i*	b_s*	ΔE_{ab}*
Conventional	Forest	144	81.0 a (1.5)	84.7 a (2.5)	3.8 a (0.6)	2.8 a (1.0)	18.8 a (1.1)	17.1 a (2.6)	4.6 a (2.6)
	Field	146	81.1 a (1.6)	84.9 a (2.4)	3.8 a (0.6)	2.6 a (0.9)	18.8 a (1.1)	16.9 a (2.3)	4.8 a (2.9)
Vacuum	Forest	60	77.6 a (1.5)	77.0 a (2.2)	5.0 a (0.8)	5.3 a (1.1)	20.7 a (1.7)	20.0 a (1.4)	2.3 a (1.1)
	Field	60	77.9 a (2.2)	77.0 a (2.5)	5.0 a (1.0)	5.5 a (1.5)	20.7 a (1.8)	20.5 a (1.7)	2.4 a (1.6)

Table 3. Effect of wood location in the trunk on colour coordinates of inner wood (i) and surface layer (s) of boards, and the results of factor test

Location in the trunk	N	L^*_i	a^*_i	b^*_i	L^*_s	a^*_s	b^*_s
Butt log							
Near pith	65	80.8	4.1	19.1	84.3	2.9	17.3
Middle	49	80.8	3.9	18.9	85.1	2.6	16.6
Trunk surface	72	81.3	3.6	18.4	84.9	2.5	16.7
Upper log							
Near pith	39	80.3	4.3	19.5	84.4	3.1	17.6
Middle	25	81.3	3.8	18.8	85.5	2.5	16.6
Trunk surface	38	81.9	3.4	18.4	85.0	2.4	17.0
Factor test results(1)							
$F_{longitudinal}$(2)		2.4	0.9	0.0	0.2	0.0	0.2
F_{radial}		13.4**	42.8**	19.0**	3.3*	12.0**	3.7
$F_{interaction}$		3.3*	4.0*	2.7	0.1	0.7	0.3

(1) $df_{longitudinal}$ = 1; and df_{radial} = 2
(2) Significance levels are indicated by asterisk**, *P*<0.01; and *,*P*<0.05

insignificant differences in colour, discolouration of birch boards during drying cannot be predicted on the basis of their fresh colour.

Even relatively slight differences in the colour coordinates measured in dried sawn birch timber from different felling seasons proved to be statistically significant. All the differences measured, especially differences in redness and yellowness, are not necessarily easily detected by a human observer, although lightly tinted shades can be more readily distinguished than deeply saturated shades (Popson *et al.* 1997). Nevertheless, the colour differences observed here are important when the physiological or chemical basis of the discolouration is considered. According to our experience, a colour difference of $ÄE_{ab}* = 1.8$ or greater between two separate samples of birch wood is distinct.

The lightest colour of the surface layer of boards in conventional drying was produced in winter and also in autumn when the logs were stored until frosty weather. Smith and Herdman (1996) also obtained the lightest surface layer in boards of sugar maple (*Acer saccharum* Marsh.) felled in winter when low-temperature and low-humidity kiln drying was used. In most applications in the birch wood industry, however, the light surface layer of the board alone is not sufficient, because the dried sawn timber must be sawn into thinner specimens where both the surface and inner layers of the original block can be seen. It was observed in this study for planted birch, as in earlier ones for naturally regenerated birch (Luostarinen *et al.* 2002, Luostarinen and Luostarinen 2001, Paukkonen *et al.* 1999) and for sugar maple (McMillen 1976), that darkening of the wood during drying is stronger in the interior of boards than in their surface layer.

A light margin is thought to result from considerable drying of the surface layer at low temperature before artificial drying begins (Luostarinen *et al.* 2002, McMillen 1976). Paukkonen *et al.* (1999) also presumed that, at the beginning of the drying process, too-intensive drying of the surface layer compared to the interior of the boards, for example, due to high temperature, may lead to a break in the capillary connection of water between the surface and the interior of the boards. This, in turn, may increase the discolouration of wood below the dry surface layer. In this study, the visibility of the light margin depended on the felling season of planted birch and, in autumn, also on storage of logs. In summer virtually no margin was detected, but in winter there was a clear margin.

