Comparison of the water absorbency of Douglas-fir and radiata pine framing timber

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NZ Douglas-fir Cooperative

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SUMMARY

A study was set up to determine if there was any fundamental difference in the moisture uptake between Douglas fir (DF) and Radiata pine (RP) framing timber when subject to submersion in water.

Water uptake of RP and DF wood samples was compared using short blocks (100x50x25 mm) and long samples (1.2 m), selected to demonstrate the differences between grain orientations (radial, tangential, longitudinal) of both sapwood and heartwood samples. The blocks were submersed in water and the weight change recorded at specified intervals over 4 days. At the end of the 96-hour monitoring period, all samples of both species attained a moisture content above 27%, (considered the threshold moisture content for decay). The water uptake rate was slower for DF samples. For the long samples both samples of RP reached 27% MC after 15 hours, DF sapwood (DPS) took 48 hours and the DF heartwood (DFH) 96 hours. Uptake was greatest in the longitudinal direction, followed by tangential then radial. The estimated diffusion coefficient for DFS was lower than both DFH and RP samples.

The study showed that DF was distinctly slower with moisture absorption than RP. At the completion of the study, radiata pine long samples averaged 50% MC compared to 30% MC for the Douglas-fir.

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INTRODUCTION

This project was set up following concerns about the moisture uptake of house framing, and the introduction of the requirement to use treated framing for external walls. Douglas fir (DF) growers and processors are not convinced that this requirement for treatment of external walls for DF framing is necessary. The Building Industry Authority has stated that information showing the fundamental differences in relative moisture uptake of DF and radiata pine (RP) is needed before timber of the two species can be differentiated in the New Zealand Building Code.

It was suggested that a study of moisture permeability should be conducted. This project set out to compare the water absorbency of DF and RP timber, and follows on from the work of Mick Hedley and others on the effect of rain wetting on DF and RP framing (Hedley *et al*., 2004). Some information is available on the moisture permeability of radiata pine, but no information is available for New Zealand-grown DF. Moisture permeability testing is a lengthy procedure, requiring precise sample preparation and measurement techniques (Booker, 1990), and the results may be difficult to relate to practical situations. It was therefore considered that these traditional techniques for measuring moisture permeability were not appropriate for this study.

Two possible tests were reviewed as possible techniques to compare water absorbency. The Cobb Test (with modifications), which is used to determine the water absorbency of paper, and an American Standard Test Method (ASTM D5401) for evaluating the water repellent coatings on wood (also with modifications). The Cobb Test places a known volume of water above a paper sample for a specified time, then the excess water is removed and the weight change of the paper is used as a measure of the absorbency of the paper. The ASTM test soaks treated and untreated samples in water and measures weight gains over a given time period.

Discussions with BRANZ indicated that they were interested in obtaining mass transfer coefficients for moisture movement in DF and radiata pine for a full building envelope modeling study they have undertaken. They suggested a possible methodology with some similarities to a modified ASTM test. Their requirements led to the following study procedures, which closely relate to a worst-case scenario of a bottom plate sitting in water, as opposed to the intermittent wetting by rainfall.

MATERIALS AND METHODS

Samples of DF and RP sapwood (RPS) were obtained from a Central North Island source, and RP heartwood (RPH) from a South Island source.
All samples were measured for water uptake in the three nominal grain directions - radial, tangential and longitudinal - using small clear wood samples of approximate dimensions 100x50x25mm in the three-grain orientations. (Appendix 1)

All surfaces apart from the top and bottom surfaces were sealed (epoxy paint). Samples were weighed and then totally submersed in a shallow tray and reweighed after varying intervals of time, to assess water uptake.
Heartwood and sapwood samples of the two species were prepared from wood that had been conditioned to approximately 12% –16% moisture content (MC).

A smaller number of longer samples (1.2 mx100x50) matched to the small samples were prepared for total submersion to confirm results of mass transfer coefficient calculations based on results from the small specimens. These larger samples were submersed and assessed over a longer time period (up to one week).

Samples and Weighing Measurements

10 small heartwood and sapwood samples for each species and grain direction were prepared, as shown in Appendix 2, together with the 10 longer matched samples. There were a total of 120 small samples, and 40 long samples.

