Discoloration of Norway spruce and Scots pine timber during drying

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ABSTRACT

The effect of growth site, felling time (winter, spring and autumn) and wet storage on the discoloration of spruce (*Picea abies* (L.) Karst.) and pine (*Pinus sylvestris* L.) dried at different temperatures was studied. Two dominant trees were selected at each cutting season from a fertile and a poor site. Some of the logs felled in May were stored under sprinklers for 6 weeks. The butt logs were cant-sawn with a circular saw.

The temperatures for drying were 50, 70, 90 and 110 °C. One group from autumn felling was dried in a vacuum kiln at 70 °C. Common drying schedules for 38-mm-thick pine boards were used.

The surface colour (CIELAB L*, a*, b*) of boards was measured before and after drying with a spectrophotometer. Some of the boards were also measured after 0.5 mm and further 1.5 mm planing.

Drying temperature was the most significant factor for discoloration of boards. The colour change of pine was quite similar to that of spruce except that there was a stronger darkening of pine heartwood compared to spruce at 90 °C. Discoloration in sapwood increased remarkably at temperatures above 70 °C. At 90 and 110 °C the lightness (L*) decreased significantly indicating darkening. The b* value increased with temperature. The a* value changed less. Timber felled in winter showed increased discoloration in drying compared to other felling times. There were no significant differences between fertile and poor sites.

The extractive content of the wood surface was analysed after the drying. The amount of soluble carbohydrates was 5- to 10–fold larger on a 2-mm-thick surface layer after drying than in the fresh samples of sapwood. The highest sugar content was detected in the samples taken in winter. However, results did not show any clear correlation between extractive content and degree of discoloration.

INTRODUCTION
Background

The elevation of drying temperatures in Nordic countries has brought many advantages like short drying times and less checking, but also disadvantages such as colour changes of timber. Discoloration appears mainly at the beginning of drying when the wood is still wet and the evaporation is rapid. High temperature and high initial moisture content promote colour changes (Paajanen & Siimes 1996).

One reason for colour changes in sapwood is suggested to be the enrichment of water-soluble extracts like sugars, starch and nitrogen compounds in the surface layer of timber during drying (Sehlstedt-Persson 1995, Terziev 1996, Saranpää et al. 1995). Discoloration is also due to darkening of resins on the surface and it is more common in Scots pine than in Norway spruce (Paajanen & Siimes 1996).

Colour changes can be controlled by drying temperature. Best results are achieved with low temperatures (Kreber & Haslett 1997). Using low temperature above fibre saturation and higher temperatures thereafter diminishes discoloration (Laytner 1995, Tarvainen 1994).

Discoloration of the wood just beneath the surface is called brown stain or caramelisation (Sehlstedt-Persson 1998). It is intensified at high drying temperatures. It is also more pronounced, in kiln drying, at low than at high relative humidity (Kreber & Haslett 1997).

Objectives

The aim was to investigate the effect of site fertility, felling time, storage under water spraying, and drying temperature on colour changes after drying in batch kiln. The material was cut from fertile and poor sites in winter, spring and autumn. Some of the spring-felled logs were stored for 6 weeks under sprinklers.

One vacuum drying at 70 °C and one press drying at 140 °C with a novel compression drying technique was also performed.
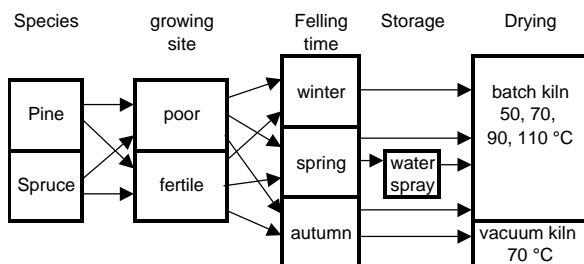

FIGURE 1. Test schedule.

Wood material

Norway spruce and Scots pine stems were harvested from the research stands of the Finnish Forest Research Institute. Sample plots were selected from fertile and poor stands. Site classification was based on the dominant height and age. Ground vegetation was also used in the classification. The characteristics of the stands are shown in Table 1.

In each stand, two dominant trees of both species were selected and felled in each cutting season. Sample disks were taken from top ends of the logs for the detailed studies of wood properties. Logs were cant-sawn with a circular saw in the field. The dimensions of the side yield were 25 x 100 mm^2 for both species. The dimensions of the centre yield were 38 x 100 mm^2.

