SEMINÁRIO INTERNACIONAL DE UTILIZAÇÃO DA MADEIRA DE EUCALIPTO PARA SERRARIA

DRYING EUCALYPTS FOR QUALITY: MATERIAL CHARACTERISTICS, PRE-DRYING TREATMENTS, DRYING METHODS, SCHEDULES AND OPTIMIZATION OF DRYING QUALITY

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SUMMARY

Drying today is recognized as a vital element in the value-added processing of solid wood products and there is currently a strong emphasis on improving drying quality and reducing drying costs. Eucalypts with their characteristically high shrinkage and low mass diffusivity values are notoriously difficult to season without degrade, especially backsawn boards.

Considering the premium price which can be fetched for appearance grade timber, this publication reviews the drying characteristics of Eucalypts, various possible pre-drying treatments to enhance ultimate quality and drying rate, the most prevalent drying methods / kilns used, drying schedules to achieve optimum drying conditions, and various measures which can be applied to improve drying quality. The major problem in hardwood drying remains the development of economical ways of drying appearance grade backsawn timber, free of degrade and in various thickness.

INTRODUCTION

The main reason for wood drying or seasoning is to ensure that the timber is dimensionally as stable as possible before use in a structure or manufactured item. When freshly cut green wood dries out, it shrinks, particularly across the grain. By drying the timber until it is in moisture equilibrium with its working environment we effectively "pre-shrink it". The objective is to ensure that any subsequent movement of the timber in furniture, fittings. Joinery, etc. is small or negligible and accommodated within the product design (Mills, 1991).

Drying today is recognized as a vital element in the value-added processing of wood products, with a strong emphasis currently being given to improving quality and reducing drying costs. The diminishing availability of wood from natural forests as well as the increasing availability from expensive man-made plantations, underline the need for improved timber processing and reduced drying degrade.

The typically high shrinkage and low mass diffusivity of most eucalypts make the material extremely difficult to season without degrade, especially backsawn boards. Because of the highly refractory seasoning characteristies of eucalypt material. it is standard practice to season timber batches with schedules designed to produce structural grade material and sell the small proportion of boards that do not suffer seasoning degrade as furniture grade material (Booker, 1994). Moderate and thus slower drying schedules must be employed to season furniture material and this has typically been considered uneconomical in the past. Howeve r, the value adding potential of the furniture grade material means this philosophy is rapidly changing.

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DRYING CHARACTERISTICS DF *EUCAL YPTS*

The supply of sawlogs of eucalypts from plantations in the Southern Hemisphere is increasing and the drying behaviour of the wood is consequently becoming correspondingly important.

Eucalypt wood generally dries slowly (Campbell & Hartley, 1978). Typical features are collapse, surface checking, high shrinkage, steep moisture gradients and pronounced drying stresses. Most eucalypt species have mean basic densities of 500 - 800 kg.m^{-3} and are relatively impermeable and difficult to season. At moisture contents (mc's) above fibre saturation point (f.s.p.), they show an increasing tendency to check and collapse with rise in temperatures. In kiln drying green timber 25 mm thick or more, the drying temperature should not exceed 45°C during the early stages and the relative humidity (r.h.) should be kept high, otherwise surface checking or internal checking (honeycombing) may develop.

Pronounced variations in drying rate within species has led to the recognition of "difficult" material i.e. material that dries slower and develops greater moisture gradients than normal. In Australia special drying techniques are used to dry this material, where it has been found that a relationship apparently exists between the mc of the core of sawn sections and collapse and recovery - the most severely collapsed boards frequently have the higher core mc's and high core mc also inhibits the recovery of the collapsed timber on reconditioning. As a result, it is necessary either to extend the normal kiln drying period with the attendant danger of overdrying the normal material, or to adopt a "holding period" at the end of kiln drying and before reconditioning. This involves storing the timber "strip stacked" in the air for up to 4 weeks to obtain an even distribution of mc between case and core. A steaming process (see below) before air-or kiln drying has been developed (Campbell, 1961) for the treatment of unseasoned "difficult" material.