The aim was to measure the water uptake in each small sample every 5 minutes for the first half hour, and then extend the time interval to 2 hourly for next 8 hours of soaking, extending over 2 days. The logistics of measuring 120 samples every 5 minutes required careful planning. A system involving a plastic rectangular tube (very similar to rectangular down piping) containing 15 samples at a time was developed. This was submerged in water and then replaced with another 15 samples at regular intervals (every 20 seconds, based on the time taken to wipe excess water off and weigh the samples). The cycle was repeated after the first blocks had been soaking for 5 minutes. This process was repeated for each of the 15 samples over a half hour period. Four groups of 15 samples were weighed each day over two days.

The longer samples were weighed dry and then totally submersed and then weighed at intervals of 1 day for four days.

Calculation of Moisture Content (MC)

Small samples were collected from each long sample board and the MC calculated based on the oven-dry weight according to the formula:

$$MC\ (\%) = \frac{W_g - W_{od}}{W_{od}} \times 100$$

W_g is the green mass of the wood; W_{od} is its oven-dry mass (the attainment of constant mass generally after drying in an oven set at $103 \pm 2^{o}C$ for 24 hours, which is a standard practice to determine MC of wood).

It is expected that the MC of oven-dried samples represented the initial MC of samples soaked in water. The estimated oven-dry mass of each soaked sample was determined from the initial MC of matched oven-dried samples. The MC's of soaked samples were then calculated for subsequent time intervals using this estimated oven-dry weight.

CALCULATION OF DIFFUSION COEFFICIENT

The estimated diffusion coefficient was calculated using the following formula:

$$D = \frac{\left(\frac{M_{(t)}}{M_\infty}\right)^2}{\frac{16t}{\pi l^2}} \qquad \text{(equation 1)}$$

Here D is diffusion coefficient in m^2/s, $M_{(t)}$ is the mass of the sample at time t (in seconds), M_∞ is mass of the sample at saturation based on the calculated theoretical saturated moisture content and calculated density, l is the thickness of the flowing direction (in m). The estimated saturation mass was calculated from sample's density and wood cell-wall density (quoted in literature as 1500 kg/m^3). This equation is derived by solving Ficks diffusion second law assuming non steady state diffusion in one dimension with uniform initial surface distribution on both surfaces at $-l/2 < x < l/2$ (Crank1970). Thus samples were submerged with two opposite exposed (unsealed) surfaces.

RESULTS & DISCUSSION

Calculated basic densities and starting MC's of the small samples are shown in Figures 1 and 2. Average density of RPH samples was 394 kg/m^3, RPS samples 465 kg/m^3; DFH 438 kg/m^3 and DFS 484 kg/m^3. The DF samples were denser than pine samples in this case.
Average starting MC of samples before submersion in water for RPH was 12%; RPS 10%; DFH 13% and DFS 14%.