Table 1. Properties of the stands of the wood material for drying experiments. H_{100} = dominant height at the biological age of 100 years, D = Mean diameter at breast height, H = Mean height, H_{dom} = Dominant height

Stand / Species	H_{100}	D cm	H m	H_{dom} m	Age years
1 Spruce	22	24.1	19.3	21.2	92
2 Spruce	32	25.3	22.5	24.6	58
3 Pine	22	27.3	21.8	23.3	115
4 Pine	30	29.2	24.6	25.8	80

The sideboards and centre yield of the butt logs were transported to VTT for the drying experiments. After every delivery, the material was cut in drying length (120 cm) and divided into five parallel groups so that their material properties were as similar as possible. The groups were packed in plastic foils and stored until the drying test in a freezer at a temperature of -3 .to -5 °C.

Drying schedules

Drying tests were carried out in a Vanicek laboratory kiln at VTT. Four kiln drying temperatures were used: 50, 70, 90 and 110 °C. One group from autumn felling was vacuum dried at 70 °C. The kiln drying schedules were common schedules used in industry for 38-mm-thick boards (Table 2).

Table 2. Drying schedules

Temperature 50 °C			Temperature 70 °C		
Time	T_d	T_w	Time	T_d	T_w
h	°C	°C	h	°C	°C
0	20	16	0	20	16
6	50	46	6	70	65
14	50	46	9	70	65
32	50	45	24	70	57
43	50	37	54	70	57
87	50	37	55	70	64
90	50	42	67	70	64
102	50	42			
Temperature 90 °C			Temperature 110 °C		
Time	T_d	T_w	Time	T_d	T_w
h	°C	°C	h	°C	°C
0	35	32	0	28	25
8	90	86	6	100	96
18	90	79	8	110	98
20	90	78	24	110	98
38	90	78	30	70	65
40	90	85	34	70	65
56	90	85	Cooling	35	

Planing

Some of the specimens were planed into depths of 0.5 mm and additional 1.5 mm at measuring points.

Colour measurements

The surface colour of every board was measured at 6 points with a Minolta Spectrophotometer CM-525i (Standard ISO 105-J01, illuminant D65 light source) before (surface wet) and after drying. The light source represents average daylight including ultraviolet radiation. Some of the boards were also measured after planing. The measurements were carried out at the same positions (diameter = 25 mm) before and after drying and also after planing. The measuring points were chosen so that they represented the average surface appearance. Thus, excessive discoloration plots, due to resin flow or brown stain, were not included in the measurements.

The colour is expressed with L*, a*, b* in colour space (also referred to as CIELAB). In this colour space L* indicates lightness and a* and b* are the chromaticity coordinates. Positive a* values indicate red and negative values indicate a green colour. Positive b* values indicate yellow and negative values indicate a blue colour. L* can have values of 0 ... 100; a* and b* values of -60 ... +60.

Measured values can be expressed with vectors in colour space. The total colour change (ΔE) is the difference of two vectors:

$$\Delta E =$$

$$\sqrt{(L*_2 - L*_1)^2 + (a*_2 - a*_1)^2 + (b*_2 - b*_1)^2}$$

When analysing colour changes, the average value of six measurements of every board was first calculated. Changes of L*, a* and b* and the total change ΔE were calculated. A difference of about 2 units can be distinguished visually.

Analysis of soluble carbohydrates

Samples were prepared from the wood surfaces after drying. The wood powder (100 mg dry weight) was extracted with 80% ethanol in a sonicator for 45 minutes. Internal standard was added to the solvent (1.0 mg m-erythritol). Trimethylsilyl (TMS) esters of carbohydrates were prepared by adding 0.4 ml of a silylating reagent (21 ml bis-(trimethylsilyl)trifluoro-acetamide and 100 ml dry pyridine). Soluble carbohydrates were determined by GLC-MS using a wall-coated fused silica column HP-5MS (Hewlett-Packard, USA).