Edge checking can be troublesome in thicker boards (Campbell & Hartley, 1978) during initial air-drying. However, the introduction of pre-dryers (see below) (Brennan *et al.,* 1966) has alleviated this problem. Material from about 50 mm of the pith of younger material is particularly prone to surface checking and end splitting. The latter is caused by the release of growth stresses and is not primarily a drying defect. Most of the eucalypts tend to check on backsawn surfaces during seasoning sometimes severely, but quarter sawn surfaces usually remain comparatively free of checks. For this reason and because of the greater dimensional stability of quarter sawn timber, it has been traditional practice in certain parts of Australia to quarter saw ash eucalypt timber for use as flooring, mouldings, joinery, etc. Where checks do occur, they frequently close towards the end of drying and may be hard to detect on sawn surfaces. Reconditioning to remove collapse (see below) usually causes the surface checks to re-open during final drying. This can severely degrade backsawn timber. However. reconditioning tends to close internal checks. Collapse in younger material causes internal checks, particularly the pith. This seriously restricts the utilization of the timber in some products.

Shrinkage varies markedly between eucalypts. Normal shrinkage is not affected to any great extent by drying conditions, but collapse shrinkage (above f.s.p.) is affected by temperature and can cause serious degrade in some species. "Gross shrinkage" describes the combined effect of true or normal shrinkage and shrinkage due to collapse.

Warp during drying is of two types:

(i) spring, bow and twist, generally associated with cell orientation not parallel to the longitudinal axis of the piece and;
(ii) cup and diamonding generally caused by differences between radial and tangential shrinkage.

Warp can also be caused by abnormally high longitudinal shrinkage of tension wood. Another important cause of warp is the release of growth stresses (very prevalent in eucalypts) in the tree as logs are sawn. The effects of growth stresses are usually greater in young than in mature trees. Spring in young sawn material can be reduced by stacking on edge and drying in weighted stacks or by employing a restraint system to hold the material straight during either normal reconditioning or a final steaming at the completion of drying. Bow is usually less important. Twist is not normally a serious problem in eucalypts, but where it does occur it can usually be controlled by good stacking practice, stack weighting and steaming at the completion of drying. The restraint applied for controlling warp should not be removed until the whole stack has cooled to ambient temperature. A promising approach to reduce warp is to dry wide boards and resaw after drying (see below: saw, dry and rip).

Wood from young eucalypts is likely to develop drying defects that are generally similar to those in wood from mature trees (Campbell & Hartley, 1978). Densities are generally lower in wood from younger trees. As low-density species generally collapse more than higher density species, collapse may be more prevalent in wood from younger trees.

The form and extent of drying degrade varies with species, tree maturity, position in tree, the thickness, width and direction of cut of the sawn timber, as well as environmental factors such as site, climate and latitude. Apparently no single factor consistently has a greater influence than the others on the quality of dried material.

DRYING REQUIREMENTS

There are no major problems in drying eucalypts for structural purposes with degrade within specified limits. However, surface checking may reduce its acceptance for "appearance" structural grades and internal checking must be limited (Hartley& Gough, 1990).

Drying appearance grade material is more difficult, particularly in thicker sizes. One method of minimizing degrade in Australia has been to quarter saw, but it is becoming less practicable due to the decreasing average log size and the presence of wood defects. Backsawing is preferred (Booker, 1994) for convenience, greater sawn recovery, more attractive figure, the limited width of quarter-sawn boards and faster drying of backsawn boards.

The major problem in hardwood drying is to develop economical ways of drying appearance grade backsawn timber, free of degrade, in both board and thicker sizes. Drying methods for appearance products are more critical and more costly than for structural timber. Freshly sawn wood must be selected and sorted for the intended product and drying process, which may be different for back and quarter-sawn material. The selection and careful handling should ideally extend back to the sawlogs.

PRE-DRYING TREATMENTS

Under this heading a variety of pre-drying "treatments" will be discussed ranging from storage in controlled environments, to wrappings of ali sorts, pre-steaming, pre-freezing, pre-surfacing, etc. Cutting boards radially rather than tangentially, can also be regarded as a form of pre-drying treatment as well as the application of an end-coating to freshly sawn logs.

Various approaches are used for protecting green timber from exposure to severe conditions and providing the mild early drying necessary for preventing degrade (Hartley & Gough, 1990). These include:

- Enclosed, controlled environments at the sawmill outfeed and stack construction area.
- Wrapping packs of green sawn timber to prevent drying before stacking.
- Surface coating of thick high-value timber with a semi-permeable polyvinyl chloride film attached with a polyvinyl acetate adhesive.
- Shrouding stacks with polyethylene sheet, which is removed when the critical early drying period has passed.
- Open-sided air-drying sheds that can be baffled with shade cloth to reduce air circulation.
- Enclosed holding or "curing" sheds for initial drying. They are generally without forced air circulation, but may have evaporative coolers to lower the temperature and raise the humidity.