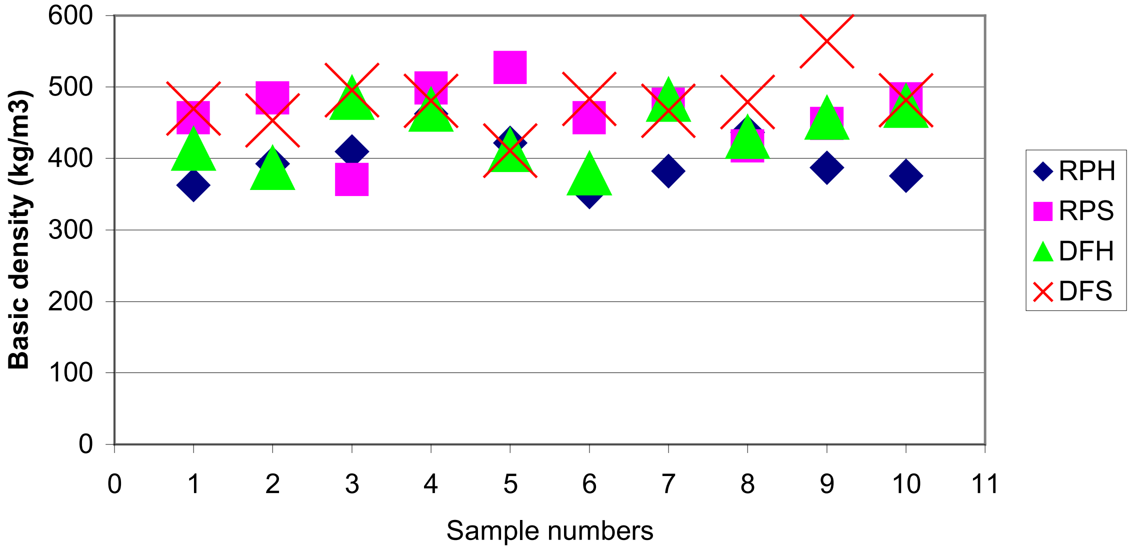

Figure 1: Calculated density of samples (RPH - Radiata pine heartwood, RPS- Radiata pine sapwood, DFH- D.Fir heartwood, DFS- D.Fir sapwood).

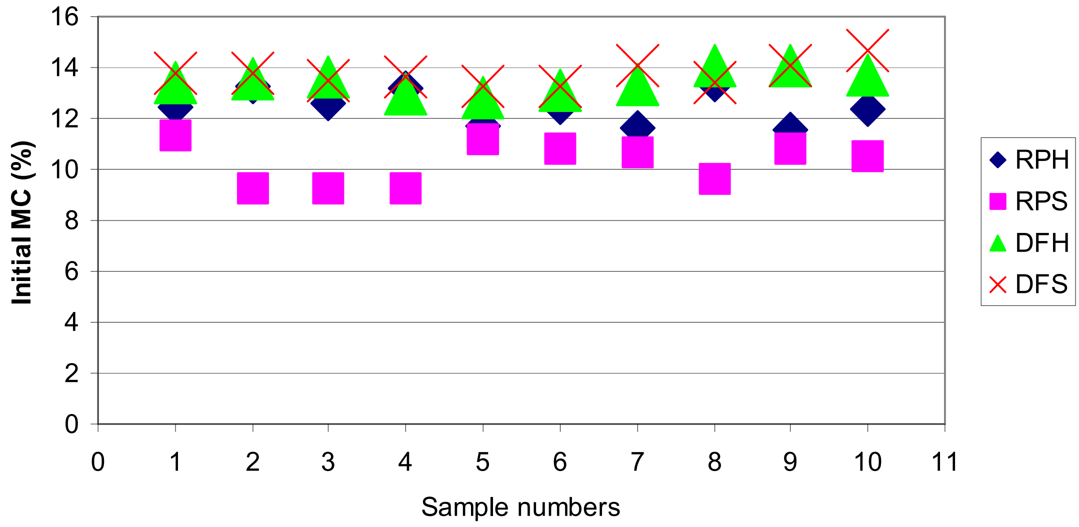

Figure 2: Calculated starting MC of samples (legend same as Figure 1).

