PEG PENETRATION AND THE EFFECTS OF PEG PRETREATMENT IN AIR-DRIED *EUCALYPTUS REGNANS*

John Ralph†

Research Scientist, Timber Resources
School of Human Life Sciences
University of Tasmania
Locked Bag 1320
Launceston, 7248
Tasmania, Australia

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ABSTRACT

E. regnans, a species of Eucalypt marketed as Tasmanian oak, was incubated in PEG 400 (30% v/v) before investigating the nature of PEG migration into the timber and moisture loss in air-drying backsawn (aka flatsawn) timber. PEG penetration was quantified, and further migration into the timber during the course of drying (120 days) was negligible. In a second investigation, samples of *E. regnans* were incubated in either PEG (30% v/v) or a saturated sodium-dodecyl sulphate (SDS) solution. Moisture content loss was monitored to determine if a chemical pretreatment can affect the rate of moisture loss during air-drying of backsawn *E. regnans*. Compared with a control, the chemically treated samples dried more slowly under harsh environmental conditions. However, the appearance of the samples treated with SDS was poor, even compared to the degraded and untreated control samples. These results suggest that to arrest permanent defects in drying *E. regnans* may require more than just a retardation of moisture loss.

Keywords: Eucalypt, backsawn, polyethylene glycol, PEG, moisture loss.

INTRODUCTION

An investigation into the penetration of polyethylene glycol (PEG) showed that rate of PEG penetration in Tasmanian oak (*E. delegatensis*, *E. obliqua*, and *E. regnans*) was indicated by the basic density of the timber (Ralph and Edwards 2004). The current research seeks to expand the small pool of knowledge that currently exists on the matter of PEG pretreatment of Tasmanian oak. PEG is known to penetrate readily many species of timber including Tasmanian oak; however the mechanism of absorption and binding within Tasmanian oak remain unclear. The establishment of a counter-current mechanism operating between in-flowing PEG and out-flowing sap has been in existence for some time (Loughborough 1948) and suggests that both currents are required to allow PEG to penetrate into timber.

In the past, PEG pretreatment has been promoted as a means to reduce the onset of permanent drying defect in air-dried and kiln-dried timber. Stamm (1956), Mitchell and Wahlgren (1959), Mackay (1972), and Alma et al. (1996) all indicated measurable decreases in surface and internal check formation with timber pretreated with PEG. Of these workers, only Mackay (1972) showed benefits in a species of Tasmanian oak (*E. obliqua*). The use of PEG in reducing drying defect has found favor in the more contemporary treatment of timber of archaeological significance and prevents the degradation that occurs due to drying (Young and Wainwright 1981; Hoffmann 1984). Given the fragile nature of archaeological timber, and the benefits given by PEG pretreatment, PEG pretreatment may confer these properties to air-dried Tasmanian oak.

This paper also examines PEG as a potential retardant of moisture loss from Tasmanian oak during drying, focusing on the use of PEG. PEG ($HO\text{-}[CH_2CH_2O]_n\text{-}H$) is a water-soluble, non-

† Member of SWST.

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ionic surfactant that binds avidly to cellulose primarily through bonding between the terminal hydroxy groups and the net negative charge on the chain oxygens in the repeating ether units. Sodium dodecyl sulphate (SDS; CH_3-$(CH_2)_{11}$-O-$SO_3^-Na^+$) is an anionic surfactant which, owing to a long aliphatic chain, is significantly hydrophobic. SDS has a solubility of 10g/100g water owing to the ionized terminal group. Although SDS has a low affinity for water, this compound was chosen because it might also retard the loss of water from wood by establishing a predominantly hydrophobic barrier at the wood/air interface.

METHOD

Sample preparation

Fifteen flatsawn boards of *E. regnans* (25 mm × 35 mm × 300 mm) were obtained as described previously (Ralph and Edwards 2004). The samples were rough-sawn and were not subjected to any planing technique prior to use. The samples were end-sealed with araldite and placed in a solution of 30% (v/v) PEG-400 (Union Carbide Corp. experiment 1 and 2) or saturated SDS (Sigma Corp. experiment 2 only). Initial moisture content of green, untreated timber samples was 102.7% (±1.6%) in experiment 1 and 106.7% (±1.2%) in experiment 2. In both experiments, samples were removed from solution and allowed to dry in an air-conditioned room with a relative humidity ranging between 45% and 55% and a variable room temperature. Samples were arranged in a charge of three laps of five samples and the laps separated with glass rods.

Moisture content sampling

Experiment 1.—At T(days) = 0, 30, 60, 90, and 120, three samples were removed from the timber charge and were replaced with dummy boards of equal dimension (25 mm × 35 mm × 300 mm).

Determination of PEG penetration

Three slices were taken from each sample in the manner previously described (Ralph and Edwards 2004) using a manual slicer, and PEG penetration was visualized using the cobalt thiocyanate method described by Young and Wainwright 1981.

