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The Effect of Moisture Content and Wood Density on the Preservative Uptake of Caucasian fir (*Abies nordmanniana* (Link.) Spach.) Treated with CCA

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Abstract: The effect of moisture content and wood density on the preservative uptake (on the basis of the percentage of void volume filled (VVF%)) of Caucasian fir (*Abies nordmanniana* (Link.) Spach.) was studied in various levels of moisture content (MC). VVF% was measured in 11 MC regimes (7 of which were designed to be below the fibre saturation point (FSP)) consequtively nominated using a conventional kiln. All the samples were treated with CCA-tanalith C via a mild schedule of full-cell impregnation. A significant correspondence between MC and both wood density and VVF% was established and an attempt was thus made to correlate VVF% with porosity (the fractional void volume) at respective moisture contents. The significance of these changes was discussed in relation to the FSP, the activity of which was barely detectable. MC values above the FSP stimulate and decrease the retention of preservative in the wood voids, whereas MC values below the FSP influence the preservative uptake due to the effect of the voids available in wood. It was found that there were significant differences in VVF% between the regimes of MC above the FSP, whereas there was quite a different trend at MC values just below the FSP. In this range, there were no differences in VVF% (figures in parentheses) between the levels of MC at 10% (61.6) and 20% (60.3) but there was a significant difference between 22% (59.4) and 28% (56.7). These observations suggest that MC at 22% (close to 20%) could be highlighted as the exact value for Caucasian fir, and hence it may be best to preferentially kiln dry this species to a target moisture content of 22%.

Key Words: Moisture content, Wood density, Preservative uptake, Full-cell process, CCA, Caucasian fir, Abies spp.

Rutubet Miktarının ve Ağaç Malzeme Özgül Ağırlığının CCA ile Emprenye Edilen Doğu Karadeniz Göknarında (*Abies nordmanniana* (Link.) Spach.) Sıvı İçerilme Miktarına Etkisi

Özet: Ağaç malzeme hücre boşluklarının koruyucu sıvıyla içerilmesi yüzdesi (KSİ%), farklı rutubet miktarları bağlamında değişen özgül ağırlık ve porozite (boşluk hacmi) çerçevesinde Doğu Karadeniz göknarı (*Abies nordmanniana* (Link.) Spach.) türünde incelendi. Koruyucu sıvı içerilme miktarı (KSİ% değeri), -yedisi lif doygunluğu noktası (LDN) altında olmak üzere- kurutma fırını ile oluşturulan toplam onbir farklı rutubet miktarına göre ayrı ayrı belirlendi. Bu belirlemede, tüm denekler, vakum/basınç değerleri düşürülmüş test yönergesi dahilinde bakır-krom-arsenik (CCA) grubundan tanalith-C ile dolu hücre yöntemine göre emprenye edildi. Rutubet miktarı (RM) ile özgül ağırlık ve KSİ% arasında istatistiksel olarak önemli düzeyde bir ilişki bulunduğu için, KSİ% ile hücre boşluğu hacmi (porozite) etkileşimi, farklı rutubet miktarı değerlerine göre incelendi. Söz konusu bu ilişki, etkisel niceliği güçlükle belirlenen LDN bağlamında değerlendirildiğinde, LDN üzerindeki rutubet miktarının hücre boşluklarındaki koruyucu sıvı düzeyini azaltan, buna karşılık LDN altında ise yükselten bir özellikte olduğu görüldü. Bu bağlamda, RM değerlerinde ortaya çıkan KSİ% düzeyleri arasındaki farklılığın LDN üzerinde oldukça büyük, LDN altında ise küçük olduğu belirlendi. Buna göre, % 10 ve % 20 RM değerlerinde oluşan KSİ% düzeyleri (% 61,6 ve % 60,3) arasında oluşan farklılığın istatistiksel olarak önemli olmadığı, ancak % 22 ve % 28 RM arasında oluşan KSİ% düzeyleri (% 59,4 ve % 56,7) arasındaki farklılığın önemli olduğu bulundu. Elde edilen bu bulgular, -optimal absorpsiyon açısından- % 22 RM değerinin Doğu Karadeniz göknarında emprenye işlemi öncesi oluşturulması gerekli ideal rutubet miktarı olduğunu gösterdiği için, bu türün % 22 rutubet miktarına kadar fırında kurutulmasının özellikle hedeflenmesi önerildi.

