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MEASUREMENT OF COLOUR DEVELOPMENT IN *PINUS RADIATA* SAPWOOD BOARDS DURING DRYING AT VARIOUS SCHEDULES♣

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ABSTRACT

Colour changes, such as kiln brown stain, that develop in *Pinus radiata* boards during kiln drying can reduce the value of the final wood products and result in significant losses due to downgrade or waste of dried wood by removing the darkened surfaces. This study measured how colour developed in *Pinus radiata* sapwood boards under different drying schedules.

The boards used in these experiments were 40x100x800mm, cut from the same log and were end- and edge-matched. Boards were dried at eight different schedules using temperatures from 50°C to 120°C and relative humidities from 14% to 67%. Separate boards were dried for 5 equal intervals through each schedule and colour profiles measured through the boards using a surface reflectance spectrophotometer. Lightness, L*, on a greyscale was used as an indication of colour change (darkening).

The results show that there is generally a greater decrease in lightness with higher temperature schedules and also with slower, higher relative humidity, schedules. This suggests that both temperature and drying time are significant factors in the formation of colour during drying. The most significant changes in colour occurred near the board surfaces, indicating kiln brown stain.

Keywords: drying schedules, kiln brown stain, *Pinus radiata*, wood colour

INTRODUCTION

In kiln drying of softwood timber such as *Pinus radiata* sapwood, wood colour commonly changes, which can reduce the quality of the final product and result in loss of value due to downgrade and waste by removing the darkened surfaces.

The main discolouration affecting the quality of kiln dried *Pinus radiata* is kiln brown stain. This is an irregular brown coloration that occurs 1 to 2 mm near the surface of drying boards and is considerably darker than the surrounding wood. The very surface of the board is not stained and this layer is consistent with the thin dry layer formed in the kiln drying of softwood timber (Pang *et al*., 1994).

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Studies by McDonald *et al* (2000) have shown that kiln brown stain in *Pinus radiata* is most likely caused by a Maillard reaction between sugars and amino acids in the wood sap. Terziev (1995) and Terziev *et al.* (1993) have measured the low molecular weight sugar distribution across the board thickness, in a closely related species, *P. sylvestris* during drying and confirmed that the sugar contents near the board surfaces are higher than the core during and after kiln drying. They also found that the sugar gradients between the surface and the core are much severer with fast-drying schedules.

Studies by Kreber and Haslett (1997) have confirmed the above findings and found that high drying temperatures intensify the formation of the stain. These studies also showed, surprisingly, that low-humidity drying schedules (lower wet-bulb temperature) intensify the stain formation. In these studies, visual inspection was used to determine the level of the stain. More recently Ledig and Seyfarth (2001) have used a spectrophotometer to measure surface colour in European beech and have successfully characterised the wood colour using the CIELab system.

Other studies by Boutelje (1990) observed that the nitrogen content at the board surface is also higher than in the core, while Dieste (2002) found the nitrogen content is strongly correlated to the colour changes at the board surfaces.

The overall objectives of this research were to investigate further the fundamental causes of the kiln brown stain formation and to develop optimised drying schedules to produce light-coloured *Pinus radiata* wood with acceptable drying time. This paper will describe the work on wood-colour measurement and colour changes during drying. The aim of this study was to measure the effect of different drying schedules on the development of colour using a spectrophotometer.

MATERIALS AND METHODS

The wood used in this experiment was cut from a single log (4m long) that was grown on the West Coast of the South Island of New Zealand. The log was selected to be free from compression wood and to have centrally located pith. The sawmill was set to cut 40x100mm flat-sawn boards from the log and the position of each board in the log was recorded during cutting. These boards were subsequently cut into end- and edge-matched 800mm long sample boards, treated with anti-sap stain chemicals and then stored, wrapped in plastic, at 4°C.

Initially boards were dried fully at eight different schedules with the drying conditions shown in Table 1. These drying operations were carried out in a single board drying tunnel with an air speed of 5m/s over the board surfaces. There was a ninth ACT schedule planned but the test failed due to equipment malfunction. The boards used for each dry-bulb temperature series were end-matched. For each schedule a second edge-matched board was cut into four smaller boards that were dried for 20%, 40%, 60% and 80% of the total drying time to determine how moisture and colour profiles develop during drying.