Depth of PEG 400 penetration was measured using digital vernier callipers (accurate to two decimal places of a mm) from the edge of the sample to the cessation of the blue (stain) color at four evenly spaced points along the four sides of each sample slice. Therefore, for any one sample, incubated for any one length of time, temperature and molecular weight, 48 data points (4 measurements × 4 sides × 3 slices) were taken. It was shown previously (Ralph and Edwards 2004) that this sample size yields data with an appropriate level of statistical confidence.

Experiment 2.—At T(hours) = −96, 0, 18, 36, 54, 168, 264, 384, 528, 720, 1200 sample slices were obtained from each board in the charge. The charge was dismantled, slices were taken, and the charge was immediately reassembled with all samples in their original position.

Obtaining slice sections and moisture content determination

This method is labor-intensive and conducted best with two people. Each sample had the sealed transverse face of the non-numbered end removed with a bandsaw to a longitudinal depth of 15 mm. The sample slice was then cut at a depth of 2 mm and immediately wrapped in copious clear plastic wrap. The cut sample ends were immediately resealed and the samples returned to their position in the charge. Processing of sample slices began immediately.

To investigate moisture content loss without the potential for confounding by the presence of the chemical, the case of each slice was removed with a mallet and chisel, leaving the untreated core of the slice to be measured for moisture content. The core slices were weighed, oven-dried (103°C ± 2) for 24 h, and then reweighed to determine the percentage of moisture lost during oven-drying, and hence the percentage mois-

ture content when at the time the sample was taken.

RESULTS

After 96 h of soaking *E. regnans* in 30% (v/v) PEG-400 (T = –4 to T = 0), penetration was 3.14 mm ± 0.36 (SEM—Standard Error of the Mean; Fig. 1). This result agrees with the PEG penetration data found for this species under the same incubation conditions in earlier investigations (Ralph and Edwards 2004). During drying, the rate of penetration was at a maximum in the first 60 days, and maximal penetration (4.61 mm ± 0.41) was reached by 90 days. Linear regression of PEG penetration during air-drying excluded T = –4 and T = 120, resulting in the linear expression $Y = 0.017x + 3.139$, $R^2 = 0.9617$. From T = 0 to T = 90, for every day of the drying trial, there was on average (radially and tangentially), an increase in penetration of 0.017 mm.

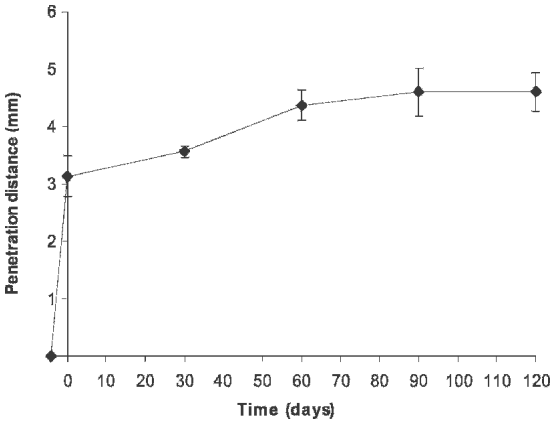

FIG. 1. Penetration (mm ± Standard Error of the Mean; SEM) of 30% PEG-400 (v/v) in air-dried *E. regnans*. Time (days) from –4 to 0 is the incubation period. Each point represents the mean distance penetrated (±SEM) of 48 measurements from 3 samples of *E. regnans*.

The massive decline in absorption of PEG after drying commenced suggests that previous penetration was greatly aided by the incubation conditions. The incubation conditions provided concentration gradients outside and within the wood cell matrix that would have been adequately supplied with PEG. Furthermore, as the solution was 70% water, there was little chance that PEG infusion would have 'out-stripped' the outwardly directed water concentration gradient inside the timber samples.

For PEG inside the wood cell matrix, the concentration gradient would have been unchanged, but the inward PEG-gradient would have been lessened as the only PEG available to form the gradient in the drying timber was already in contact with the wood.

When the samples were removed from the solution and left to dry in conditions that would be regarded as very harsh for drying flatsawn eucalypt timber (45 to 55% RH), the rate at which water was being drawn from the timber down its concentration gradient would have accelerated. This not only increased the rate of movement down the moisture gradient, but did so in an environment where water was not being replaced by an aqueous solution of PEG. The rapidity of the movement of water may also have provided a physical barrier that opposed the movement of PEG into the timber. However, the investigations in this study only permit speculation on this point.

ANOVA showed there was a significant difference ($P < 0.05$) in the loss of moisture from *E. regnans* in treated and untreated samples from T = 384 to T = 720. Although there was a statistically significant difference in MC% at T = 1200, this was due principally to a low standard deviation and is of no practical significance.

Linear regression analysis revealed strongly linear rates of moisture loss in each timber charge from T = 168 to T = 528, (denoted by high R^2 values, Table 1). The differing rates of loss for each treatment type underscore the differences highlighted by ANOVA.