Anahtar Sözcükler: Rutubet miktarı, Özgül ağırlık, Koruyucu sıvı içerilme miktarı, Dolu hücre yöntemi, CCA, Doğu Karadeniz göknarı, Göknar türleri.

Introduction

Like most timbers, Caucasian fir (*Abies nordmanniana* (Link.) Spach.), if used correctly and not exposed to biological or chemical hazards, will maintain its integrity beyond the planned lifetime of almost any structure. Deterioration of wood due simply due to age is almost negligible, and buildings (e.g., Norwegian stave kirks) of *Pinus sylvetsris* are serviceable after some 800 years and

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of *Chamaecyparis obtusa* and *Cryptomeria japonica* after some 1200 years (e.g., Buddhist temples, Nara, Japan). In this respect, it is unfortunate that Caucasian fir is non-durable (i.e. average life of 50 x 50 mm stakes in ground contact is 5 to 10 years) and is one of the refractory species of which either the sapwood or heartwood is difficult to treat with preservative solutions by pressure impregnation, or in other words is resistant (EN 350, 1994 part 2). It should be assumed therefore that in situations in which biological or chemical hazards exist, treatment with an appropriate preservative is essential for both sapwood and heartwood (Baines and Saur, 1985). Siau (1970) has confirmed that with refractory species it is often very difficult to obtain more than about 3-6 mm lateral penetration in sapwood, which is known to be several times more permeable than heartwood. This is especially the case with natural rounds (piles, poles and posts), where a deep envelope of well-treated wood is essential (Petty, 1970), and also with the sawn wood complete sapwood penetration is not always obtained using the full-cell process (i.e. structural use in buildings) (Siau and Shaw, 1971).

The difficulty of obtaining satisfactory treatment of refractory species of wood is a problem facing the timber preservation industry. Most studies, therefore, were carried out to identify and understand the factors dictating the permeability of wood species, and to look for novel preservation techniques and/or chemicals by a much deeper penetration and uniform distribution in the treated wood to achieve better performance (Keith and Chauret, 1988). The amount of moisture in wood has a profound influence on the quality of preservative treatments (Bamber and Burley, 1983). In this concept, the need to dry before treatment is well known, but there is little information on optimum moisture levels for individual wood species. Eaton and Hale (1993) have shown that when wood is treated by diffusion or by sap displacement a high wood moisture content (MC) is desirable. However, when wood is treated by other bulk flow processes, any free water occupying wood void spaces (i.e. at MCs above the fibre saturation point (FSP)) reduces the volume available for air to be compressed within the wood. This also reduces the space for preservatives to be forced in and increases the pressures necessary to force air bubbles through minute pit pores. Recommendations are therefore made that wood is air seasoned or kiln dried to an MC value at or just below the FSP. The exact MC value varies from country to country but in the UK it is specified (Hall and Barnet, 1990) that wood to be treated with water-borne preservatives is dried to 28% MC or less, although certain UK specifications with organic solvent-based preservatives state 25% MC or less (BWPA, 1986). The effect of MC on preservative uptake has also been studied extensively by Kumar and Morrell (1989) for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.); treatment at 18% MC provided better penetration than treatment at 28% MC, but there was no further advantage in drying to 9% MC.

Although many studies have been carried out on the exact MC value in most refractory softwood species worldwide, the precise nature and sequence of the Turkish species before the process of preservative treatment are still not well known. Caucasian fir (*Abies nordmanniana* (Link.) Spach.) is one of these. It can be used in indoor work (such as architectural or decorational material as exposed beams or in furniture/joinery) because it is easy to work with and aesthetically pleasant due to its soft and light structure. This species can also be used outdoor as fence posts or sawn products after being well treated with preservative chemicals. It was, therefore, the purpose of the present study to show the exact value of moisture (in Caucasian fir) before the full-cell preservative treatment, which in turn influences the quality of treated wood in use. Other physical properties of Caucasian fir, including oven-dry density, volumetric shrinkage and swelling, FSP, and the maximum theoretical moisture content were determined.