Lipid analysis

Samples of the wood powder (300 mg dry weight) were extracted with acetone in a mini-Soxhlet apparatus for 6 hours. Internal standard was added to the solvent (0.24 mg heptadecanoic acid, 0.24 mg cholesterol, 0.24 mg cholesteryl heptadecanoate, and 0.64 mg triheptadecanoin). Neutral lipids were fractionated by an SPE column (phase type aminopropyl-silyl, 200 mg). Lipophilic compounds were determined by high temperature (HT) GLC-MS using a wall-coated fused silica column DB-1HT (J&W 9120414B; USA).

RESULTS AND DISCUSSION
Effect of different factors on colour changes
Drying temperature

Drying temperature was the most significant factor causing colour changes of boards. The increase in drying temperature intensifies colour changes on the surface and inside the wood. High drying temperature also usually produced an uneven result, i.e. higher variation of L*, a* and b* in a board and between boards. Most uniform was the colour after drying at 50 and 70 °C. At elevated and high temperature drying the lightness (L*) of boards significantly decreased (Repola et al. 2001, Saranpää & Repola 2000) (Figure 2).
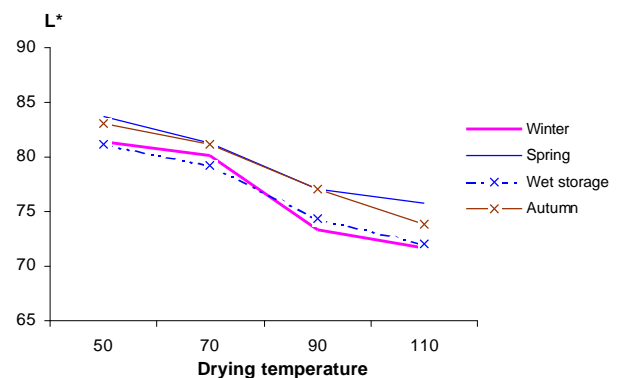

FIGURE 2. The effect of felling time and drying temperature on the L* values (lightness) of Scots pine sapwood boards after drying.

Felling time and wet storage

The felling time and wet storage slightly affected L*, a* and b* values of green and dried timber. Felling in winter, and spring felling with additional wet storage, produced a darker surface compared to spring and autumn felling. This difference was the same before and after drying (Figure 2).The a* value increased slightly in the red direction with increasing drying temperature. The b* value changed more than the a* value. The effect of felling time was minor on both values (data not shown).

Site fertility

There were no significant differences between fertile and poor sites (Table 3).

Table 3. Effect of drying temperature and growing site on the total colour change ?E and its standard deviation of pine and spruce sideboards.

Species / Site	50 °C	70 °C	90 °C	110 °C
Scots Pine				
Fertile	4.9 (1,5)	3,6 (1,3)	6,2 (1,5)	7,5 (1,7)
Poor	4,8 (1,5)	3,9 (1,5)	6,2 (1,7)	6,7 (1,6)
Norway Spruce				
Fertile	5,2 (2,0)	6,1 (3,2)	7,0 (2,5)	8,2 (2,8)
Poor	5,2 (1,6)	4,4 (1,9)	6,4 (2,9)	8,2 (2,8)

Differences between pine and spruce

In most cases the colour changes in pine are quite similar to those in spruce. One exception was the colour change of Scots pine heartwood compared to Norway spruce heartwood at 90 °C. Supposedly due to resins, the pine darkens already at 90 °C (Figure 3).
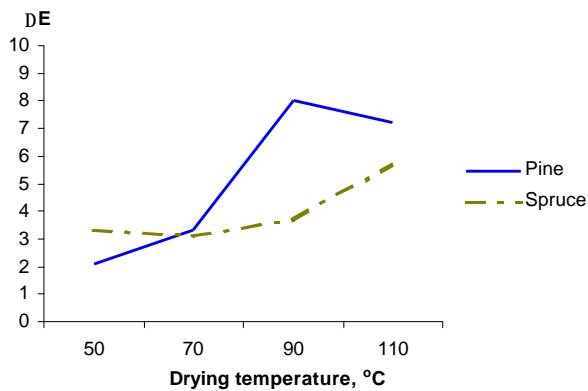

FIGURE 3. The discoloration ?E (total colour change) of heartwood boards.

Colour changes inside the boards
Sideboards

Increases in drying temperature thickened the surface layer with colour change. The planing depth of 0.5 mm was enough to remove the discoloured layer from boards dried at low temperatures (50 and 70 °C). When higher drying temperatures were used the colour change was still considerable after 1.5 mm of additional planing. The results for pine sapwood are presented in Figures 4–6.

