Surface Colour Change in Wood during Drying Above and Below Fibre Saturation Point

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ABSTRACT

A technique has been developed to measure the surface colour change in a single wood sample during drying. This method is useful for studying the development of kiln brown stain. The wood sample is planed carefully in the green state to remove any surface wood that was damaged during cutting. This exposes intact tracheids at the surface rather than the damaged tracheids normally found at the surface of rough-sawn timber.

The intact tracheids cause the evaporative front to remain at the surface during drying and therefore colour formation also occurs right at the surface. This means that the colour can be measured using a spectrophotometer at various stages during drying without having to slice the sample. This reduces errors associated comparing matched or unmatched samples.

Experiments were carried out to measure the change in colour of wood from green to EMC at different schedules. At the end of each schedule the boards were held at the EMC to determine how the colour changed below fibre saturation point. The results show that the colour of the wood continues to change below fibre saturation point and the nature of the colour change indicates an increase in the complexity of the coloured compounds present.

INTRODUCTION

NZ pine, *Pinus radiata* grown in New Zealand, is a very versatile wood. The properties of NZ pine wood, the dominant species grown in NZ, make it suitable to a wide variety of end uses. In two separate studies this wood has been shown to be comparable or superior to Asian (NZFRI, 1999) and North American (Miller *et.al.*, 1996) woods for use in panelling, mouldings, joinery and furniture. This shows that the wood resource in NZ offers a lot of flexibility for product diversity.

NZ pine is generally a light coloured wood, especially when grown in southern regions and is tolerant of many wood stains available. This means it can be stained to look like other species that may be more expensive or in short supply (Dawson *et. al.*, 1996). This makes NZ pine a versatile appearance grade timber as long as the light colour is maintained during processing.

One process where the colour of wood changes is in kiln drying. This colour change can be in the form of an overall change in colour or the formation of kiln brown stain (McCurdy *et. al.*, 2003).

Kiln brown stain has the greater effect on quality for high value appearance products. This is an irregular brown colouration that occurs 1 to 2 mm near the surface of drying boards that is considerably darker than the surrounding wood. This layer is consistent with the thin dry layer formed in the kiln drying of softwood lumber (Pang *et al*., 1994).

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 as it is concentrated at the wood surface during drying.

Various methods have been developed to measure kiln brown stain formation in samples of wood during drying. Studies by Kreber and Haslett (1997) used visual inspection to determine the level of stain. Dawson *et. al.* (2003) used a colorimeter to measure the colour of 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. Photographic techniques (McCurdy et.al., 2001; Dieste, 2002) and microscopic techniques (McCurdy et.al.,

2005) have also been developed that combine digital photography with computer image analysis.

The major difficulty encountered when measuring kiln brown stain is that the most significant stain formation occurs about 1mm below the surface of the timber. This means that any measurement of the surface may not measure the full extent of the stain formed. Also if the surface is removed to reveal the stain it is a destructive test so cannot be performed at intervals during drying. This paper describes a technique developed to overcome this problem and some results from initial experiments.

EXPERIMENTAL

The colour measurement technique described in this paper is applied to samples while they are being dried. The samples used were cut from green *Pinus radiata* boards to a size of 25×25×100mm. The ends and two of the sides of the samples were sealed with paint so that only the tangential faces were available for evaporation of moisture. Prior to further preparation before drying the samples were stored in a freezer.

The surfaces of the samples were prepared green by carefully smoothing them with a hand plane. The key in this step was to remove the damaged layer from the surface of the wood gently so that there are intact tracheids near the surface. Preparing the surface while it is still saturated with water made this process easier. The advantage of planing the is that the blade slices through the wood rather than

The surface to be measured was marked with sample areas before drying commenced so that the parts of the surface measured were consistent throughout the process. This was done by marking each point with a circle slightly larger than the aperture of the spectrophotometer. A pencil was used for this marking as the graphite does not dissolve or melt in the drying conditions. In these experiments four measurement points were used for each sample.

The measurement of the surface colour during drying was performed by removing the sample from the dryer, recording the time and weight. The colour of each of the measurement points is then determined using a surface reflectance spectrophotometer. The surface reflectance spectrophotometer used in this project is a Minolta CM-2500d portable integrating sphere spectrophotometer. This instrument uses two pulsed xenon lamps as a light source, a diffraction grating for spectral separation and a silicon photodiode array as the light-receiving element. This array is a dual 40-element device that can measure at 10nm intervals over the range from 400nm to 700nm.