Materials and Methods

A freshly cut log of Caucasian fir (*Abies nordmanniana* (Link.) Spach.) about 120 cm long, obtained with the bark intact, was selected for this study. As previously described by Banks (1970), a section of 40 cm in the stem direction was taken from the centre of the cut log as soon after the felling of the tree as possible. The remainder of the log was discarded so that no part-dried material was included. This short log (40 cm in longitudinal length) was then converted according to TS 2470 (1976), as shown diagrammatically in Figure 1. Eight stakes (which were selected from around the outer sapwood zone on the transverse surface) were cut in cross-sections of 2 x 2 cm. Thereafter, each stake was marked along its length for 24 blocks, 2 of which were

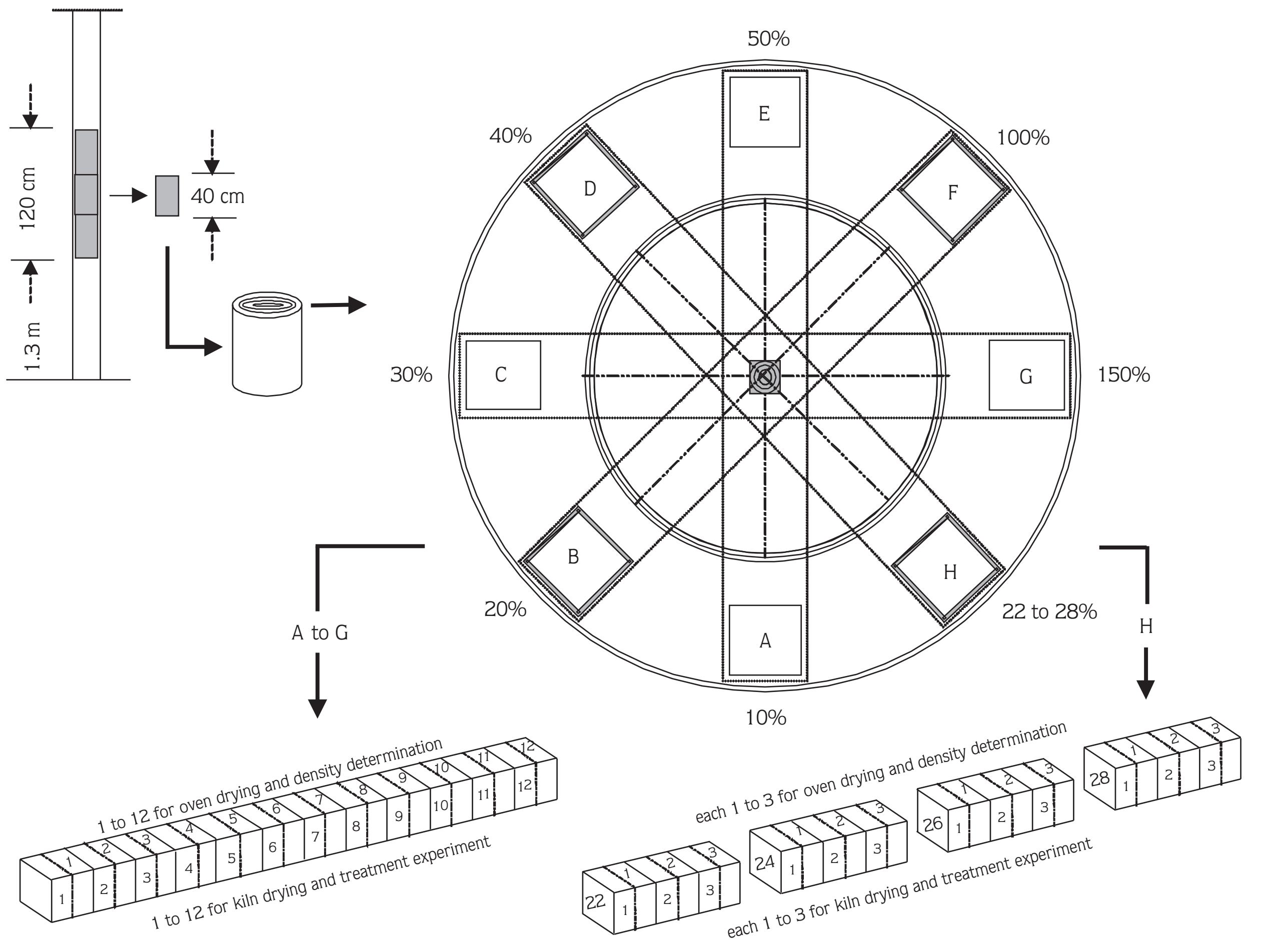

Figure 1. A diagram showing the collection and preparation of the experimental samples (not to scale).

twin-labelled from 1 to 12, except for stake H, which was subdivided into 4 experimental groups and the samples in each group were twin-labelled from 1 to 3. In this format, each pair was assumed to be representative for the considered properties of one another. Each sample along the stakes was then cut to 1 cm in longitudinal length, and the pairs were separated into 2 categories: 1) *a*- for determination of volumetric shrinkage (%), *b*- for oven-dry density (g cm^{-3}) and wood porosity (%), *c*- FSP (%), *d*- for the amount of maximum possible MC (%), and *e*- for observation of the preliminary data for the kiln drying process of the rest of the pairs that were selected for the treatment study; and 2) for determination of the treatment characteristics of trial species at various MC levels. In this manner, data assembly and experimental processing are shown in Figure 2, which was designed according to the information and descriptions presented separately elsewhere (Olesen, 1971; BRED 201, 1977; TS 4085, 1983; TS 4086, 1983; Johansson and Edberg, 1987; Tsoumis, 1991). Figure 2 was created in this study as a novel guide to assist wood scientists to determine all the required physical properties of wood sequentially, including its kiln drying and preservative treatment processes.

As the existing amount of moisture in wood can be reduced to any desired value by kiln drying, a mild drying schedule (schedule K: 70 °C dry bulb, 60 °C wet bulb) was chosen for this study in accordance with the recommended kiln drying schedule for the species of *abies* (Pratt, 1974) to minimize any drying degrade (Smith, 1986). The experimental samples were dried to