- Pre-dryers: normally operated with closely controlled fairly constant equilibrium moisture content (emc) conditions.

The word "pre-steaming" has been coined (Campbell, 1961) to describe a steaming operation given to green ar near-green lumber prior to air or kiln drying for the purpose of reducing drying time - reductions of from 20% to 35% of that required for unsteamed material could be obtained by pre-steaming green material from 2 to 4 hours. Longer treatments failed to effect an further improvement in drying rate but tended to accentuate collapse. A short pre-steaming treatment favours reduction in drying degrade with no deleterious effects on strength. It has also been established that besides increasing the average drying rate, the pre-steaming treatment reduces moisture gradients in "difficult" material. A 5% to 20% loss in me as a direct result of pre-steaming was also observed. Improved recovery from collapse, less degrade and better machining qualities are also claimed.

The pre-steaming / pre-drying / "holding" / reconditioning / final drying treatment for ***Eucalyptus obliqua*** described by Campbell (1961) entails:

(i) Heating-up and then 2h pre-steaming (100°C/100% r.h.) as early as possible of green material (25-50 mm thick) in a steaming chamber.
(ii) Timber removed to pre-dryer (or kiln) and pre-dried at 38°C/32°C to a mc of 14%. *(The Kauri Timber Company in Smithton, Tasmania, dries down to 20% (Personal communication,* 1994)).
(iii) Timber removed from pre-dryer and held ("holding or equalization period") for 10 days to reduce the high core mc. *(The Kauri Timber Company keeps* 25 mm *material in* a *covered shed for up to* 3 *weeks to equalize, ideally to 18-20%* me *(Personal communication,* 1994)).
(iv) Kiln-dried at 54°C/38°C to an average mc of 11 %.
(v) Reconditioning for 6 hours at 100% / 100% r.h. in a concrete conditioning chamber (average me approximately 15% and all core mc's below 25%).
(vi) Final kiln drying at 60°C/49°C to an average me of 10%.

The Kauri Timber Company omits step (iv) above and reconditions (step (v)) when material is at a mc of 18-20%. Heating-up is in 2 hours and treatment time varies from 3 to 8 hours (19 mm to 38 mm stock) at 90-95°C using depressurized and desuperheated steam. Redrying is then carried out in a normal kiln commencing with 50°C/40°C and progressing over 3-4 days (25 mm stock) to 72°C and an increased wet bulb depression (w.b.d.) to yield the final mc of 8-12%. After re-drying charges are held under cover for 24-56 hours before destacking.

Alexiou *et al.* (1990) also found an increase in drying rate of 7-16 % by pre-steaming ***Eucalyptus pilularis*** *Sm.* while Alexiou and Marchant (1990) obtained reduced moisture gradients from centre to surface, less face checking and reduced stress and set gradients for pre-steamed material of the same species. Simpson (1975) found for several species that the drying rate of pre-steamed specimens was greater than that of the unsteamed.

Schaffner & Doe's (1984) investigation of drying stress and surface checking in backsawn ash led to the development of a surface coating system to reduce me gradients near the wood surface and reduce or eliminate surface checking. The coatings (polyvinyl acetate) were found to reduce or completely eliminate surface checking in Tasmanian eucalypt boards depending on the thickness of the coating applied.

Pre-surfacing or planing of green timber prior to drying directed at the removal of saw fractures on the surface, appears to be an effective way to minimize surface check development in species prone to this defect such as oak (Cuppett & Craft, 1972; Cech & Pfaff, 1975) and beech (Rietz & Jenson, 1968). Other advantages include: reduced check sensitivity and thus more severe drying conditions; uniform board thickness; increased stack volume; improved stacking quality. Simpson (1980) found reduced drying times by pre-surfacing and pre-steaming oak and using an accelerated and smoothed schedule. Rice (1986) found that pre-surfacing oak lumber before kiln-drying resulted in reduced degrade from warping and practically eliminated surface checking.

Cooper (19??) found that several hardwoods (including eg. ***Eucalyptus regnans)*** dried with significantly less collapse, honeycomb as shrinkage if pre-frozen at -23°C. llic (1993) found a collapse reduction of 36% by pre-freezing green ***E. regnans*** F. Muer. and Sharma (19??) obtained reduced shrinkage and collapse in refractory Indian hardwoods which were pre-steamed.