Two 25mm long samples were cut from each board upon drying. The first of these was immediately cut into a 25×25×100mm block and then this block was sliced from surface to centre into 20 approximately 1mm thick slices to determine the moisture-content profile. The second 25mm long sample was vacuum-dried at 40°C for 2 days and then sliced in the same way as described above to determine the colour profile. A Minolta CM-2500d surface reflectance spectrophotometer was used to measure the colour of each slice. The colour was represented using the CIELAB colour space where L* is lightness, a* is red-green share, and b* is blue-yellow share.

RESULTS AND DISCUSSION

The lightness profiles for the boards dried at HT are shown in Fig 1.This graph shows that later in drying there is a significant reduction in lightness near the surface, indicating the formation of kiln brown stain. The overall lightness throughout the boards has also decreased with increased drying time.

The graph in Fig. 2. shows the lightness profiles for a selected ACT schedule. The other ACT schedules show similar trends with the main differences being in the lightness values. Overall, these schedules show trends similar to the HT schedule, though some of them do show some inconsistency, with the partially dried samples being darker than the fully dried samples.

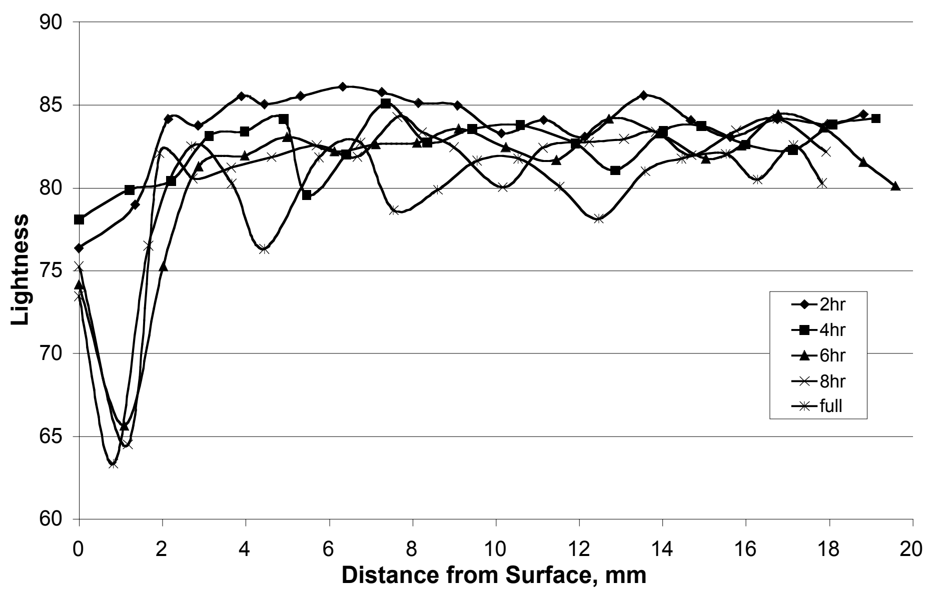

Fig. 1. Lightness profiles (L*) for end- and edge-matched *Pinus radiata* boards dried at HT

The graph in Fig 3. shows the lightness profiles for a selected CT schedule. The lightness changes show considerable variation for these schedules especially at the surface. The same is true for the LT schedule in Fig 4.

The results of the colour development in the eight schedules are summarised in Table 1. To get an indication of the total colour change throughout drying the mean core lightness (slices 4-20) for the first sample (20% drying time) was subtracted from the mean surface lightness (slices 1-3) for the fully dried sample, for each schedule. This was repeated for the values of a* and b* and the quantity ΔE was then calculated from these values, using Equation (1) to give a measure of the total change in colour.