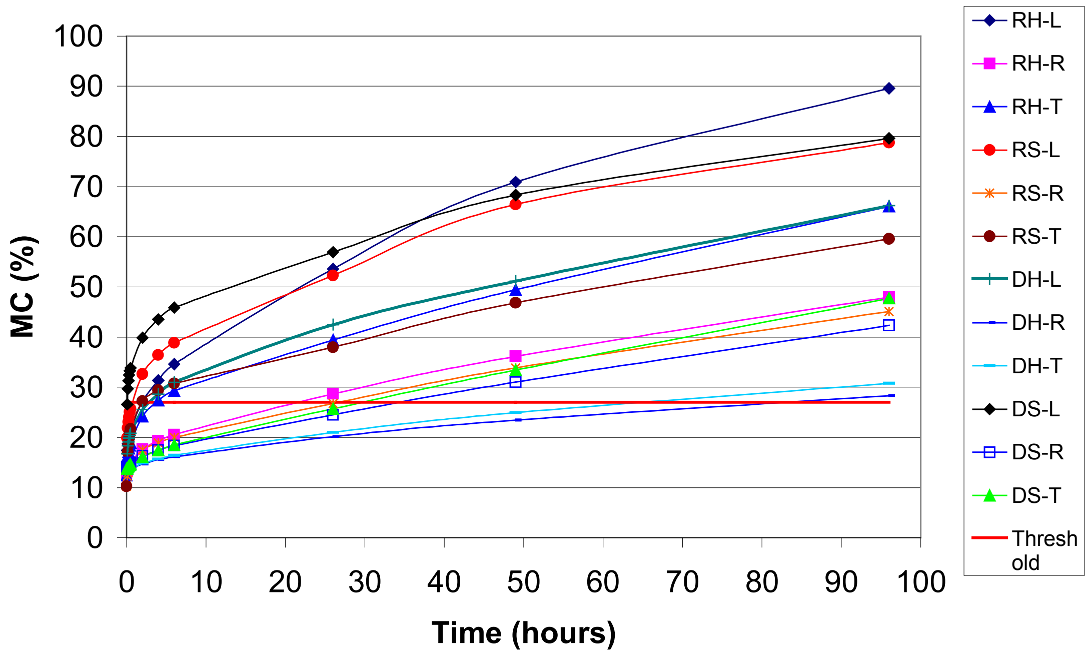

Figure 3: Moisture content change due to soaking in water with time (RP - Radiata pine, DF- D. fir, H- Heartwood, S- Sapwood, L- Longitudinal, R- Radial, T- Tangential).

The average moisture content change of the small samples due to submersion in water is shown in Figure 3.

For the period assessed (96hrs submersion), longitudinal samples achieved an average moisture content of 90% for RPH, 80% for RPS and DFS, and 66% for DFH. Tangential samples of RPH attained 66%, RPS 60%, DFS 47%, and DFH 31%. For the radial samples RPH reached 47%, RPS 45%, DFS 42%, and DFH 28%.

Generally water uptake rate of RPH samples was slightly higher than RPS samples.

From the literature it is generally quoted that liquid flow in wood is highest in the longitudinal direction, followed by tangential and slowest in the radial direction. The study results agree with these trends. Uptake was greatest in the longitudinal direction, followed by tangential then radial.

The average moisture content change with time of long samples during submersion in water is shown in Figure 4. The samples followed the same pattern as the small radial and tangential samples. RPH long samples, after 96 hours, attained an average moisture content of 52%, RPS 49%, DFS 33% and DFH 27%.

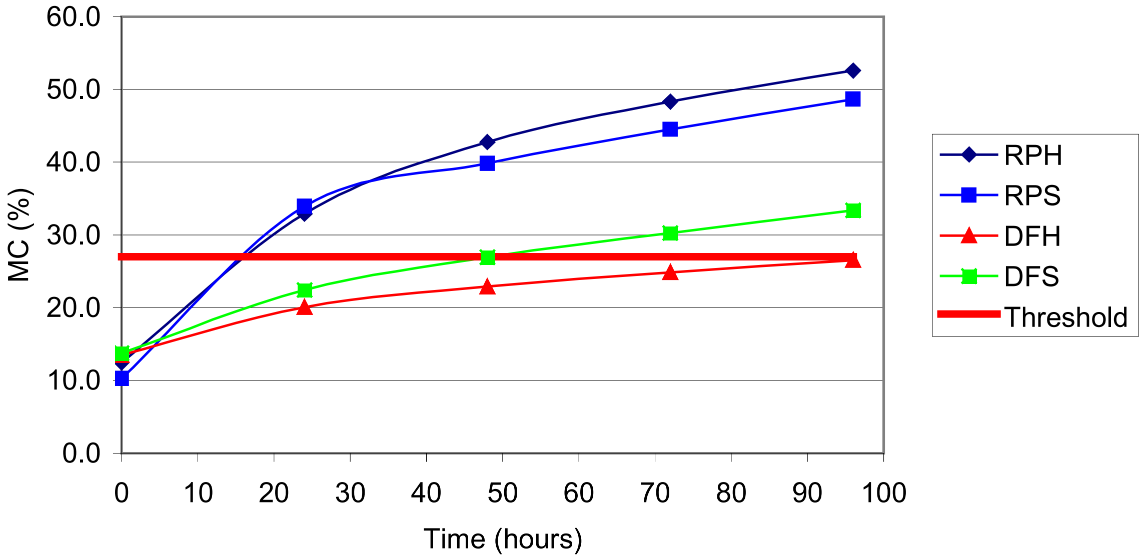

Figure 4: Average moisture content change of end-sealed long samples due to soaking in water with time (legend same as in Figure 1).