Pandey *et al.* (1984) reported that pre-treatment with urea eliminated surface and end cracking but not collapse and warping which are major defects in tangentially sawn planks of ***E. tereticornnis***. Sharma (19??) found that presoaking of refractory Indian hardwoods in polyethylene glycol, urea or urea-sorbitol solutions proved quite effective for the control of surface checking.

Chafe (1993) explored the effect on shrinkage, collapse and internal checking of pre-heating green mountain ash and depending on temperature, time and type of treatment, obtained significant increases and collapse recovery and reduction in internal checking.

A promising approach to reducing warp in smaller sized hardwoods and therefore in wood from young eucalypts, is the process of saw-dry-rip (Campbell & Hartley, 1978). This process (which can be regarded as partially a pretreatment) involves sawing logs through and through in the green condition, dry the wide boards and resawing to final size after drying. Campbell (1975) found an increased recovery for ***E. regnans*** treated in this way and "that the general straightness of the scantling sawn from the dried planks was very much better than scantlings sawn in the green condition from the same class of logs and then dried". Similar observations were made by Marshall (1973).

Drying methods/kilns

Traditional practice in countries like Australia and South Africa for the early drying of eucalypts from green to below f.s.p. has been to air dry. Drying to final me, was then usually accomplished in a conventional kiln, although in the past air-drying was used for the complete drying process. Since drying requirements for appearance products are much more demanding than for structural timber and because of the other disadvantages of air-drying (such as long drying periods and no control over quality), this drying method will not be further considered here.

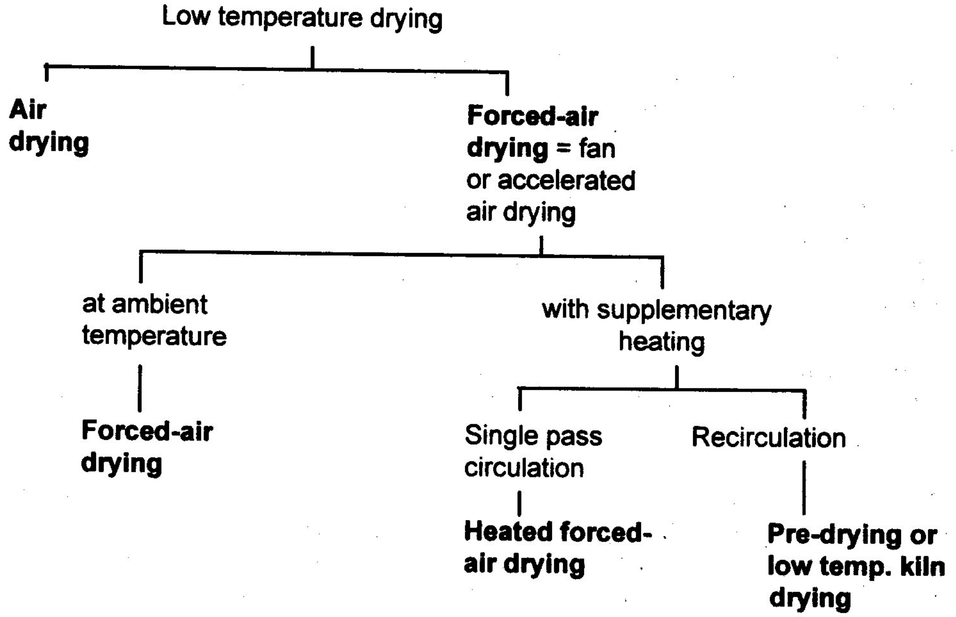
Alternatives to the use of air-drying as a pre-drying treatment for kiln drying are forced air dryers, pre-dryers of various sorts, low temperature dryers, fan shed dryers, warehouse dryers or even progressive dryers. Unfortunately the terminology used in various countries lack uniformity and often the same kiln is called different names. What most of these kilns, however, do have in common is the fact that they operate at low temperatures. Sometimes conventional kilns are used as low temperature pre-dryers during the initial phase of drying down to f.s.p.

Wynands (1963) stated that the term pre-drying was "adopted for a preliminary drying treatment usually intended to bring green timber to approximately the air-dry condition, using a relatively simple type of drying chamber equipped with fans, heating coils and air vents, but without the elaborate equipment normally incorporated in a modem timber drying kiln.

In Australia (Brennan *et al.* 1966) pre-drying was considered to be "essentially a method for stimulating favourable air-drying conditions and is therefore most useful in - and mainly limited to - regions where cold and wet conditions occur during an appreciable part of the year". The modem trend, however, is that pre-dryers are no longer used in this restricted sense only.