In addition a photograph was also taken of the surface each time the colour was measured for qualitative analysis of the colour development. The entire measurement process only took a few minutes, so the cooling and drying outside of the drying apparatus was kept to a minimum.

The results presented in this paper are from three drying runs performed to test the technique and determine if colour development changes below fibre saturation point. In each of these drying runs the samples were brought to a set moisture content using one set of drying conditions and then held at that moisture content with another set of conditions for 36-48h. The conditions used for each run are shown in Table 1 below.

Table 1. Drying and holding conditions used in the three experiments. The last column shows the intended EMC at the holding conditions.

Run	**Drying Conditions (°C)**	**Holding Conditions (°C)**	**Target EMC (kg/kg)**
1	50/40	50/48	0.2
2	70/60	70/69	0.2
3	50/40	70/69	0.2

RESULTS

The spectrophotometer measurements produced a spectrum for each area measured at each time interval as well as the colour expressed using the CIELab colour coordinates L*, a* and b*. The colour coordinates were converted into ΔE values, which represent the overall change in colour, using the following equation:

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

The point of greatest lightness was chosen as the datum from which the change in colour was calculated. This point occurred within a few hours of drying when the surfaces of the samples had dried out but discolouration had not begun. The ΔE values calculated for each run have been plotted in Figure 1 to Figure 3, with the moisture content also plotted on these graphs.

The results for the first run (Figure 1) show that the colour change drops sharply at the beginning of drying, as the surface loses moisture dues to the wood colour getting lighter. After reaching peak lightness at about 5h into the schedule the surface colour of the sample darkens in an approximately linear fashion. There appears to be a slight change in the slope at 72h when the schedule was changed to hold the moisture content.

The results for the second run (Figure 2) show a similar sharp increase in lightness at the beginning of drying. The development of colour beyond this point is clearly not linear and has the appearance of tending toward an asymptotic value. At 48h when the schedule was changed to hold the moisture content the rate of colour development seems to decrease even more.

The results for the third run (Figure 3) also show a sharp increase in lightness when the surface is drying. This is followed by a slow increase in colour, up to the point where the schedule is changed. At this point the rate of colour development increases sharply and then gradually decreases as the colour appears to tend toward and asymptotic value similar to the second run.

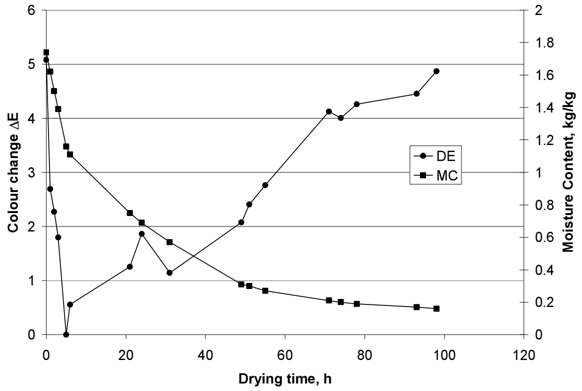

Figure 1. Results for Run 1 showing the change in colour and moisture content as a function of time.

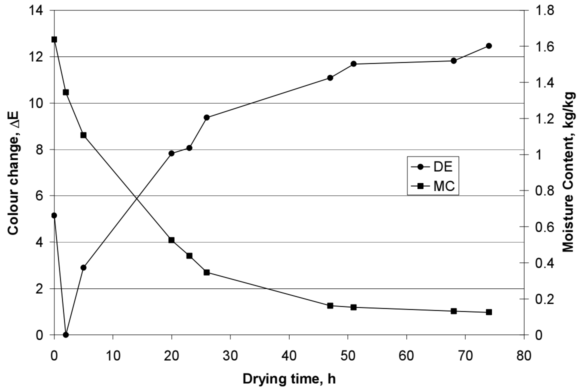

Figure 2. Results for Run 2 showing the change in colour and moisture content as a function of time.