Both sapwood and heartwood samples of both species reached above the MC of 27%, which is considered to be the threshold for decay, within 4 days of continuous soaking. For the long samples, both samples of RP reached 27% MC after 15 hours, DFS took 48 hours and the DFH 96 hours. At the completion of the study, radiata pine samples averaged 50% MC, compared to 30% MC for the Douglas-fir.

This was a tougher test compared with the findings of the earlier work of Hedley et. al. 2004, where under intermittent rain wetting conditions, the DF did not exceed the 27% threshold. In this test the long samples had their four side grain surfaces freely and continuously available to absorb water over the four days.

General Discussion

From this study it was found that the water uptake rate for RPH samples in all three directions was higher at the end of monitoring compared with RPS samples. This may appear somewhat surprising because generally green sapwood is associated with high moisture content, high density and high saturation levels, compared with heartwood with low density, low moisture content and low saturation level. However for this study RP samples of heartwood and sapwood were collected from two different sources. Heartwood samples came from the South Island and were lower density than the sapwood samples which came from the North Island. The difference in water uptake is a density issue. Lower density wood will always contain more water for the same percentage saturation, producing a higher moisture content %.

E.g. For a samples at 350 kg/m^3 density and 100% saturation level, the maximum theoretical moisture content is around 220%. However in general in the green log, the actual average saturation for sapwood is around 90%, whereas average saturation for heartwood is around 25%. This is why the typical green moisture content of sapwood is around 150% whereas for heartwood it is 50%.

For DF, this phenomenon of greater amount of water uptake by heartwood did not occur. However, DF is quite an impermeable timber compared to RP. Transverse flow was relatively low and would not have gained such high saturation levels as the RP. DF water uptake was greater in the transverse direction for sapwood samples compared to heartwood.

Diffusion Coefficient

Mass transfer coefficients were determined using the diffusion equation (equation 1) and shown graphically in figure 5.

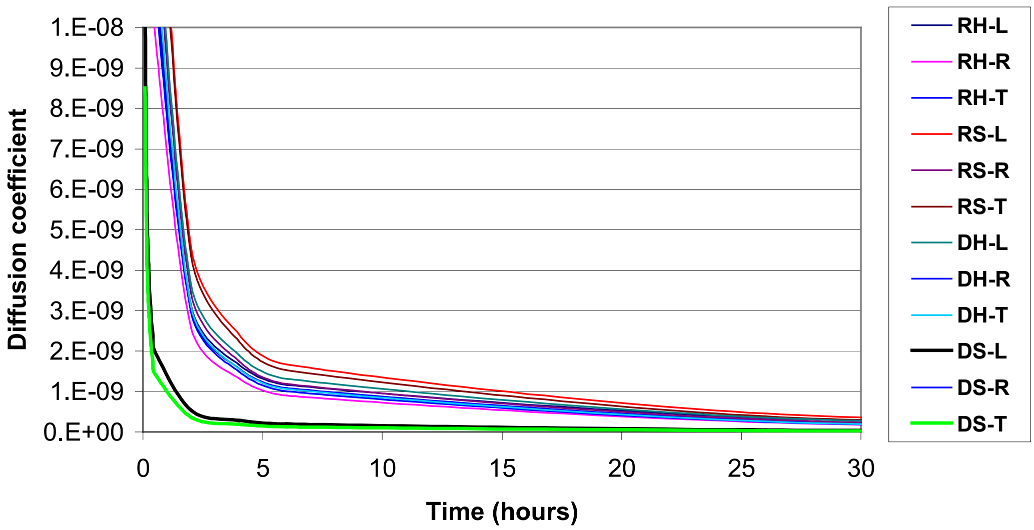

Figure 5: Calculated mass transfer coefficient with time (legend same as in Figure 3).

Full details based on the changing MCs of the samples with time, are provided in Appendix 3. These are not true diffusion coefficients, but can be regarded as mass (liquid water) transfer coefficients. Diffusion is one kind of mass transfer process, which generally refers to molecular transfer due to the concentration differences of two gases. In this case water was used as a medium, which can flow within the wood tracheids due to the capillary tension effect, in addition to the diffusion process within wood cell walls. This might include mass flow of water initially, then diffusion of water within the cell wall of wood. This is why after some 5 hours, the determined coefficient dropped significantly and changed very slowly with time thereafter. From this time onwards it can be regarded as diffusion coefficient.