The term “forced-air drying” as generally used in American literature, covers a wider field than “pre-drying” in that the term is also used to denote drying without the addition of heat, fans being used to accelerate circulation of the ambient air.

Banks (1970) proposed the following scheme to illustrate the relationship of the various low temperature drying methods and clarify the terminology:



The increasing cost of lumber, interest costs on inventory during long air-drying times and quality requirements with respect to appearance lumber, have caused an upsurge in the use of previously little-used low temperature dryers as a replacement for the air-drying of hardwoods (Simpson, 1983-84)0 Low temperature dryers are typically low-cost dryers that provide a minimum of air circulation and temperature and r.h. control, but just enough to reduce drying time and drying defects significantly o Temperatures typically are 27 - 40°C. Pre-dryers may be very large, holding up to 1200 m^3. Pre-drying is faster and causes fewer defects than air-drying.

In addition to use in pre-drying to be followed by kiln drying, low temperature dryers are also used for the entire drying process. In Australia (Anon., 1967) there was a swing to drying from green to final mc in a pre-dryer, thus bypassing the traditional completion period recommended in a kiln. This action combines the initial pre-dryer advantages with higher final output from a unit that has greater capacity and lower capital cost than the conventional' kiln.

Characteristics of typical Australian pre-dryers (Brennan *et al,* 1966):

- Very large; installed cost about 1/3 that of a number of smaller kilns.
- Multiple parallel drying lines (4-8); not necessary for all lines to be discharged/loaded simultaneously since stock on one line influenced to minor extent by other lines.
- Single fan system for all lines; no reversal of air-flow.
- Smaller heating surface in proportion to charge capacity than higher temperature kilns. Primary coils above sub-ceiling; re-heat coils between lines; steam heated.
- Less robust construction than orthodox kilns.
- Constant low temperature conditions: dry bulb temperature (dbt) 38-43°C; w.b.d. 4-8°C; air-velocity 1,25-2$m.s^{-1}$.
- Humidifying steam sprays provided.
- Slight increase in dbt between air-inlet and air-discharge side to maintain constantw.b.d. across each line.

According to Wengert (1985) warehouse pre-drying has replaced air-dring in the U.SA The system consists of drying stickered lumber in large warehouse buildings holding up to 3 540 m of stickered lumber. The temperature (30°C) and r.h. (75%) are closely controlled. The system provides perfect air-drying 24 hours a day but without rain, direct sunlight and blowing dust. Due to reduced inventory cost and reduced degrade, the pre-drying system has a two year payback. After pre-drying Eastern hardwoods to mc's in the 25% range, the lumber is kiln dried for 4-7 days to a final mc of 5-8%. Most pre-dryers are steel framed buildings with steel or aluminium sheeted walls with interior insulation and are steam heated. A row of fans near the ceiling on each side of the pre-dryer circulate air through the lumber piles. Vents in the side walls and powered bents at the gable are provided to remove excess humidity.

A particularly popular and widely implemented type of low temperature dryer for the entire drying process is the dehumidifier dryer, which typically operates below 50°C. Instead of the usual venting systems to remove moisture from kilns, dehumidifier kilns operate by passing air over the cooling coils of the unit and condensing water. The dried air is then reheated and sent back to the drying chamber. The latent heat of vaporization is recovered and used in drying. Lack of venting losses and recovery of the heat of vaporization combine to make dehumidification drying more energy efficient than conventional drying. The energy needed to remove water is only about one-third of that required in a conventional kiln (Lewis, 1986). Dehumidification drying has become a very popular method of kiln drying hardwoods in the United States and Canada.

Another low temperature dryer type for the entire drying process, is the progressive kiln. A low cost "once through progressive kiln" of approximately 60 m length with the air following a sinuous path through the hardwood stacks was described by Campbell (1976) and kilns of this type are currently in operation in Australia (Mills, 1991). Further improvements were described by Fricke (1983) and Brennan & Glossop (1989). Possibly the world's most advanced progressive pre-dryer is found in Western Australia at the Deanmill of Binnings Forest Products Pty. Ltd. The 1 800m pre-dryer has the capacity to dry up to 10000m of ***E. marginata*** per year. The shed is separated into eight successive drying chambers and each chamber has its own air-handling unit, supplied with hot and cold water from a single heater/ chiller unit. The drying process is quite simple: timber is placed on a trolley in a loading area and moves into the first chamber (25°C/90% r.h.). The conditions gradually change to a temperature of 45°C and rh of 65% in the last chamber. Each chamber may be regarded as a segment of an 8-stage drying schedule. The air inside each chamber is circulated around the timber to allow moisture in the timber to evaporate into the air stream. This moisture-laden air stream then passes over cooling coils which condense the water vapour into liquid water which is pumped out of the building. The cold, dry air is passed over heating coils and re-heated so that it can again absorb moisture when circulated through the timber stacks. The progression of timber from one stage to the next is based on time (and an expectation of mc): 25, 38 and 50 mm materials respectively moved every 5, 8 or 11 days to reduce moisture content from 80% to 25%. This pre-drying technology improves recovery of high-grade seasoned jarrah, reduces seasoning costs and increases market flexibility.