TABLE 1. *Rate of moisture loss in all samples treatments from T = 168 to T = 528.*

Treatment	Moisture loss (%MC/hour)	R^2
Untreated control	0.171	0.997
SDS (saturated)	0.130	0.980
PEG 400 (30% v/v)	0.101	0.997

Difference between chemical treatments

The structure of the chemicals used should be considered to provide part of the explanation of the difference in the observed values for each treatment type compared to the untreated control. PEG penetrated the timber surface to a layer depth that was consistent with previous findings. It was apparent visually that SDS was not readily taken up into the timber and showed very little (estimated less than 1 mm) penetration beyond the surface.

Due to the milling process, the outermost surfaces of the timber board consist of greatly disrupted structures and compromised cell walls. Consequently, it is not unexpected that a chemical structure, even of substantial hydrophobicity, could penetrate these compromised cell layers. However, deeper into the timber, the cell structure is whole and only chemicals that can bind with the cell wall might easily be transported into the vessels and would be expected to migrate further. In addition, SDS migration and binding to cellulose would be greatly impeded by the aliphatic chain and low strength of attachment between either the terminal sodium or net negative charge on the oxygen atom in the terminal group.

Figure 2 illustrates that the rate of moisture loss from treated samples was less than from the control samples during the period where there is a decrease from about 100% MC down to FSP (≈25% MC). It is during this phase that timber is susceptible to cellular collapse and change in shape owing to moisture loss. However, the greater control of moisture loss was not necessarily coupled with an increased visual quality of the timber.

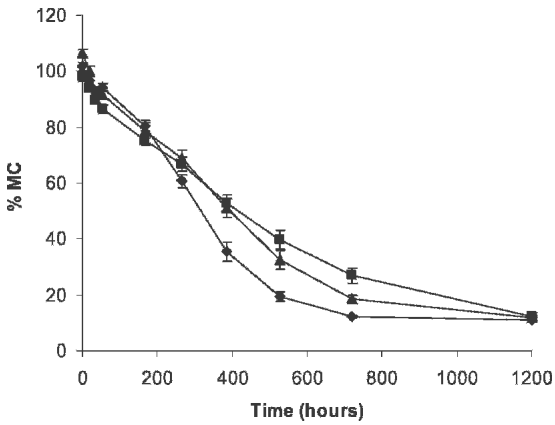

FIG. 2. Average moisture content (% MC) loss from *E. regnans* treated with PEG 400 (30% v/v, ■), saturated SDS solution (▲) or untreated control (♦). Each point represents the mean % MC loss (±SEM) of 15 sample means (a mean of three results for each of 15 samples) of *E. regnans*.

Over the latter part of the drying period, and as the timber approached FSP (about 25% MC for *E. regnans*), the moisture loss from the core of PEG-treated samples was almost linear and occurred at a lower rate (Table 1). During this period, the PEG-treated samples showed the greatest retardation of moisture loss. PEG-treated samples also demonstrated less drying defect and less departure from original dimension. These observations will be the subject of further investigations including quantitative assessment of shrinkage, swelling, and drying defect.

Most samples incubated in a saturated SDS solution warped markedly. In most cases, the visual condition of the SDS-treated samples was poorer than those of the untreated control. SDS-treated samples frequently showed evidence of surface check, splitting, and warping. Although likely to be significant, these observations on drying defect are somewhat cursory and qualitative in the current investigation, but warrant further critical and quantitative evaluation.

CONCLUSIONS

The net increase in average post-incubation PEG penetration in *E. regnans* is negligible. However, this lack of post-incubation migration of PEG into the timber may be considered as a benefit. Although Stamm (1959) indicated that PEG-treated timber can be satisfactorily finished or glued, for the commercial drying of Tasmanian oak, a preferred chemical treatment may be one that allows timber to be presented to the market as 'chemical free.'

Consequently, an ideal situation may be the use of a chemical whose rate and depth of penetration can be predicted before the timber is

immersed in a solution and where the penetration is essentially limited to the incubation period. This may allow the preparation of a leaching process for a calculated depth of PEG penetration in the case of undressed timber or planing to a calculated depth in the case of dressed timber. In both cases, using PEG to assist in the drying of Tasmanian oak, then preparing a chemical-free end product is feasible.

The results have shown that two chemical preparations, (PEG 400 (30% v/v) and saturated SDS) can decrease the rate of moisture loss from *E. regnans* under air-drying conditions that would be considered severe by standard methods. However, there were vastly different effects on dimensional stability with PEG-treated samples retaining a greater proportion of their original dimension at the end of the drying trial. PEG penetrated into the timber to a depth consistent with previous trials, whereas SDS did not show any appreciable penetration to any depth. The findings of this investigation suggest that the ability to control the rate of MC loss from timber is not necessarily concomitant with dimensional stability. The veracity of this statement will be the cause and at the center of future research.

It could be suggested that the presence of PEG within the wood matrix could have had some stabilizing effect on the timber, which was partly independent to the effect that PEG has on moisture loss. Greater attention and quantitative assessment will be given to these aspects in later investigations.

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