The diffusion coefficient is a function of temperature and MC of wood (Keey *et al*., 2000). It increases proportionately with temperature, but only slightly affected with MC. Above the fibre saturation point (FSP - around 30%) it is hardly affected by MC. The diffusion coefficient also depends on the grain direction. In this study temperature was ambient (24^0C) and sufficiently constant, to allow comparison of diffusion coefficients between samples.
Generally the diffusion coefficients measured by various workers lie between 10^{-8} m^2/sec and 10^{-10} m^2/s (Keey *et al*., 2000). According to Kininmonth (1970), diffusion coefficients for RP at 28°C have been recorded as:

Sapwood Radial:	3.1×10^{-10} m^2/sec
Sapwood Tangential:	2.2×10^{-10} m^2/sec
Heartwood Radial:	0.5×10^{-10} m^2/sec
Heartwood Tangential:	0.3×10^{-10} m^2/sec

Since the figures from this experiment are not true diffusion, rather a mixture of diffusion and other mass transfer processes; the figures are somewhat higher than expected (in range of 10^{-9} m^2/sec instead of around 10^{-10} m^2/sec).

Generally, diffusion coefficients for green sapwood should be greater than heartwood and longitudinal direction greater than transverse. It was observed here that the DFS diffusion coefficient was lower than the DFH, which may be due to aspiration of pits in the sapwood during drying. However, the DFS diffusion coefficient was confirmed to be lower than the RPS, which is expected because of higher permeability of RPS.

CONCLUSIONS

Water uptake by RP and DF wood samples showed that the absorption rate was slower for the DF samples. For the long samples, both samples of RP reached 27% MC after 15 hours, while DFS took 48 hours and the DFH 96 hours. The small samples demonstrated uptake was most rapid in the longitudinal direction, followed by tangential then radial.

The diffusion coefficients determined in this study, using equation (1), are not considered true diffusion coefficients because the transfer mechanism also included capillary movement. The determined diffusion coefficient (after some five hours submersion) was found to be an order of magnitude higher than generally quoted in the literature. The diffusion coefficient for DFS was lower than DFH and the RP samples.