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \qquad (1)$$

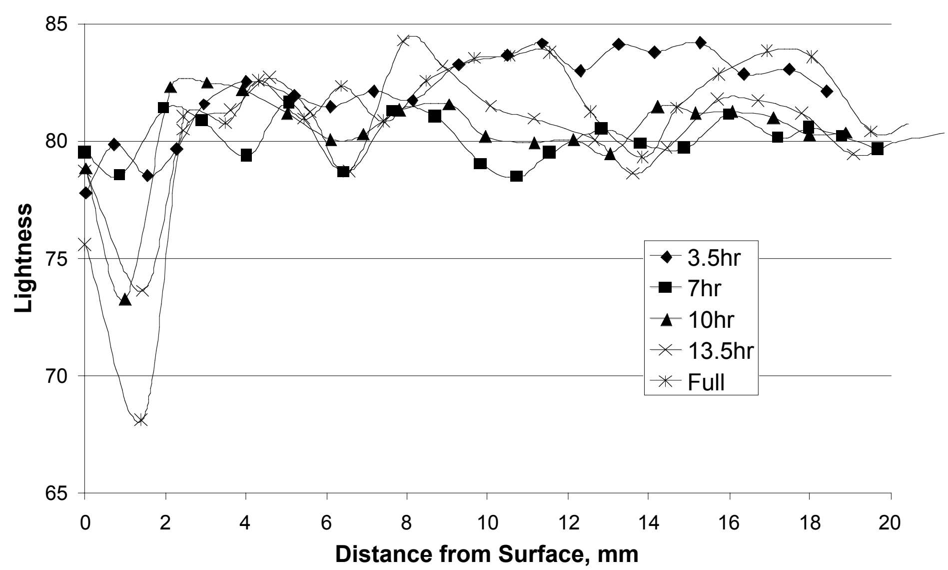

Fig. 2. Lightness profiles (L*) for end- and edge-matched *Pinus radiata* boards dried at ACT-LRH2 schedule.

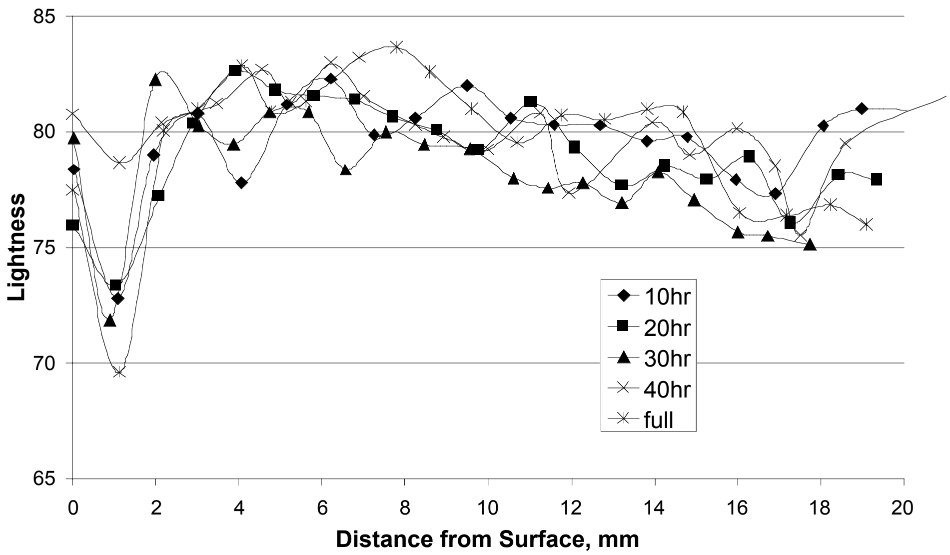

Fig. 3. Lightness profiles (L*) for end- and edge-matched Pinus radiata boards dried at CT-MRH schedule.