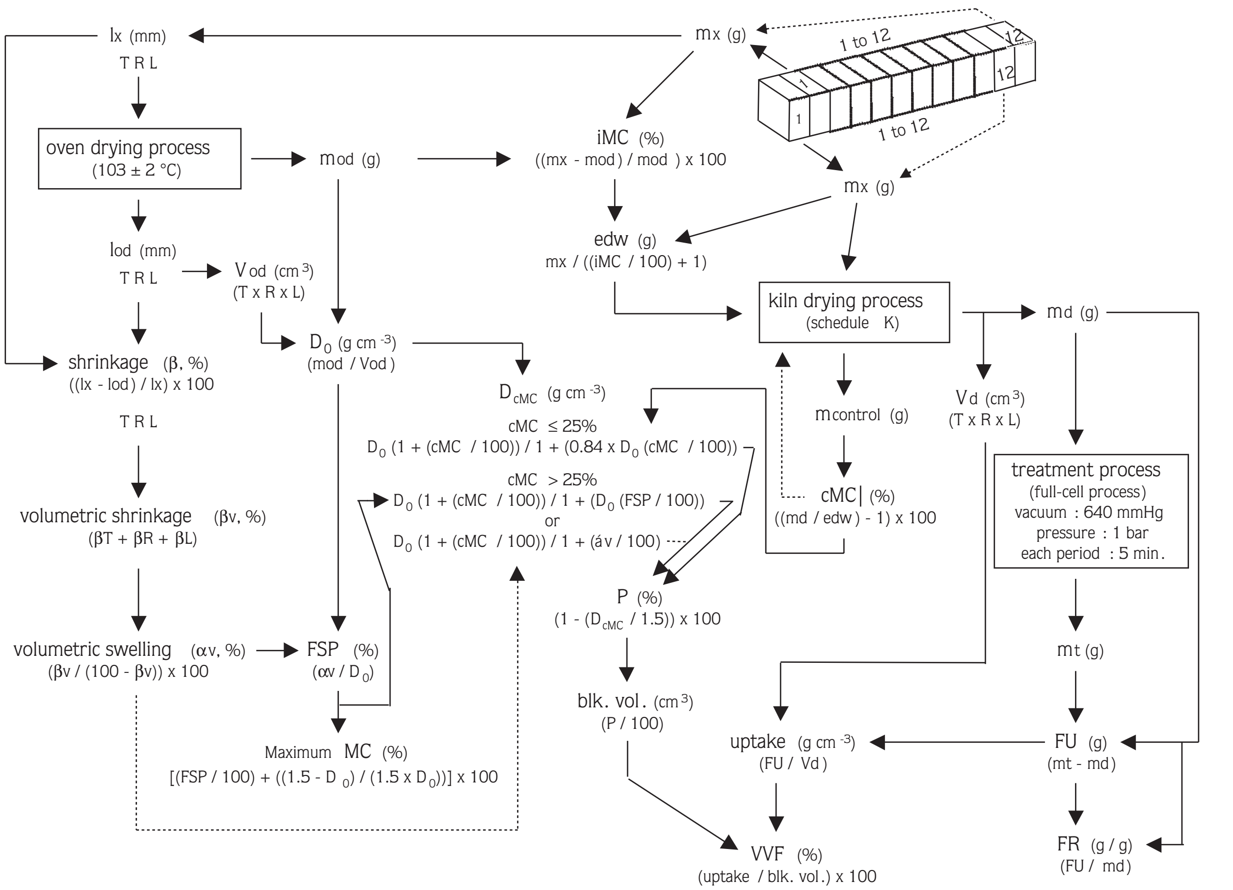

Figure 2. A schematic representation of data assembly and the experimental processing: mx (g), the green mass; lx (mm), length at green condition in either of the 3 directions (T, tangential; R, radial; L, longitudinal); lod (mm), length after oven drying; Vod (cm^3), block volume after oven drying; mod (g), oven-dried mass; D_0 (g cm^{-3}), oven-dry wood density; D_{cMC} (g cm^{-3}), wood density at respective moisture contents (cMC ≤ 25%, equal to-and/or-below 25 percent moisture content; cMC > 25%, above 25 percent moisture content); P (%), porosity; blk. vol. (cm^3), the amount of space available in a given block volume; FSP (%), fibre saturation point; iMC (%), inital moisture content; edw (g), estimated dry weight after kil drying; cMC (%), current moisture content at regular intervals during drying; Vd (cm^3), block volume after kiln drying; md (g), mass after kiln drying (before treatment); mt (g), mass after treatment process; FU (g), fluid uptake (the gross preservative solution absorption), FR (g/g), fluid retention (preservative retention on a whole-block basis); uptake (g cm^{-3}), dry salt loadings based on weight per volume; VVF (%), void volume filled by preservative solution.

within the range of the MC regimes (Figure 1) using a conventional kiln. Each set was taken from the kiln as soon as the average MC of the experimental samples reached the designed MC level. All the kiln-dried samples were then treated with a 2.5% concentration of CCA (Commercial Tanalith C, Hicksons) in 11 charges due to the different time periods for the kiln drying of the experimental samples. The treatment was carried out by using a model pressure treatment plant according to BS 4072 (1987 part 2). The treating schedule was a full-cell process consisting of a 5 min vacuum at -0.84 bars (640 mm Hg), followed by a pressure of 1 bar (14.5 psi) for 5 min. No final vacuum was used. Each sample was weighed before treatment and again after a 5 min drip period following treatment to obtain the maximum theoretical possible solution uptake and dry salt absorptions based on void volume (%) (McQuire, 1975).