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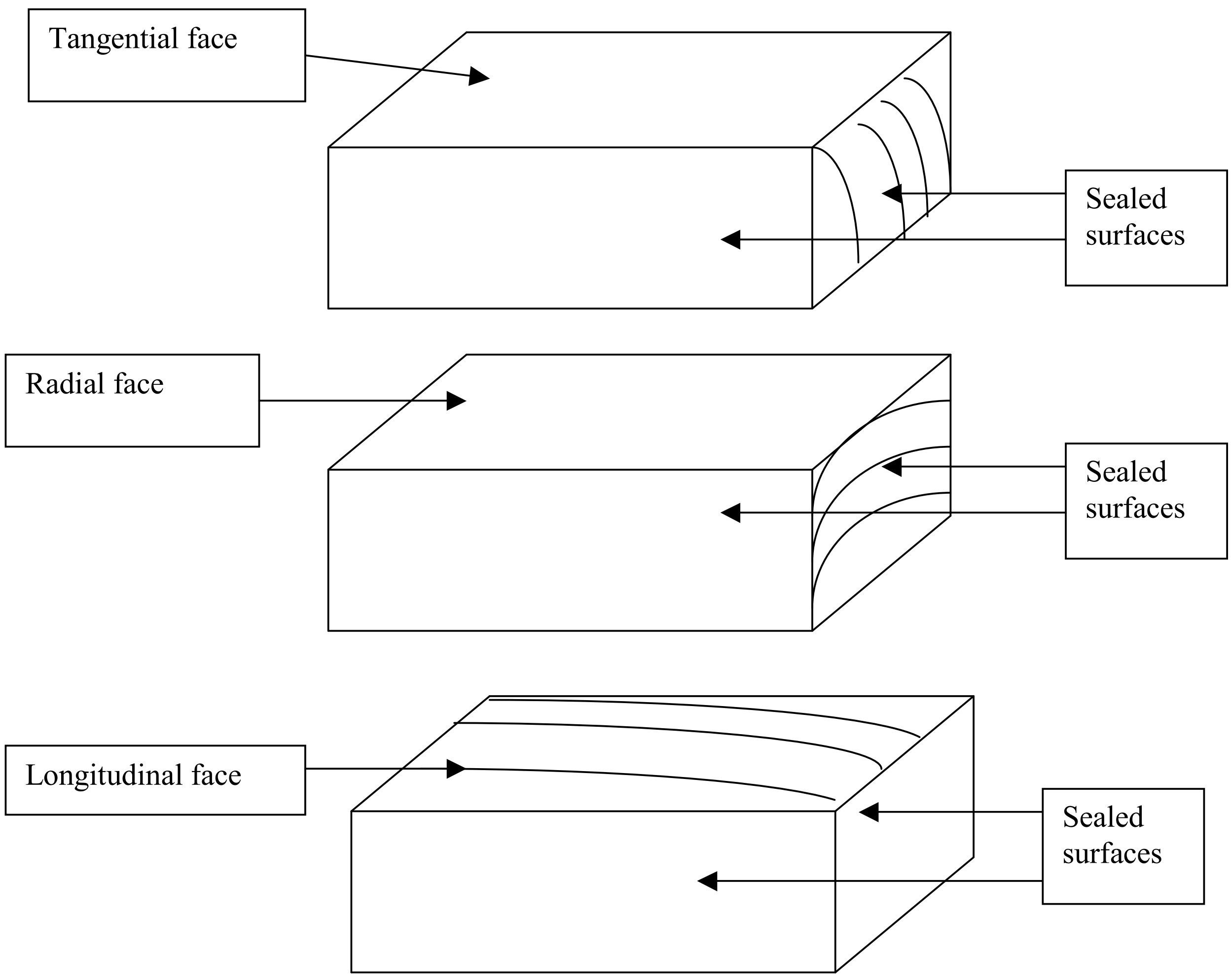
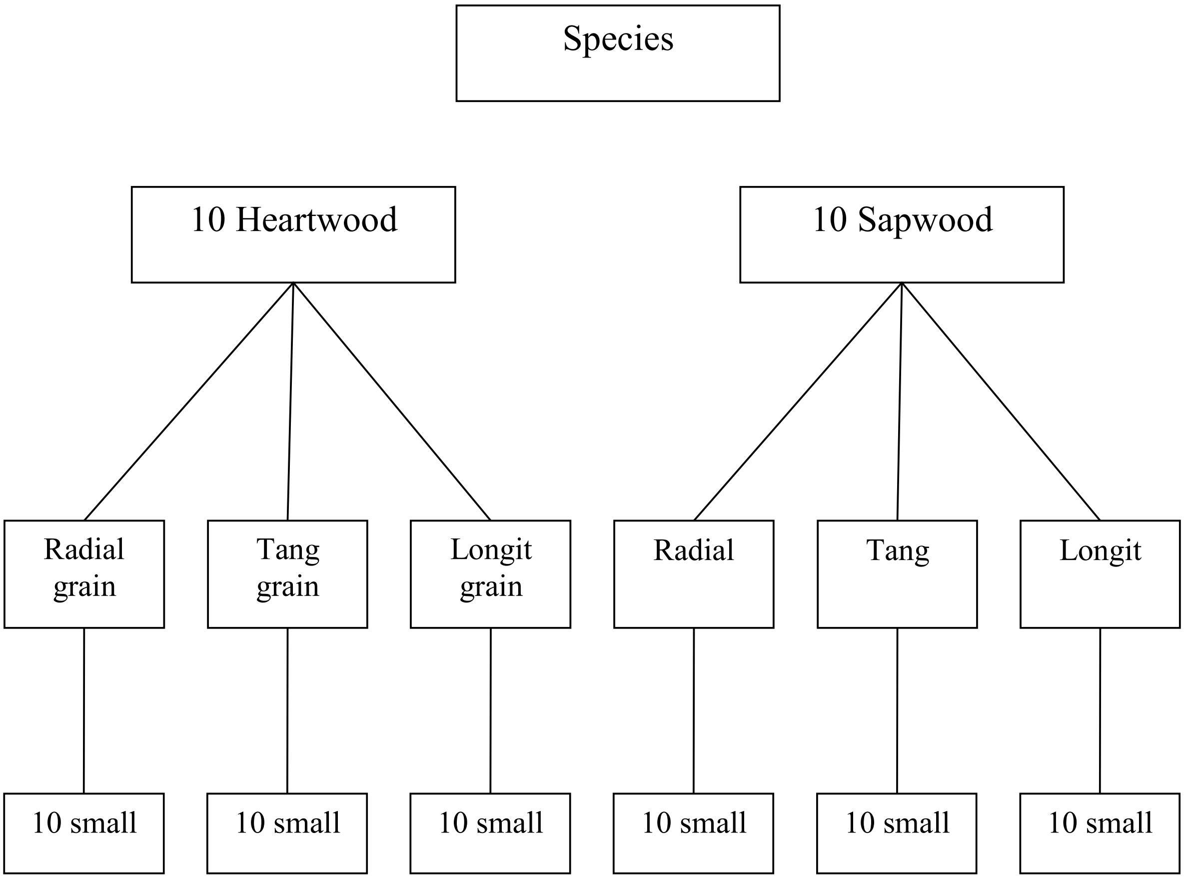
APPENDIX 1: SAMPLE ORIENTATION PREPARATION