The observation that the perceptibility of the margin differed between felling seasons may, in addition to premature drying of surface layer of boards, be due to freezing of water in the wood in winter. During freezing, only free water in the liquid fraction is capable freezing; and with decreasing temperature, the water of the cell walls freezes to ice crystals in the cell cavities (see e.g. Kübler 1962, Skaar 1988). This phenomenon is reversible, but a distinct hysteresis has been observed. It is probable that at the beginning of conventional drying a part of the formerly frozen water in the cell cavities, especially near the surface of the boards, may be removed relatively rapidly from the board without returning to the cell wall. This, in turn, may lead to too intensive drying of the surface layer, which remains light in colour, and affects various chemical reactions, causing discolouration in the inner parts of the board.

The darker wood obtained after vacuum drying, compared to that after conventional drying, was obviously due to the fact that the temperature was already too high at the beginning of the vacuum drying process. However, despite the darker colour of vacuum-dried boards, their colour was more uniform throughout the different layers of the boards. The light margin of the boards obtained with conventional drying was not formed at all after vacuum drying. In fact, during vacuum drying the surface layer tended to darken more than the interior of the boards did. These results indicate that the mechanism of discolouration during vacuum drying differed from that in conventional drying, as Wastney *et al*. (1997) also assumed.

Regardless of felling season, storage had a stronger effect on the colour of the wood when it was vacuum-dried than when it was dried conventionally. The effect of storage was surprisingly small in summer, even though discolouration of fresh birch round timber due to prolonged storage in the forest before artificial drying is well known (see e.g. Verkasalo 1993).

The location of wood in the trunk had a greater impact on colour than the growing site. The radial location of the wood in the trunk clearly affected the colour, the wood being lighter and less red and yellow near the trunk surface. More chemical components affecting wood colour may be concentrated in older wood near the pith than in wood near the trunk surface, although distinct heartwood, in the ordinary sense, is not formed in birch. The colour differences in the radial direction were greater in the upper than in the lower parts of the trunk.

Birch wood used in the mechanical wood industry should be light and uniform in colour. The drying schedules used in this study were adjusted to form some discolouration. Therefore, the results obtained here do not represent the overall colour of birch wood from plantation forests obtained with the normal drying practices used in the mechanical wood industry. However, the results clearly show that the factors studied here, especially felling season and storage of logs, contribute to discolouration of birch wood. Furthermore, the effect of these factors on discolouration of birch wood seems to differ with different drying methods. Therefore, additional research is needed to clarify the physical and chemical factors associated with discolouration of birch wood during drying.

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ЦВЕТОИЗМЕНЕНИЕ ДРЕВЕСИНЫ БЕРЕЗЫ (*BETULA PENDULA*) ЗАГОТОВЛЕННОЙ В ИСКУССТВЕННО СОЗДАННЫХ ЛЕСАХ, В ХОДЕ СУШКИ: ВЛИЯНИЕ МЕСТА ПРОИЗРАСТАНИЯ, СЕЗОНА ЛЕСОЗАГОТОВКИ И СПОСОБА ХРАНЕНИЯ НА ОБЕСЦВЕЧИВАНИЕ ДРЕВЕСИНЫ

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Резюме

Цветоизменение березовой древесины в ходе сушки является одной из самых больших проблем деревоперерабатывающей промышленности. В будущем все большие объемы березовой древесины будут поступать из искусственно посаженных лесов, которые во многих отношениях отличаются от естественных. В данной публикации рассматривается цветоизменение пиломатериалов березовой древесины. Для сравнительного эксперимента традиционной и вакуумной сушки древесины были выбраны два участка искусственно созданных лесов. Самый светлый цвет поверхностного слоя пиломатериала был получен при традиционной сушке, после заготовки древесины и сушки пиломатериалов в зимнее время. С другой стороны, цветовые дефекты, т.е. разница в цвете между внутренними и внешними слоями древесины, преобладали как раз в зимнее время. Наблюдалась разница в степени изменения цвета при применении разных видов сушки. Предполагается, что физиологические изменения деревьев в межсезонье и при температурах ниже замерзания вызывают сезонные различия в цветоизменении.

Ключевые слова: искусственно созданные леса, береза бородавчатая, цветоизменение древесины, сушка древесины