Results and Discussion

The average oven-dry densities between specimens of all locations were identical, which was proof of uniformity between the treatment groups (Table 1). As shown in Table 2, a significant relatioship was found between increasing the percentage of void volume filled with preservative (VVF%, from 29.7% to 61.6%) and decreasing wood density (Dmc, from 0.996 g cm^{-3} to 0.441 g cm^{-3}) due to a decrease in MC (from 150% to 10%).

The percentage of void volume filled with preservative (VVF%) and wood density were significantly different among the experimental samples that were designed at various level of MC from 150% to 10%. In this range, all the levels were significantly different from each other, except for 20% which was not significant to 10% ($P < 0.001$). It was found that there were no differences in VVF% between the levels of MC of 10% and 20%, but there was a great significance between 20% and 30% (Table 2).

According to the overall results of this investigation, the drying process significantly improved the percentage of void volume filled with preservative in the case of porosity related to wood density at respective moisture contents. As the higher level of moisture proved difficult to treat without drying, Caucasian fir will require drying to below the FSP to allow the most adequate preservative uptake. As the FSP of Caucasian fir was 32.1% in this study, the exact value of MC of wood before the preservative treatment has to be below this level. In this case, further studies below the FSP (from 28% to 22%) showed that, although the difference was slight, the VVF% (figures in parentheses) of 28% (56.7) was significantly ($P < 0.043$) lower than that of 22% (59.4). In this range, all the VVF% figures appeared to be significantly different from each other. It was observed that the VVF% of 22% (59.4) was not statistically

Table 1. Means of the variables of some physical properties of Caucasian fir indicating several locations around the outer sapwood zone of the short trial log.

	D_0	Shrinkage (%)				max. Swelling	FSP	max. MC
	(g cm^{-3})	R	T	L	vol.	%	%	%
A	0.415 (0.001)	3.60 (0.08)	7.99 (0.02)	0.20 (0.01)	11.8 (0.04)	13.4 (0.05)	32.2 (0.16)	206.8 (0.85)
B	0.418 (0.002)	4.00 (0.02)	7.75 (0.06)	0.10 (0.02)	11.8 (0.03)	13.4 (0.04)	32.2 (0.14)	204.9 (0.95)
C	0.415 (0.002)	3.90 (0.04)	7.65 (0.05)	0.10 (0.01)	11.7 (0.06)	13.2 (0.08)	31.8 (0.17)	206.4 (0.93)
D	0.418 (0.001)	4.05 (0.01)	7.60 (0.01)	0.20 (0.02)	11.8 (0.05)	13.4 (0.06)	32.2 (0.16)	205.0 (0.87)
E	0.416 (0.002)	4.05 (0.02)	7.65 (0.02)	0.20 (0.01)	11.9 (0.03)	13.5 (0.04)	32.5 (0.16)	206.5 (0.89)
F	0.417 (0.001)	4.00 (0.03)	7.50 (0.01)	0.10 (0.02)	11.6 (0.05)	13.1 (0.06)	31.5 (0.12)	204.4 (0.75)
G	0.416 (0.03)	4.15 (0.01)	7.65 (0.03)	0.10 (0.01)	11.9 (0.04)	13.5 (0.05)	32.5 (0.11)	206.5 (0.90)
H	0.417 (0.002)	3.60 (0.04)	7.85 (0.01)	0.20 (0.02)	11.7 (0.03)	13.2 (0.04)	31.6 (0.09)	204.5 (0.78)
mean SD	0.417 (0.001)	3.92 (0.21)	7.71 (0.15)	0.15 (0.05)	11.8 (0.10)	13.3 (0.15)	32.1 (0.39)	205.6 (1.01)

Locations listed here from A to H shown in Figure 1.
D_0: oven-dry density; R: radial direction; T: tangential direction; L: longitudinal direction;
vol.: volumetric (R+T+L); max.: maximum; FSP: fibre saturation point; MC: moisture content.
Each value is the mean ± SD of 12 replicates in each location.
Figures in parentheses are standard deviations (SD).