Interest in solar energy as heat source in wood drying has seen a flurry of activity (Plumptre 1967, 1973; Gough 1977; Tschernitz & Simpson, 1979; Chen *et al.,* 1982; Robertson & McCormick, 1977; Steinmann *et al.,* 1980, 1981). A recent development which deserves attention is the implementation of a solar assisted greenhouse style timber drying system for the drying of eucalypts in Western Australia (McDonald, 1991; Glossop, 1992). The drying of hardwoods needs to be slow to prevent seasoning degrade and heating using solar energy has considerable advantages. Control is constant r. h. but floating temperature and an auxiliary heater (which is recommended for kilns of 20m^3 or more capacity) (wood waste) can smooth out fluctuations in the solar heating.

Very little vacuum drying is done commercially in the United States (Lamb & Wengert, 1993), while in Europe there is an increase in the utilization of this technology (Vanicek, 1993). Results obtained by Lamb & Wengert (1993) showed that the drying quality from two vacuum (vacuum only and vacuum and radio frequency heating) systems compared favourably with that from a standard pre-dryer and dry kiln. Vanicek (1993) mentioned flexibility, fast drying and quality as main advantages. Ressel (1994) confirmed the increasing use of vacuum drying in Europe. Smith *et al.* (1994) reported that 57 mm red oak were successfully dried by a radio frequency vacuum process in less than 60 hours from 85% to 8% mc. Final mc variation and residual drying stress was comparable to conventionally dried wood. Rozsa (1994) reported a preliminary study of the use of microwave energy to dry eucalypt under reduced atmosphere conditions. The two main defects of eucalypts viz. surface checking and collapse could both benefit from a drying treatment at lower temperatures where the wood is stronger and more able to resist the forces. Lowering the atmosphere pressure at which drying takes place would enable water to be evaporated at lower temperatures. Vacuum drying should, therefore, be well suited for the drying of eucalypts.

DRYING SCHEDULES

Good seasoning practice involves the rapid transfer of sawn timber from the green deck into drying stacks, strict attention to sound stacking practice, protection of the sides and tops of air-drying stacks exposed to severe drying conditions and the use of combined air- and kiln drying or preliminary drying in a pre-dryer followed by kiln drying where accelerated drying is required (Campbell & Hartley, 1978).

For economic reasons the drying conditions should be the most severe that a particular charge can tolerate, without degrading it to a greater degree than acceptable for the purpose required. The conditions are rarely kept constant throughout the process of drying, because wood is usually weakest when green, but attains strength as it dries. The drying conditions applied in the early stages must necessarily be milder than those acceptable later - with eucalypts in general low temperature high humidity low air-velocity schedules are needed in the initial stages of drying (Brennan *et al.,* 1990).

The table of drying conditions used for a particular species and thickness, is known as a drying schedule. This is a series of combinations of temperature (dry bulb temperature = DBT; wet bulb temperature = WBT; Depression = (DBT-WBT) = WBD) and relative humidity (= RH, or equilibrium moisture content = EMC), usually increasing in severity, each combination being applied over a particular stage in the drying process. The stage at which each combination is applied is usually dictated by a particular point in the progress of drying, such as when the charge is at (or has dried to) a particular average mc.