The surface of spruce sideboards darkened a little more than that of pine but after planing the spruce was lighter than pine.
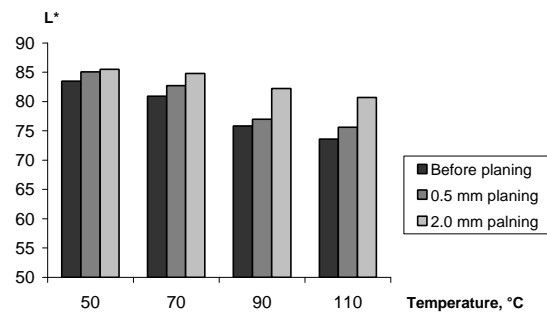

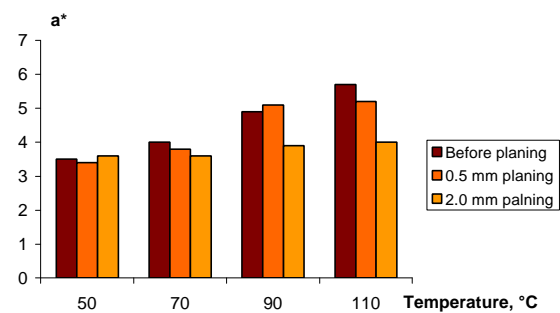FIGURE 4. The effect of drying temperature and planing depth on the average L* value of pine sideboards.

FIGURE 5. The effect of drying temperature and planing depth on the average a* value of pine sideboards.

At low temperatures, the difference in a* value between the surface and inner parts was minor for pine and spruce sideboards. At higher temperatures the difference was 2 units (i.e. visible).

The b* value increased (yellow direction) with drying temperature. The difference between temperature levels still remained after planing. There was a visible difference in yellowness on the surface before and after the first planing at all temperature levels. This difference was slightly higher for spruce than for pine.
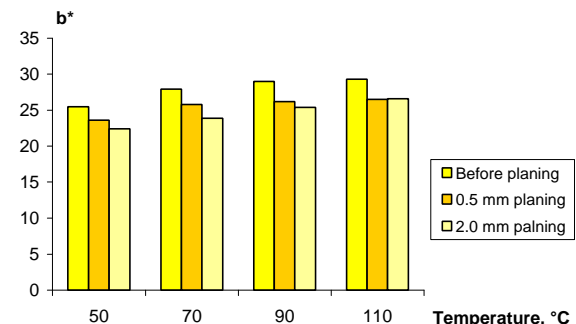

FIGURE 6. The effect of drying temperature and planing depth on the average b* value of pine sideboards.

The changes of L*, a* and b* show that the most important factor for wood appearance is the darkening, i.e. diminishing of the L* value. An increase in a* and b* values has less of an influence. As the surface darkens and higher a* and b* values are obtained it is not easy to visually distinguish the changes in each component of colour changes. In the case of pine and spruce it is normally adequate to measure only the L* value (lightness). In some cases for example, due to a Maillard-reaction, the change in b* can also be very pronounced and easy to see visually. Also, the change in resin content is seen in the a* value despite changes in L* also.

The fertility of the growing site only slightly affected the colour of surface layers. The difference between fertile and poor sites was about one unit after 0.5 and 2.0 mm planing. The b* value was a little higher for both species from a poor site.

Centre yield

The heartwood darkened less than sapwood with increasing temperature, especially on the surface. It is assumed that this difference is due to the enrichment of nutrients in sapwood and chemical reactions in nutrients, which caused darkening of the surface layer (brown staining). In heartwood, there are no nutrients left.

The surface of pine heartwood was redder (higher a* values) than the layer just beneath the surface due to resins. In spruce this difference was smaller. Pine showed a small difference at 0.5 and 2 mm depths but this difference could not be found in spruce. The b* value was, interestingly, slightly higher at higher drying temperatures after 2 mm planing than after 0.5 mm planing.

The discoloured layer in the heartwood is much thinner than in the sapwood. That means that normal planing depth is adequate to remove the discoloration in heartwood. The discoloured layer (brown staining) of sapwood is sometimes too thick to be removed with normal planing. This is especially true at high temperatures.