Table 2. Comparison of changes of wood density (Dmc) and porosity (void volume), and the percentage of void volume filled with preservative (VVF%) at various moisture content levels among the green to kiln-dried aspects.

	Experimental regimes of moisture content [1]										
	A	B	H1	H2	H3	H4	C	D	E	F	G
	10	20	22	24	26	28	30	40	50	100	150
Dmc [2]	0.441 (.002)	0.468 (.002)	0.473 (.001)	0.477 (.001)	0.508 (.002)	0.515 (.003)	0.518 (.003)	0.555 (.001)	0.584 (.002)	0.738 (.002)	0.996 (.001)
Porosity [3]	70.6 (0.13)	68.8 (0.13)	68.5 (0.07)	68.2 (0.07)	66.1 (0.13)	65.7 (0.20)	65.4 (0.20)	63.0 (0.07)	61.1 (0.13)	50.8 (0.13)	33.6 (0.07)
VVF% [4]	61.6 a (0.10)	60.3 a (0.08)	59.4 a (0.03)	58.6 b (0.01)	57.4 c (0.01)	56.7 d (0.03)	56.5 d (0.02)	55.1 e (0.02)	49.3 f (0.07)	37.1 g (0.05)	29.7 h (0.06)

[1] Experimental regimes of moisture content (%) were designed to the green condition at 150% to kiln-dried level at 10%. Also, the levels from 28% to 22% were arranged for comparison the figures below fibre saturation point
[2] Dmc (g cm^{-3}) is wood density at respective moisture contents
[3] Porosity (%) is the fractional void volume of wood
[4] VVF% is the percentage of void volume filled with preservative. Values are means of 12 replicates in each MC regime at the ranges from 150% to 10%, and of 3 replicates within the regimes 28% to 22%. Means that are not significantly different by Tukey comparison test (at $P < 0.05$ level) have the same letter in a given row.
Figures in parentheses are standard deviations (there is zero before the decimal point in Dmc)

significant to 20% (60.3), which was not significantly different to 10% (61.6).

It was the purpose of this study to obtain reliable experimental findings for Caucasian fir, a refractory species which is difficult to impregnate under pressure and requires a long period of treatment, for the exact value of MC before the preservative treatment, which in turn influences the quality of treated wood, allowing better performance. In this case, the effect of MC confirmed significantly that the degree of increase in mean preservative uptake due to treatment varied among the MC levels. The experimental results mainly show that preservative uptake was limited to the level of MC in the amount of space available (void volume) in wood, and hence the observable improvement in the maximum volume of preservative which could be absorbed by wood would be achieved by reducing the MC due to drying. This agrees with work done by McQuire (1975).

The cell wall is fully swollen and cell lumens should be under no mechanical stress at the FSP since no free water is theoretically present in wood at this stage (Skaar, 1984). As stated by Kumar and Morrel (1989), this situation should provide ideal conditions for preservative flow through the lumens, as well as for the diffusion of water-borne salts into the cell wall, and thus, wood near the FSP should be most treatable. However, this effect was not apparent in the present study. Moisture pockets could have blocked fluid movement (Arsenault, 1973), or treating wood with partially saturated cell walls might have established a water-vapour front that restricted further chemical movement (Nicholas, 1982). Since water-borne preservatives fix rapidly in the wood (Hartford, 1986), even a small time lag in chemical movement can result in poor penetration.

The experimental observations indicate that moisture contents below the FSP result in greater preservative uptake (as the percentage of void volume filled); however, drying to a very low moisture content does not appear to improve treatment and would appear to be uneconomical. Therefore, the MC of Caucasian fir before the full-cell treatment process should be below the FSP for adequate preservative uptake which may influence the depth penetration of these species. Accordingly, to reduce the free water in the cell lumens and to leave voids for the bulk flow of the preservatives, it may be suggested to kiln dry this species until the nomination of its MC to around 22%.

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