A large amount of work has been done on the development of schedules for eucalypts by research organizations such as CSIRO, AFRDI and CALM in Australia (Mills, 1991) and by institutes and individuals in countries such as South Africa, England, Germany, U.S.A. and Chile. In this process a variety of schedules were developed eg.:

- **Normal mc based sehedules** (Mills, 1991; Campbell, 1975; Pandey *et al.,* 1984; Neumann, 1989; Stöhr & Mackay, 1984; Stöhr *et al.,* 1984; Priest *et al.,* 1982). In this case schedules normally start at green moisture content, suggesting normal kiln-drying right from the start, but often it is suggested that drying be preceded by an initial air-drying (or pre-drying in pre-dryer) period to a mc of 25-30%. Typical pre-drying conditions to be employed in a low temperature pre-dryer are given above in the discussion of pre-drying treatments.
- **Constant temperature/constant r.h. schedules** as applied in Holland for the complete drying of hardwoods in so-called climatic chambers.
- **Time based schedules** (Campbell, 1975) which are developed out of mc based schedules after suitable experience.
- **Continuously varying sehedules** (Nassif, 1983; Vermaas & Neville, 1989) where DBT and WBT (after an initial heating-up stage to 35-45°C) continuously increase at a fixed rate from heating-up temperature until the wood reaches 25% mc after which the gradients of DBT and WBT are increased until final mc is reached. An example is given below:

Mc (%)	**DBT** (^{o}C) =	**WBT** (^{o}C) =
Green → In.mc In.mc → 25% 25% → 12%	20° → 35° (1°C/h) (35 + 0,1-t)^{o} → A^{o} (A + 0,25-t)^{o} → D°	(DBT-2°) → 33° (33 + 0,07) → B^{o} (B + 0,15-t)^{o} → E^{o}

where t = drying time in hours.

A variation of CVS schedules is where the dbt and wbt increase at a fixed rate per percent mc loss.

- **Intermittent schedules** (Lerz *et al.,* 1987) where the drying phase is alternated with a phase where heating and ventilators are switched off and the vents closed. The theory is that mc and stress gradients will be reduced during the non-drying phase and thus result in a higher final quality of dried wood. Good results were obtained by Vermaas (unpublished) with this schedule in the drying of ***E. grandis*** but longer drying times are a consequence.
- **Smoothed schedules** (Simpson, 1980; Little, 1989) - the hypothesis is that the relatively large abrupt changes in e.m.c. conditions in a conventional kiln schedule subject the wood surface to abrupt and steep moisture gradients that tend to aggravate or cause surface checking. If these changes were smaller and more numerous, lumber should be less susceptible to surface checking. Furthermore if the tendency toward surface checking was reduced, it should be possible to make these smaller changes in kiln conditions a little earlier in the drying schedule and thus effectively accelerate the schedule. Although Simpson (1980) and Little (1989) developed their schedules for the drying of oak, the principle should be equally applicable to eucalypts which tend to exhibit surface checking.

The most successful schedules for the pre-drying of eucalypts have undoubtedly been developed in Australia, an example of which is given above in the discussion of pre-drying treatments. Constant temperature / constant r.h. schedules (e.g. 40°C/65% r.h.) such as used by the Dutch in their climatic kilns and also in the U.S.A. in warehouse pre-dryers are also giving excellent results. Own work (Vermaas, unpublished) indicates that the latter type of schedule might be somewhat slower than the former but the final drying quality at approximately 25% might be better. The intermittent "holding period" appears to be used only in Australia and undoubtedly contributes towards the particular quality sought in appearance grade timber. The final drying in conventional kilns from 25% mc down to 10-12% mc is not problematic at all and Christensen (1984) has shown that it is even possible to push up the dbt considerably in this phase.

Reconditioning for collapse is also standard practice in Australia and cannot be neglected when quality of final products is the criterion. Collapse which occurs during drying is dependent upon a complex interaction of things such as drying temperature, wood moisture content and density and a host of other factors listed by Bariska *et al.* (1987) and still not completely understood. What is important in drying is that the deformation (washboarding) caused by this drying defect can be successfully removed by a reconditioning procedure (100°C /100% h /6-8 h) as practised by the Australians. Cracks caused by honeycombing will also be closed during this treatment but the strength losses of course is irreversible.

IMPROVING DRYING QUALITY

Measures such as quarter sawing, pre-steaming, closely controlled low temperature pre-drying, intermittent holding period and final reconditioning in a separate steaming chamber are all important contributing factors in the quest for high quality dried timber which can command the best possible price for appearance applications. Timber used in furniture manufacture should be dried to the mc required for its final use and then stored in a controlled environment to maintain it at the required moisture content.

Wrapping in p.v.c. film is a method of quality control, that would substantially reduce the need for strict environmental controls in storage (Newby & Brennan, 1990).