Vacuum drying

Differences in colour change between vacuum and conventionally dried timber at a temperature of 70 °C could not be distinguished visually. The L* value of vacuum-dried timber was 1–2 units higher than in conventionally dried timber before and after planing in both depths. The difference was slightly higher for pine than for spruce. The differences in a* and b* values were even smaller.

Press drying

In press drying the dimensions of pine boards were 32 x 100 mm^2. After drying at 140 °C the surface appearance was quite similar to boards conventionally dried at 90 and 110 °C. The discoloured layer was thin. After 0.5 mm planing the surface colour was quite similar to the colour of boards conventionally dried at 90 and 110 °C which were planed 2 mm. Further 1.5 mm planing of the press-dried boards resulted in a colour comparable with that of boards conventionally dried at 50 and 70 °C and planed.

Chemical changes related to discoloration

According to preliminary results, the soluble carbohydrates (fructose, glucose, and saccharose) concentrate on the surface of the wood during the drying process. The average amount of sugars in fresh samples of Scots pine was 0.2% of the dry weight and the average amount of sugars after drying was 1.0% (of the dry weight on the wood surface (2 mm in thickness)). Similar results were reported by Terziev (1995). The smallest amounts of carbohydrates were found after drying at 50 °C. The highest sugar content was detected in the samples taken in winter and the lowest in the samples taken from spring felled logs after 6 weeks wet storage. There was however no clear correlation between degree of discoloration and the amount of carbohydrates on the wood surface (Fig. 7).

The amount of acetone-soluble extractives (lipids, sterols and resin acids) did not increase on the wood surface after drying at 70—110 °C. However, the amount of triacylglycerols decreased remarkably after drying. Norway spruce showed similar results. The correlation between discoloration and wood chemistry has not yet been clarified. It seems reasonable to assume that extractives form a complex during the drying process and may react with hemicellulose or other cell wall components.
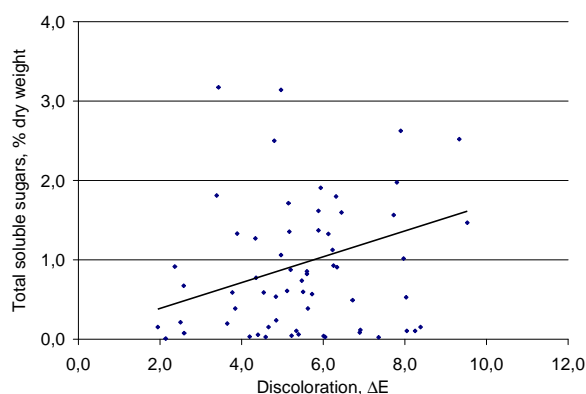
FIGURE 7. The correlation between the amount of soluble carbohydrates on the wood surface and the total colour change of pine boards.

CONCLUSIONS

Drying temperature was the most significant factor causing the discoloration of boards. The colour change of pine was quite similar to that of spruce except that there was a more intense discoloration of pine heartwood compared to that of spruce at 90 °C. Discoloration of sapwood increased remarkably at temperatures above 70 °C. At 90 and 110 °C the lightness (L*) decreased significantly. The a* and b* values increased with increasing drying temperature but it had less of an effect on wood appearance than changes of L*. In most cases it is adequate to note only the lightness but for accurate analysis it is necessary to also take a* and b* into account.

There were no significant differences between fertile and poor sites on colour changes.

Differences in colour change between vacuum and conventionally dried timber at a temperature of 70 °C could not be distinguished visually. The L* value of vacuum-dried timber was only 1–2 units higher than in conventionally dried timber before and after planing. After press drying at 140 °C the surface appearance was quite similar to boards conventionally dried at 90 and 110 °C. The discoloured layer was thin. After 2 mm planing the surface colour was quite similar to the colour of boards conventionally dried at 50 and 70 °C and planed.

The amount of soluble carbohydrates was 5- to 10–fold greater in a 2-mm-thick surface layer after drying than in the fresh samples of sapwood. The highest sugar content was detected in the samples taken in winter and the lowest in the samples taken from spring felled logs after 6 weeks wet storage However, results did not show any clear correlation between extractive content and degree of discoloration.

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