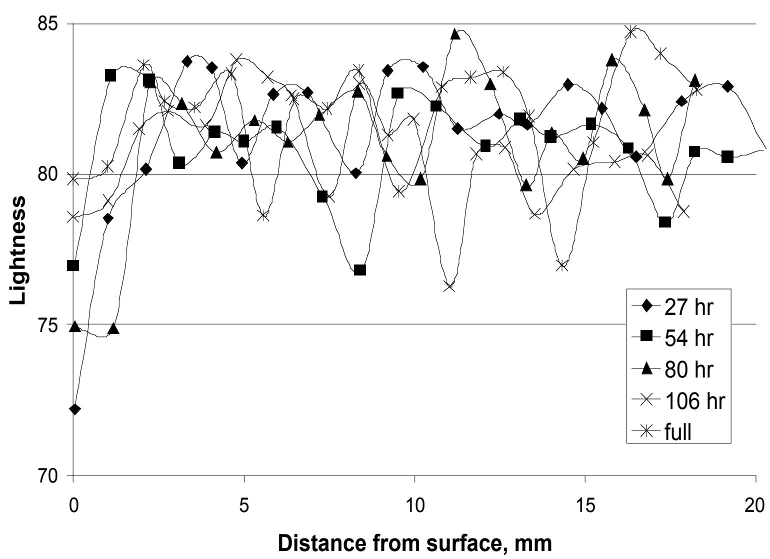

Fig. 4. Lightness profiles (L*) for end- and edge-matched Pinus radiata boards dried at LT schedule.

In general, the results show that in the early stages of drying only the surface (1mm thick) is darkened but the colour difference from the core is less than 10%. In the early stages of drying, liquid moves to and evaporates near the surface, but due to the fast drying rate the wood temperature would be low and the elapsed time is short so the discoloration is not significant. Terziev (1995) found that the concentration of low molecular weight sugars and nitrogen at the surface were increased in the early stage of drying regardless of drying temperatures. This observation can be evidence to show that Maillard reaction is not very active during this stage because the reaction consumes the sugars and nitrogen, reducing their concentration.

In the late stages of drying, the colour changes are more pronounced and this is particularly significant in the second sliced layer (1-2 mm) from the drying surface. This behaviour is consistent with the thin dry layer formed in the kiln drying of sapwood softwood lumber. During drying the liquid flow to the surface is inhibited by the pit aspiration during sawing process. In this way, more liquid will evaporate beneath the thin layer of 0.5 to 1 mm, thus the discoloration precursors concentration will be higher in this region, promoting the Maillard reaction.

Table 1. Drying schedules tested showing the drying conditions and the colour development.

Schedule	Dry Bulb	Wet Bulb	ΔL	Δa*	Δb*	ΔE
HT	120¡C	70°C	-13 (16%)	3 (71%)	5 (23%)	14.7
ACT-HRH	90°C	80°C	-11 (14%)	2 (42%)	7 (32%)	13.6
ACT-MRH	90°C	70°C	-6 (7%)	1 (24%)	6 (29%)	8.8
ACT-LRH2	90°C	50°C	-8 (9%)	1 (20%)	3 (14%)	8.5
CT-HRH	70°C	60°C	-4 (5%)	0	4 (17%)	5.3
CT-MRH	70°C	50°C	-4 (6%)	0	2 (9%)	4.9
CT-LRH	70°C	40°C	-3 (3%)	0	2 (9%)	3.3
LT	50¡C	40°C	-1 (1%)	0	7 (33%)	7.0

Note: In Table 1, HT = High temperature schedule; ACT = Accelerated conventional temperature schedule; CT = Conventional temperature schedule; LT = Low temperature schedule; HRH = High relative humidity; MRH = medium relative humidity; LRH = Low relative humidity.

These experiments have shown that higher drying temperatures produce more darkening of wood colour, which is in agreement with the findings of Kreber and Haslett (1997). The development of this darkening appears to be quite rapid for the HT schedule, but becomes slower and more erratic at lower temperature schedules. This variability may indicate that wood properties have more effect on colour development at lower temperatures than at high temperatures, when the temperature-dependent kinetics is much slower.

These experiments have also shown that there is less darkening and stain formation on drying at low relative humidity. This can be explained as the influence of drying time. The lower relative humidity schedules dry faster and therefore the colour has less time to develop. The temperature at the evaporative front is also lower due to the lower wet bulb temperature. However, this observation is not in agreement with previous studies of Kreber and Haslett (1997).

These experiments have also shown the value of using a spectrophotometer for measuring kiln brown stain in *Pinus radiata*. This has enabled the measurement of magnitude of colour change compared with qualitative measurements by eye and could be an important tool for quality control in the future.

CONCLUSION

The surface colour development in *Pinus radiata* boards increases as the dry bulb temperature of the drying schedule increases. The surface colour development decreases as the wet bulb depression of the schedule increases. The latter effect is mostly due to the shortened drying time but is also influenced by the lower surface temperature during the capillary drying phase.

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NOTA

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