Langrish *et al.* (1992) studied the effect of cycling the external conditions on the timber quality and drying time for red beech *(Nothofagus fusca),* a difficult to dry New Zealand hardwood. Intermittent drying at an air temperature of 45°C and WBD of 10°C took longer to yield a given mc than continuous drying under the same conditions, but produces timber without honeycomb or severe casehardening as observed in continuous drying. The experiments also indicated that the timber can tolerate a higher DBT (55°C) in intermittent drying at the same WBO with less casehardening and without showing honeycomb compared with continuous drying at 45°C, having a similar total drying time. Intermittent drying at a slightly higher DBT (60°C) and a much higher WBD (18°C) gave a similar degree of casehardening to that found in samples dried continuously at a DBT of 45°C.

Checking has always been a major cause of timber degradation during drying, especially in the case of hardwoods. In conventional drying the drying rate must be slowed down in order to eliminate checking, so that degradation is reduced at the expense of drying time. As a result the time required to dry hardwoods susceptible to degradation can be very long. Vacuum drying can significantly shorten the drying time of hardwoods, but checking remains a mayor problem even with this method. Zhao (1988) found that a surface cooling phase introduced between each heating and vacuum phase in the drying of 45 mm thick *Castanopsis nigrescens* greatly reduced the moisture gradient and thereby eliminated checking effectively. The final mc gradient from surface to core was substantially flat with a maximum difference of 3%.

Alexiou (1991) measured strain gradients, sets mc gradients and size of checks during the kiln drying from green of 100x50 mm backsawn ***Eucalyptus pilularis*** Sm. in order to optimize the drying and develop an accelerated schedule. Energy consumption and severity of collapse were reduced during the accelerated schedule.

Neumann & Saavedra (1992) studied the effects of DBT, WBD and high humidity (hh) treatments on the check formation during the drying of ***Eucalyptus globulus***. The results showed that damage caused by checks inside the boards was significantly lower than unconventional drying when the initial drying temperature was low (preferably below 30°C) and the surface layers were periodically rewetted with hh treatments at low temperatures (four times a day; 30 min; DBT = 50°C; WBD = 2°C). As further reduction of checking was attained when boards were presteamed before drying. Under the above conditions it was possible to dry up to 60 mm thick quarter and backsawn boards without significant checks. Stöhr *et al.,* (1984) also obtained less degrade using hh treatments on young ***E. grandis***.

Ralph *et al.* (1984) described a process which involved coating the faces of boards with a semi-permeable material (PVC film glued with PVA glue) before kiln drying to minimize the moisture gradient through the timber and hence the surface stresses causing checking. The process lead to significant improvements in recovery percentages, yields and end-product values. Waugh & Rozsa (1991) did not consider this treatment a success because the parameters of the adhesive film combination must be carefully matched to the optimum drying rate for degrade-free timber. Although they found a marked decrease in the rate of early surface checking, their experiment had to be abandoned. as the drying rate was 50 slow that decay started to spread through the boards. They also obtained marked improvements in surface and internal checking as the board thickness was reduced from 50 mm to 40 mm and 25 mm. Valwood. an edge and face laminated panel made from 10-12mm boards of Eucalypts. is a product developed in Western Australia to take advantage of the easier drying of thinner boards.

Waugh & Rozsa (1991) recommended the following procedure for the quality drying of young regrowth ***E. regnans***. Boards to be kept in stacks wrapped in plastic film of enclosed sheds with water sprays from the time they were sawn until stacked for drying; to minimize pre-drying degrade; kiln drying from green under tightly controlled (microchip based controller) pre-dry conditions of around 35°C DBT and WBD = 2°C and an air speed of 0,5 *m/sec;* water sprays for humidification reconditioning (6 hours) and final kiln drying treatment to bring me to a normal 12%; drying of thinner boards. Drying times for 40 mm material in the pre-dryer were approximately 10 weeks.

The very latest attempt to improve the drying quality of Tasmanian eucalypts is the work done by Booker (1994) which implemented a system or the kiln drying of hardwood based on real-time measurement of acoustic emissions (AE) in drying boards. His work was facilitated by the existence of a one-dimensional nonlinear drying model developed by Oliver (1991). Oliver wrote KILNSCHED, a computer program which stimulates the drying behaviour of a single board with arbitrary bulk material properties, subject to arbitrar drying conditions. Booker meanfully modified KILNSCHED and developed SMARTKILN which develops drying schedules to maintain the surface strain at a certain levei below the ultimate instantaneous strain: SMARTKILN and AE measurement from the beams of Clever Kiln Controller (CKC) a patented commercial kiln controller to dry Tasmanian eucalypt timber in the minimum time with minimum degrade.

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