APPENDIX 2: SAMPLE NUMBERS



APPENDIX 3: TABLE SHOWING ESTIMATED MASS TRANSFER COEFFICIENT (M^2/S) USING EQUATION (1)

Time (hours)	Radiata heart			Radiata sap			D. Fir heart			D. Fir sap		
	RH-L	RH-R	RH-T	RS-L	RS-R	RS-T	DH-L	DH-R	DH-T	DS-L	DS-R	DS-T
0.08	6.42E-08	5.76E-08	6.18E-08	8.91E-08	7.48E-08	8.44E-08	7.60E-08	6.94E-08	7.19E-08	1.07E-08	8.43E-09	8.50E-09
0.17	3.28E-08	2.91E-08	3.16E-08	4.60E-08	3.79E-08	4.40E-08	3.90E-08	3.48E-08	3.61E-08	5.61E-09	4.23E-09	4.27E-09
0.25	2.21E-08	1.95E-08	2.13E-08	3.13E-08	2.55E-08	3.01E-08	2.64E-08	2.29E-08	2.41E-08	3.84E-09	2.83E-09	2.85E-09
0.33	1.68E-08	1.47E-08	1.62E-08	2.39E-08	1.92E-08	2.31E-08	2.00E-08	1.75E-08	1.81E-08	2.92E-09	2.13E-09	2.15E-09
0.42	1.36E-08	1.18E-08	1.31E-08	1.94E-08	1.55E-08	1.88E-08	1.61E-08	1.40E-08	1.45E-08	2.37E-09	1.71E-09	1.72E-09
0.50	1.14E-08	9.88E-09	1.10E-08	1.64E-08	1.30E-08	1.59E-08	1.35E-08	1.17E-08	1.21E-08	1.99E-09	1.43E-09	1.44E-09
2.00	3.13E-09	2.58E-09	3.00E-09	4.57E-09	3.43E-09	4.36E-09	3.65E-09	2.96E-09	3.10E-09	5.40E-10	3.60E-10	3.70E-10
4.00	1.67E-09	1.33E-09	1.58E-09	2.42E-09	1.76E-09	2.25E-09	1.91E-09	1.50E-09	1.57E-09	2.90E-10	1.90E-10	1.90E-10
6.00	1.17E-09	9.00E-10	1.09E-09	1.67E-09	1.19E-09	1.53E-09	1.32E-09	1.01E-09	1.06E-09	2.00E-10	1.30E-10	1.30E-10
26.00	3.50E-10	2.40E-10	2.90E-10	4.60E-10	3.10E-10	3.90E-10	3.60E-10	2.50E-10	2.60E-10	5.00E-11	3.00E-11	3.00E-11
49.00	2.30E-10	1.40E-10	1.80E-10	2.90E-10	1.80E-10	2.40E-10	2.20E-10	1.40E-10	1.50E-10	3.00E-11	2.00E-11	2.00E-11
96.00	1.40E-10	8.00E-11	1.10E-10	1.70E-10	1.10E-10	1.40E-10	1.30E-10	8.00E-11	8.00E-11	2.00E-11	1.00E-11	1.00E-11