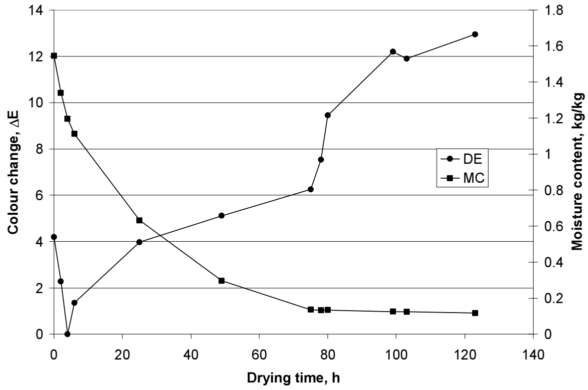

Figure 3. Results for Run 3 showing the change in colour and moisture content as a function of time.

The subtraction spectra for the third run are plotted in Figure 4. These spectra were obtained by subtracting the spectra for each time after 4h from the 4h spectrum. This means that the higher the value on the y-axis the greater the absorbance of light at that wavelength. The spectra show that as drying progresses there is an overall increase in light absorption across all wavelengths. As drying progresses there is also a shift in the wavelength of peak light absorption towards higher wavelengths.

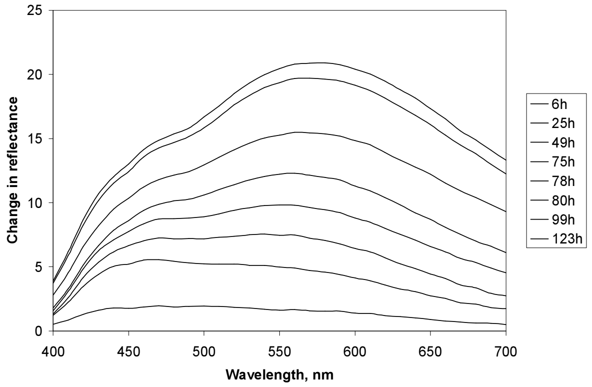

Figure 4. Subtraction spectra for the third run. The spectra have been subtracted from the spectrum at 4h, the point of greatest lightness.

DISCUSSION AND CONCLUSIONS

The smoothing of the surfaces of green wood samples with a plane has caused the kiln brown stain to form closer to the surface where it has been successfully measured using a reflectance spectrophotometer.

In normal rough-sawn timber the evaporative front recedes through the layer of damaged tracheids at the surface early in drying forming what is known as the thin dry layer (McCurdy and Keey, 2002). This means that most colour development occurs a 1 to 2mm below the surface and is not always apparent on the surface. The process of removing the damaged layer means that the evaporative front stays at the surface and the formation of colour is more obvious and can be measured non-destructively during the drying process.

The results from the first and second drying runs initially seem to suggest that there is a reduction in the rate of colour development as moisture content decreases. The results from the third run however show that the higher rate of colour development caused by the increase in temperature from the drying schedule to the holding schedule is not affected by the moisture content. This means that there must be another explanation for the change in rate of colour development.

The change in slope for the first run is not as clear as it is for the second run and may just be a result of experimental error. There is clearly some error involved in the data for this run as the surface colour appears to lighten at some points which is highly unlikely. If it is assumed that the slope is essentially linear for this run then there is an alternative explanation for the results.

The alternative explanation is that there is a maximum possible colour development caused by initial reaction of sap compounds based on the concentration of these compounds in the board before drying. Once these compounds have reacted, further reactions become more complex and proceed at a slower rate. The early stages of the Maillard reaction are reasonably well understood, but beyond the first (Amadori) products there are a large number of possible reactions (Fayle and Gerrard, 2002a), so it is difficult to imagine the actual structure of the coloured compounds produced.

The shift towards more complex reactions is supported by the shift to higher wavelengths in the subtraction spectra. The colour exhibited by the Maillard reaction products is most likely caused by a combination of extended polyene structures attached to electron-donor and –acceptor groups as is the case with most organic colorants (Nassau, 2001). The addition of more conjugated double bonds or donor-acceptor groups will cause the reaction products to absorb longer wavelengths. Studies of the Maillard reaction have shown that complex products containing cyclic polyenes and donor-acceptor groups are produced (Fayle and Gerrard, 2002b).

This technique for measuring the development of colour in wood during drying shows potential to be a useful research tool and results from initial experiments show that further research is warranted and should yield useful and interesting results. In particular the formation of kiln brown stain below fibre saturation point is significant for the design of schedules to combat the formation of such discolouration.

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